Regional anesthesia for cardiothoracic surgery

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Abstract
Cardiac and thoracic surgery have been connected to high perioperative opioid use for a long time. With increasing knowledge of regional anesthesia in the thoracic region, thoracic nerve blocks have become supplemental methods of analgesia. As part of multimodal analgesia, they are important factors of enhanced recovery after surgery and contribute to a diminished opioid use. Myofascial nerve blocks are more superficial than the classic thoracic epidural anesthesia or paravertebral block and are therefore safer for use in anticoagulated patients. In this article, we present a number of thoracic blocks; the paraneuraxial paravertebral block; the myofascial plane blocks which are the retrolaminar block, the erector spinae plane block, the serratus anterior plane block, the pectoral nerves I and II block, the transversus thoracis plane block and the parasternal intercostal nerve block; the perineural intercostal nerve block and also local anesthetic infusion by a wound catheter. We conclude with local experience from a cardiac and thoracic surgical center.

Keywords
Regional anesthesia; Cardiac anesthesia; Thoracic anesthesia; Nerve block; Pain management

1. Introduction
Regional anesthesia has found its place in cardiac and thoracic surgery only in recent times. Cardiac and thoracic surgeries have until recently been connected to high opioid consumption with only thoracic epidural anesthesia as an alternative [1, 2]. Providing adequate analgesia after cardiothoracic surgery is essential since postoperative complications often postpone hospital discharge and are linked to higher morbidity and mortality. Constant respiratory movement of the chest potentiates the pain from thoracic drainage and the postoperative wound [3]. Postoperative pain can contribute to complications, such as pneumonia, pulmonary atelectasis, prolonged hospital stays and chronic pain [4, 5]. The most common opioid side effects such as respiratory depression, lethargy, nausea, constipation and pruritus also contribute to postoperative complications. Nowadays, multimodal analgesic techniques are gaining popularity in a desire to reduce the use of opioids.

Regional anesthetic techniques emerged with the development of ultrasound, awareness of the opioid side effects and their potential long-term abuse. Ultrasound-guided interventions enable more exact injection of the local anesthetics to desired locations with fewer complications, which results in more efficient pain relief. The golden standard, which used to be thoracic epidural anesthesia, is now accompanied by thoracic wall blocks (Fig. 1). They can reduce the total postoperative opioid consumption and contribute to faster recovery after surgery. Fast track recovery after cardiac and thoracic surgery includes shortening time to tracheal extubation and hospital discharge [6, 7]. While the efficiency of truncal blocks has already been proven in clinical studies, the optimal dosage, concentration and choice of the drugs used in specific truncal blocks are still investigated [8–10]. Another alternative analgesic technique is the local wound infiltration with a catheter after mini-sternotomies and mini-thoracotomies [11, 12]. This article gives information about a variety of truncal blocks in cardiothoracic surgeries.

2. Neuraxial block
Thoracic epidural anesthesia (TEA) has long been the golden standard for thoracic surgeries due to its high efficiency [13]. On the other hand, it is very invasive and it causes unwanted arterial hypotension by sympathetic block. As for cardiac anesthesia, the use of TEA is still controversial because of concomitant anticoagulant use and the risk of epidural hematoma [14]. TEA reduces the risk of perioperative myocardial infarction, respiratory depression and atrial arrhythmias when used for cardiac surgery [15, 16]. In a large meta-analysis, researchers compared the risks and benefits of cardiothoracic TEA from 66 randomized studies. They concluded it provides excellent analgesia for cardio-thoracic surgery with a reduction in mortality (number needed to treat (NNT) = 70). No cases of epidural hematoma have been reported [17].

To reduce the risk of epidural hematoma, TEA must be administered at least 18 hours prior cardiac surgery. When
anticoagulants are continued in the postoperative period, the epidural catheter can only be removed after a certain period of time. The catheter can be removed 4 hours after discontinuing therapeutic doses of non-fractioned heparin and the activated partial thromboplastin time is at normal value. Non-fractioned heparin infusion can be continued one hour after the catheter removal. For low-molecular-weight (LMW) heparin, 18 hours must pass from the last application before the epidural catheter removal. LMW heparin can be continued in a preventive dose 6 hours after the catheter removal, whereas therapeutic doses may only be administered 48 hours after the catheter removal [18]. Authors believe the fear of neurologic complications following TEA in cardiothoracic surgery is too high. TEA is safe when administered in a correct timeline with anticoagulant drugs. Anesthesiologist should educate all the medical team members for a better compliance with the chosen anesthetic method.

Spinal anesthesia, on the other hand, has not found its place in cardiothoracic surgery. In a large meta-analysis, researchers concluded that spinal analgesia does not improve perioperative morbidity or mortality in patients undergoing cardiac surgery. Clinicians avoid intrathecal administration of local anesthetics or opioids because of the increased risk of neuraxial hematoma formation, which can lead to paraplegia in patients receiving heparin during surgery. The risk of spinal hematoma because of central neuraxial anesthesia in cardiac surgery has statistically been evaluated at 1:1528 for epidural and 1:3610 for spinal block. However, authors of the study have not found any of these complications recorded [19].

3. Paraneuraxial block

According to the Italian VATS (Video-assisted thoracic surgery) association, paravertebral block (PVB) is the first choice of regional anesthesia in thoracic surgery, because it provides a unilateral block and causes less hemodynamic compromise in comparison to TEA [20]. Local anesthetic is injected into the paravertebral space at one or more levels (Fig. 2). Paravertebral space is wedge-shaped in transverse cross-section and is limited by the bodies of thoracic vertebrae and intervertebral foramina medially, the parietal pleura anteriorly and by the transverse processes, head and neck of the rib and the upper costotransverse ligament posteriorly. Local anesthetic, injected into the paravertebral space, diffuses medially into the epidural space, laterally into the intercostal space and cranio-caudally to adjacent paravertebral spaces [21]. The PVB causes sensory, motoric and sympathetic block, depending on the volume and concentration of the injected local anesthetic. Contraindications for PVB are infection at the injection site, empyema or pleural tumor or a tumor of the paravertebral space. Coagulation disorders are considered a relative contraindication. Specific complications of the block are pleural puncture and pneumothorax [22]. Features of thoracic regional anesthetic techniques are listed in Table 1.

Several meta-analyses have shown that thoracic PVB may be as effective as TEA for post-thoracotomy pain relief and is also associated with fewer complications. Yeung and colleagues executed a meta study of 14 studies with almost 700 participants and proved that PVB reduced the risks of developing minor complications compared to TEA. PVB was as effective as TEA in controlling acute pain. However, there was no difference in 30-day mortality, major complications, or length of hospital stay [23]. In another meta-analysis of 12 clinical trials, they concluded that thoracic PVB may be as
<table>
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<tr>
<th>Regional anesthetic technique</th>
<th>Puncture site</th>
<th>Local anesthetic spread</th>
<th>Clinical use</th>
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<tr>
<td><strong>Thoracic epidural anesthesia (TEA)</strong></td>
<td>Sagittal or parasagittal in the level Th6–7</td>
<td>The epidural space approx. 6 levels around the puncture site, spreading 1:2 cranio-caudal</td>
<td>The golden standard of analgesia for thoracotomy, (un)wanted bilateral sympathetic and sensory block, hypotension, greater fluid requirements, specific anticoagulation precautions</td>
</tr>
<tr>
<td><strong>Paravertebral block (PVB)</strong></td>
<td>One or more puncture sites parasagittal in the level of operative wound</td>
<td>Paravertebral space</td>
<td>First choice for VATS surgeries; pleural puncture is a possible complication</td>
</tr>
<tr>
<td><strong>Erector spinae plane block (ESPB)</strong></td>
<td>Above the transverse process of vertebrae Th4–5</td>
<td>Myofascial plane between the erector spinae muscle and lateral process of the thoracic vertebrae</td>
<td>One of the safest and most efficient thoracic plane blocks in alternative to TEA with the puncture site far from pleura, lungs or spinal cord. Safe for use in anticoagulated patients.</td>
</tr>
<tr>
<td><strong>Retrolaminar block (RLB)</strong></td>
<td>Multiple puncture sites above the thoracic lamina, 1 cm parasagittal</td>
<td>Myofascial plane between thoracic lamina and paraspinous muscles</td>
<td>Less efficient than ESPB, lack of RCTs</td>
</tr>
<tr>
<td><strong>Serratus anterior plane block (SAPB)</strong></td>
<td>Midaxillary in the level of the 5th rib</td>
<td>Above for the superficial and below for the deep block</td>
<td>Most suitable for anterior thoracotomy, rib fracture or breast surgery</td>
</tr>
<tr>
<td><strong>Pectoral nerves block</strong></td>
<td>PECS I between the pectoralis major and minor muscles, US landmark is the pectoral branch of the thoracoacromial artery; an additional lateral injection at the anterior axillary line at the level of the fourth rib between the pectoralis minor and the serratus anterior muscle for PECS II</td>
<td>PECS I: medial and lateral pectoral nerves between the pectoralis major and minor muscles, PECS II also under the pectoralis minor muscle (between the clavicular fascia and the superficial border of the serratus muscle)</td>
<td>Most suitable for breast surgery, pacemaker or implantable cardioverter-defibrillator insertion</td>
</tr>
<tr>
<td><strong>Transversus thoracis plane block (TTPB)</strong></td>
<td>Parasagittal medial to the mid-clavicular line over the 3rd and 4th rib, needle tip located parasternal</td>
<td>Myofascial plane between the transversus thoracis muscle and the internal intercostal muscles to block the anterior branches of Th2–Th6 intercostal nerves</td>
<td>Sternotomy, sternal fractures, medial coverage for breast surgery or for tunneled pacemaker or implantable cardioverter-defibrillator insertion</td>
</tr>
<tr>
<td><strong>Parasternal intercostal nerve block (PSIB)</strong></td>
<td>2 cm lateral to the midline in the 3rd and 5th parasternal intercostal spaces</td>
<td>Between the pectoral major and external intercostal muscles</td>
<td>Median sternotomy</td>
</tr>
<tr>
<td><strong>Intercostal nerve block (ICNB)</strong></td>
<td>Multiple injections transcutaneous parasagittal around the level of surgical incision or intrathoracic by the surgeon</td>
<td>Between the medial and innermost intercostal muscles</td>
<td>For rib fractures, chest and upper abdominal surgery such as thoracotomy, mastectomy or gastrostomy</td>
</tr>
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*Thoracic, RCT—randomized controlled trial, US—ultrasound, VATS—video-assisted thoracic surgery, PECS—pectoral nerves block.*

effective as TEA for post-thoracotomy pain relief with a visual analogue pain score (VAS) on activity at 48 h significantly better in the PVB group. They also reported less hypotension and urinary retention in the PVB group [24]. On the other hand, a meta-analysis of 5 studies involving thoracoscopic surgeries showed that the numerical rating scale (NRS) score for resting pain was higher in the thoracic paravertebral block (TPVB) group than in the TEA group at 1–2 hours and 4–6 hours after surgery. Giving a closer look, the difference is statistically significant, but clinically irrelevant (mean difference (MD) =
0.44, 95% coincidence interval (CI) = 0.24 to 0.64, p < 0.0001, I² = 0%; MD = 0.47, 95% CI = 0.23 to 0.70, p < 0.0001, I² = 0% [25].

Bilateral PVB for cardiac surgery was researched by El Shora and colleagues, who proved its analgesic efficiency for median sternotomy. 140 patients were divided into groups receiving either PVB or TEA. No statistically significant difference in VAS was measured at 12, 24, and 48 hours post operation, rendering the PVB comparable but not superior to TEA [26].

4. Thoracic myofascial plane blocks

4.1 Retrolaminar block

For the retrolaminar block (RLB), local anesthetic is injected between the lamina of thoracic vertebrae and paraspinal muscles, approximately 1 cm lateral to the sagittal plane (Fig. 3). For a better block efficiency, a large volume must be injected, that is at least 30 mL [27]. Cranio-caudal spread is limited to 2–4 segments and the transverse spread to approx. 2.5 cm. The main action site is the interfascial plane, where it blocks the lateral cutaneous branches of the intercostal nerves. Its spread often excludes the paravertebral space, so it does not block the spinal nerves [28, 29]. The utility of the RLB was described only in case reports, while large randomized prospective clinical studies are still missing. In a retrospective analysis, they compared the analgesic efficacy of continuous RLB compared to TEA for VATS marginal lung resection. They proved comparable analgetic efficacy, post-operative pain scores and similar use of rescue analgesia in comparison to TEA [30]. However, not all studies are in favor of the RLB. In a prospective study of patients undergoing minor VATS procedures, they described the RLB as inferior compared to PVB [31].

Bilateral thoracic RLB was used for pediatric open cardiac surgery via median sternotomy in a study by Abdelbaser, where they confirmed a significantly smaller postoperative opioid consumption compared to the placebo group [32].

4.2 Erector spinae plane block

The erector spinae plane block (ESPB) was initially described as rescue analgesia for serial rib fracture [33]. Its use later spread to surgeries that involve the chest wall [34]. ESPB can be used as a single shot or continually with a catheter. Local anesthetic is injected into the myofascial layer between the erector spinae muscle and the lamina of thoracic vertebrae on the level Th4 or Th5 (Fig. 4). Local anesthetic diffuses into the paravertebral space, where it blocks the dorsal and ventral branches of thoracic spinal nerves, lateral branches of spinal nerves that innervate the skin and communicant branches that innervate the sympathetic chain [35]. ESPB blocks multiple levels with a single injection as the local anesthetic spreads cranio-caudally, usually from Th2 to Th9 or even C7 to Th10, depending on the volume of injectate and the level of injection site [36]. The main advantage of the ESPB is its safety profile, because the injection site is far from the spinal cord, pleura and lungs. If an inadvertent vascular puncture occurs, the site can be locally compressed, so it is safe to use in anticoagulated patients [37]. In a meta-analysis from 2020 which included 14 studies, they proved a significant reduction in opioid consumption, smaller pain scores and less post operative nausea and vomiting (PONV) in patients with ESPB compared to those without regional anesthesia for thoracic surgery [38]. Bilateral ESPB with a catheter is a comparable method to TEA for patients undergoing cardiac surgery, with similar results not only regarding pain scores, but also postoperative incentive spirometry, ventilator-dependency duration and intensive care unit length of stay [39].

4.3 Serratus anterior plane block

Serratus anterior plane block (SAPB) has emerged as a regional anesthetic technique for surgery on the anterolateral wall of the
chest, including breast surgery [40, 41]. Local anesthetic is injected under serratus anterior muscle for the deep or above the same muscle for the superficial block. Studies comparing the deep and the superficial block showed superiority of the latter, that lasts longer and has a higher success rate [42]. The needle insertion site is at the level of 5th intercostal space, residing in the mid-axillary line (Fig. 5). The SAPB blocks the lateral cutaneous branches of the intercostal nerves from Th2 to Th7–9. According to cadaveric studies, the local anesthetic also spreads to n. pectoralis lateralis and medialis, n. thoracicus longus and n. thoracodorsalis (Fig. 6). A greater block area is connected to larger injected volumes, up to 40 mL of local anesthetic [43].

The use of SAPB after thoracic surgery was researched in a meta-analysis of 8 studies. They discovered a statistically significant reduction in pain levels and reduced opioid use than in the control group without regional anesthesia, which also experienced more PONV [44]. The use of continuous deep SAPB was investigated by Toscano et al. [45], who confirmed its analgesic and opioid sparing effect in patients undergoing mini-thoracotomy mitral valve replacement.

**FIGURE 5. The serratus anterior plane block.** P—pleura. The needle pathway is marked yellow.

### 4.4 Pectoral nerves block

The pectoral nerves (PECS) block was initially described for postoperative anesthesia in breast surgery [46]. The PECS block is divided into two different nerve blocks. The PECS I targets the medial and lateral pectoral nerves. Local anesthetic is injected between the pectoralis major and minor muscles. The main landmarks to identify the point of injection under ultrasound guidance are the pectoralis major and pectoralis minor muscles with the pectoral branch of the thoracoacromial artery. With an additional lateral injection at the anterior axillary line on the level of the fourth rib between the pectoralis minor and the serratus anterior muscle, the PECS II also blocks upper intercostal nerves, as well as the long thoracic nerve and the intercostobrachial nerve [47].

A meta-analysis of PECS II as analgesia for breast cancer surgery showed that it reduces pain intensity and morphine consumption during the first 24 hours postoperatively when compared to systemic analgesia alone; it also offers analgesic benefits non-inferior to those of PVB after breast cancer surgery. Evidence supports incorporating PECS II as an alternative to PVB for breast cancer surgery [48].

It is also a useful anesthetic method for the implantation of cardiovascular electronic devices, such as pacemakers or implantable cardioverter-defibrillators [49]. Large meta-analyses of the method for major cardiac surgeries are still missing. A study comparing bilateral PECS II block with intravenous analgesia only for coronary artery bypass grafting surgeries or coronary valve surgeries via median sternotomy showed that pain scores evaluated at rest and cough were substantially lower in the PECS group at times 0, 3, 6, 12, and 18 hours from extubation [50].

### 4.5 Transversus thoracis plane block

The transversus thoracis plane block (TTPB) is a regional anesthetic method for relieving post-sternotomy pain. The local anesthetic is administered as a single shot into the myofascial plane between the transversus thoracis muscle and the internal intercostal muscles in order to block the anterior branches of Th2–Th6 intercostal nerves [51–53].

A study by Shokri et al. [54] compared cardiac surgery patients receiving bilateral TTPB with those receiving general anesthesia only. In the first 24 hours after surgery, they found that the proportion of patients needing extra opioid analgetic doses, total postoperative opioid demand and pain scores were substantially lower in the group which received TTPB than in the comparative group with general anesthesia only. Ventilation time and intensive care unit stay in the TTPB group were substantially shorter. Between the study groups, they found no distinctive differences in postoperative complications. Abdelbaser and colleagues studied the analgesic potency of TTPB when used in pediatric cardiac surgery. They discovered its use decreased perioperative opioid consumption and reduced postoperative pain intensity in comparison to general anesthesia only [55].

### 4.6 Parasternal intercostal nerve block

Parasternal intercostal nerve block (PSIB) targets the anterior and posterior intercostal nerves that reside on the inferior side of each rib lateral to the sternum (Fig. 7). The technique is typically performed by the surgeon at the time of sternal closure by multiple injections of local anesthetic into the parasternal intercostal spaces between the parasternal major and external intercostal muscles, but can also be performed pre-operatively under ultrasound guidance [15].

Preoperative PSIB was studied for use in coronary artery bypass grafting via median sternotomy. The PSIB reduced the maximum concentrations of remifentanil and propofol required to maintain hemodynamic stability and depth of anesthesia during sternotomy [56]. PSIB was also studied for postoperative analgesia in pediatric patients undergoing cardiac surgery. Time to extubation was significantly lower in patients who were administered the PSIB with ropivacaine than in the control group. The pain scores were lower in the PSIB group with a significantly lower cumulative fentanyl dose requirement over a 24-hour period [57].
A study evaluated the effectiveness of ultrasound-guided parasternal intercostal nerve block for postoperative analgesia in patients undergoing median sternotomy for mediastinal mass resection. They applied local anesthetic in the 3rd and 5th parasternal intercostal spaces bilaterally. The PSIB group required 20% less sufentanil added by the patient-controlled analgesia (PCA) pump compared to the control group and reported lower pain scores in rest and cough 24 hours after surgery [58].

In a meta-analysis of 59 studies, the single shot ICNB was associated with a reduction of pain during the first 24 hours after thoracic surgery and was clinically non-inferior to TEA or PVB. However, TEA and PVB were associated to larger decreases in postoperative opioid use, suggesting that ICNB may be most beneficial for cases where TEA and PVB are contraindicated [62]. In a study comparing regional anesthetic methods for cardiac surgery via thoracotomy, ICNB was declared inferior to PECS II and SAPB blocks [63].

Local anesthetic, delivered through a wound catheter is a successful method of postoperative analgesia in most surgical fields. Nevertheless, it has produced mixed results in cardiac surgery when used after full sternotomy. In a study by Mijovski et al. [64], the effectiveness of 0.2% ropivacaine wound infusion through a catheter delivered by PCA pump was investigated in 70 patients for mini-thoracotomy aortic valve replacement. The cumulative dose of the opioid needed in the first 48 hour after surgery was significantly lower in the group receiving local anesthetic compared to placebo. They reported high patient satisfaction regarding pain relief and there were no infections of the wound or local anesthetic toxic
side effects. A similar study by Dowling et al. [65] confirmed that continuous infusion of local anesthetics improved postoperative pain control while lowering the total opioid analgesia required in patients who underwent full median sternotomy. In another study by Agarwal et al. [66], the data safety monitoring board stopped the study after enrolling 85 patients because of excessive sternal wound infections (9%, n = 44) in the ropivacaine group. It is unclear why they provided contradictory results.

As for thoracic surgery patients, Fiorelli et al. [12] investigated the effects of local anesthetic through a wound catheter in patients undergoing muscle-sparing thoracotomy and lung cancer resection. The local anesthetic group compared with the control (placebo) group had a significant reduction of postoperative interleukin-6, interleukin-10 and tumor necrosis factor alpha blood concentration levels, lower pain scores, and a decrease of additional morphine intake during the entire postoperative course. Spirometry results, such as the recovery of the flow expiratory volume in one second % and the forced vital capacity % were also reported better in the research than in the placebo group.

7. Institutional experience

Anesthesiologists, intensivists and cardiac surgeons at the University medical center Ljubljana Cardiovascular surgery department collaborate in the local anesthetic wound infusion protocol. Patients, undergoing mini sternotomy, receive the local anesthetic via a pre-programmed PCA pump without a continuous opioid infusion. In the occasion of breakthrough pain, the patients receive a bolus of piritramide. They report high patient satisfaction and low opioid consumption [64].

The team of anesthesiologists in cooperation with thoracic surgeons at the Surgery Bitenc center in Slovenia implement regional anesthetic techniques for thoracic surgery patients to provide optimal, safe and patient-centered analgesia. The most commonly performed block is the continuous ESPB with a catheter for VATS lung resections. The use of ESPB diminished total opioid consumption in VATS patients and is used especially in older, fragile patients. They report good efficacy and high patient satisfaction with the analgesic method [35].

8. Conclusion

Numerous studies and meta-analyses show that analgetic treatment after cardiothoracic surgery can be improved by adding regional anesthetic techniques in context of multimodal analgesia. There is no single method which excerts superior analytic proprieties and is completely safe. Therefore, we must combine different types of post-operative analgesia and adjust them inter-individually according to the patient and surgery. New regional techniques emerged as a step towards minimal opioid use to diminish their side effects and potential addiction. Implementation of regional blocks is safer under ultrasound guidance and with some precaution, they can also be performed on anticoagulated patients. Deepened knowledge of anatomy and regional anesthetic techniques enables the anesthesiologist to provide the optimal, safe and patient-centered analgesia.

AUTHOR CONTRIBUTIONS

PG—designed the article and wrote the original draft. JK—contributed to the initial concept and article design. MS—contributed to the initial concept, supported the process and provided expert supervision. All authors reviewed, edited and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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