Review Article

Regional anesthesia for thoracic surgery: a narrative review of indications and clinical considerations

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Background and Objective: Surgical procedures involving incisions of the chest wall regularly pose challenges for intra- and postoperative analgesia. For many decades, opioids have been widely administered to target both, acute and subsequent chronic incisional pain. Opioids are potent and highly addictive drugs that can provide sufficient pain relief, but simultaneously cause unwanted effects ranging from nausea, vomiting and constipation to respiratory depression, sedation and even death. Multimodal analgesia consists of the administration of two or more medications or analgesia techniques that act by different mechanisms for providing analgesia. Thus, multimodal analgesia aims to improve pain relief while reducing opioid requirements and opioid-related side effects. Regional anesthesia techniques are an important component of this approach.

Methods: For this narrative review, authors summarized currently used regional anesthesia techniques and performed an extensive literature search to summarize specific current evidence. For this, related articles from January 1985 to March 2022 were taken from PubMed, Web of Science, Embase and Cochrane Library databases. Terms such as "pectoral nerve blocks", "serratus plane block", "erector spinae plane block" belonging to blocks used in thoracic surgery were searched in different combinations.

Key Content and Findings: Potential advantages of regional anesthesia as part of multimodal analgesia regiments are reduced surgical stress response, improved analgesia, reduced opioid consumption, reduced risk of postoperative nausea and vomiting, and early mobilization. Potential disadvantages include the possibility of bleeding related to regional anesthesia procedure (particularly epidural hematoma), dural puncture with subsequent dural headache, systemic hypotension, urine retention, allergic reactions, local anesthetic toxicity, injuries to organs including pneumothorax, and a relatively high failure especially with continuous techniques.

Conclusions: This narrative review summarizes regional anesthetic techniques, specific indications, and clinical considerations for patients undergoing thoracic surgery, with evidence from studies performed. However, there is a need for more studies comparing new block methods with standard methods so that clinical applications can increase patient satisfaction.

Keywords: Ultrasound; thoracic wall nerve blocks; fascial plane blocks; regional anesthesia; thoracic surgery

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Introduction

Postoperative pain is common and sometimes severe after thoracic surgery. Inadequate postoperative analgesia has been associated with insufficient mobility, more atelectasis, prolonged hospital stays, and increased costs for the healthcare system (1-3). High-dose opioid use is not ideal due to undesirable side effects such as nausea, vomiting, constipation, urinary difficulty, respiratory depression, sedation, possible persistent postsurgical pain, and concerns relating to opioid use dependency (4,5). Therefore, balanced multi-modal analgesia techniques have been used in recent years and regional anesthesia techniques have become one of the indispensable cornerstones (6).

Until recently, regional techniques were limited to the thoracic epidural, thoracic paravertebral blocks (TPVB), and intercostal blocks (7,8). However, with the introduction of ultrasound into clinical practice of regional anesthesia in the last decade, nerve blocks have become safer and more successful (9,10). Different approaches to previously defined blocks, as well as novel blocks like fascial plan blocks have been developed and introduced into clinical practice.

This review article summarizes current research and addresses popular regional anesthetic techniques for patients having thoracic surgery, including thoracotomy, video-assisted thoracoscopy, and rib resection. We present the following article in accordance with the Narrative Review reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-22-599/rc).

Methods

For this review, the authors first conducted an extensive literature search. For this, a computer-based search was performed in English databases, including PubMed, Web of Science, Embase, and Cochrane Library. The date range for the search was set from January 1985 to March 2022. Among the search terms were the names of all the blocks included in our study (*Table 1*). Care was taken to ensure that the studies were in a prospective randomized controlled design to be included in this review. After reading the titles and abstracts, the records obtained from the database were pre-selected by the authors. Afterward, it was tried to reach the full texts of the studies planned to be included in the review. Those whose full text could not be accessed or which, after reading the full text, were not thought to be random and would not contribute to the review in terms of content were excluded. Since our study was designed as an article in the category of narrative review, standard methodological methods and statistical analyzes were not used in meta-analyses.

Chest wall anatomy and innervation

Typical intercostal nerves and atypical intercostal nerves are the two most common types of intercostal nerves. T_3 through T_6 are typical intercostal nerves, while T_1 through T_2 and T_8 through T_{11} are atypical intercostal nerves. The fundamental difference between the two groups is that typical intercostal nerves remain limited to their own intercostal spaces, whereas atypical intercostal nerves pass through the thoracic wall and partially or completely serve other areas (11).

The typical intercostal nerve enters the intercostal space between the parietal pleura and the intercostal membrane, running laterally behind the sympathetic trunk. It flows along the intercostal vessels and in front of the internal thoracic artery while in the costal groove. The rami communicantes, muscle branches, collateral branch, lateral cutaneous branch, and anterior cutaneous branch are the primary branches of the typical intercostal nerves. Gray and white rami innervate the corresponding thoracic ganglion via the rami communication branches. The intercostal muscles, parietal pleura, and rib periosteum are all innervated via the collateral branch. The muscles are crossed by the lateral cutaneous branch.

The anterior cutaneous branch, which separates into medial and lateral branches to supply the skin of the anterior thoracic wall, is the terminal branch of the typical intercostal nerves (12).

Along with the ventral ramus of C_8, the first intercostal nerve contributes to the lower trunk of the brachial plexus. The rest of the first intercostal nerve is devoid of both the lateral and anterior cutaneous branches that are found in conventional intercostal nerves. The intercostobrachial nerve is a branch of the second intercostal nerve that provides cutaneous information from the axilla floor and superior region of the upper extremity. This nerve might be responsible for the pathognomonic pain that patients having coronary artery disease describe on the medial side of the arm (13).

Chest tubes in thoracic surgery are frequent causes of pain that are difficult to address. Thoracostomy tube pain potentially can emanate from a variety of sources. The parietal pleura receives somatic afferent (sensory) innervation from two different sources; the intercostal

Table 1 The search strategy summary

Items	Specification
Date of search	From 1 February 2021 to 15 March 2021
Databases and other sources searched	PubMed, Web of Science, Embase and Cochrane Library
Search terms used	Refer to Table S1
Timeframe	From 1 January 1985 to 30 March 2022
Inclusion and exclusion criteria	Mainly prospective randomized controlled trials and meta-analyses were included in the study
	Those whose full text could not be reached or who would not contribute to the review in terms of content were excluded from the study
Selection process	All authors performed the search strategy independently. Two researchers (GS, YT) then re-performed a secondary access of eligible studies and evaluated potentially relevant articles against the selection criteria above

nerves (T_1-T_{11}) and the phrenic nerve (C_3-C_5). The intercostal nerves (T_1-T_{11}) provide innervation to the costal pleura and peripheral diaphragmatic pleura. The mediastinal pleura and the central parietal pleura are innervated by the phrenic nerve (C_3-C_5) (14). This innervation pattern is likely why chest wall blocks that potentially penetrate the paravertebral space seem to be more effective in thoracic surgery (with thoracostomy tubes) than others.

Intercostal nerve block (ICNB)

Understanding chest wall anatomy and innervation is important when considering clinical indications for and the application of ICNB. Intercostal nerves are ventral continuations of spinal nerves T_{1}-$_{11}$. In the intervertebral foramen, each nerve exits the pleura and endothoracic fascia and then pierces the posterior intercostal membrane (posterior continuation of the innermost intercostal muscle) to flow between the innermost and internal intercostal muscles within the subcostal groove (15) (*Figure 1*). Along their course, the intercostal nerves have lateral cutaneo us branches at the level of the midaxillary line and finally continue anteriorly towards the midline to give rise to anterior cutaneous branches (15). T_1 usually does not have lateral or anterior cutaneous branches. The intercostal nerves provide segmental innervation with an overlap between the adjacent nerves, requiring blockade of 1–2 nerves above and below the level of injury/incision to provide effective analgesia. The ICNB can be performed anywhere along the nerve course dorsal to the midaxillary line (before the lateral cutaneous branches take off).

Any procedure involving the chest wall (thoracic surgeries), as well as rib fractures, could be an indication for ICNB (16). Indications outside the operating room include postsurgical analgesia after thoracostomy and postherpetic neuralgia (17). Thoracic epidural analgesia (TEA) has been considered the gold standard for postoperative pain control after thoracic surgery and was an integral part of early Enhanced Recovery After Surgery (ERAS) protocols for many years. However, adverse events and complications such as dural puncture, postoperative radicular pain, subarachnoid block, spinal cord-root injury leading to permanent motor deficits, TEA-associated cardiovascular/respiratory collapse, peripheral nerve lesions, and epidural hematomas or infection (18) associated with it have led clinicians to seek alternative regional methods with similar efficacy and lower risk of adverse events, especially for minimally invasive thoracoscopic surgeries (19-21). Both, the ERAS and the European Society of Thoracic Surgeons (ESTS), recommend either TPVB or ICNB for thoracic surgery as part of ERAS protocols (22,23). Contraindications for ICNB include clinically significant coagulopathy, local infection, or patient refusal (24). When used in thoracic surgery, ICNB is rarely performed via transcutaneous injection (ultrasound or traditional landmark-based technique), and more commonly via transparietal injection from within the pleural cavity or direct injection through surgical or port incision by the surgeon (25,26). Evidence suggests that ICNB is superior to systemic analgesia alone in thoracic surgery (27). However, it is inconclusive when comparing ICNB with other techniques such as paravertebral block (PVB) or TEA, as also concluded by two systematic reviews and meta-analyses (3,21,28,29). A recent meta-analysis compared TEA with

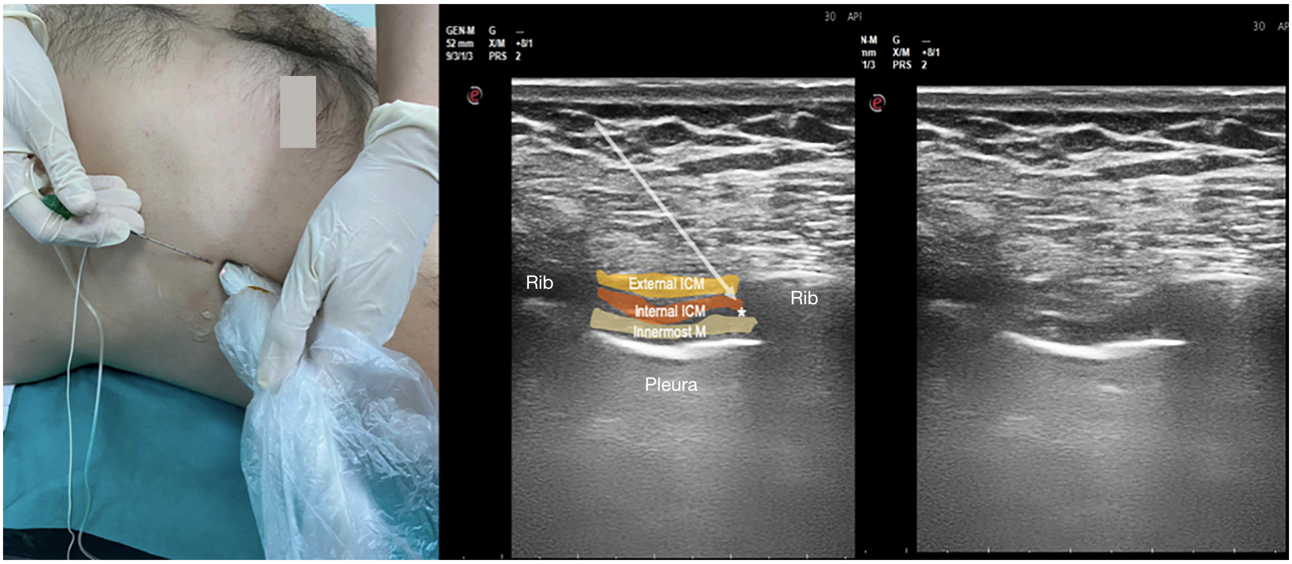

Figure 1 Ultrasound probe positioning and sonographic image of the intercostal nerve block. This image is published with the patient/participant's consent. *, needle tip place. ICM, intercostal muscle.

ICNB and reported that single-injection ICNB was not clinically inferior to TEA in terms of pain reduction within the first 24 h after thoracic surgery. In this article, it was emphasized that ICNB analgesia has opioid sparing effects, but the decrease in postoperative morphine milligram equivalents (MMEs) is not greater than that of TEA. The authors therefore reported that ICNB may be most useful when TEA is not indicated (28).

Comparisons of ICNB with some of the novel facial plane blocks suggest similar efficacy, but the evidence is limited (30). Unlike other regional techniques, ICNB can also be performed with cryoanalgesia, which involves cooling the nerve and reversible inhibition of function lasting weeks to months (31). Although studies show the effectiveness of intercostal nerve cryoanalgesia in the immediate postoperative period, concerns have been raised about its contribution to post-thoracotomy chronic neuropathic pain. Further investigation is needed to evaluate this modality in thoracic surgery (32,33). The main complications of ICNB are infection, bleeding, pneumothorax or intraneural injection. Although local anesthetic systemic toxicity (LAST) is a rare event, local anesthetic (LA) uptake from this region is high. Therefore, providers should be alert to LAST. A few case reports of spinal block after ICNB have been reported (34). This is thought to occur after injection of a LA spreading medially through the dura or into a dural sac protruding laterally from the vertebral foramen. Aspiration must be performed beforehand to avoid intravascular, intrapleural or intrathecal injection (24).

Thoracic paravertebral block

TPVB is a nerve block administered by injecting LA into the thoracic paravertebral space (TPVS) (*Figure 2*). TPVB aims at spinal and sympathetic nerves to create an ipsilateral segmental somatic and sympathetic block. The TPVS is a cuneiform chamber that lies on the lateral side of the vertebral column between the heads and necks of the upper and lower ribs. The largest dimension of the TPVS is its medial side. The TPVB is performed to obtain regional anesthesia and analgesia for thoracic surgery as an alternative to thoracic epidural surgery patients (35-37).

The block-level should be as close to the location of the dermatome for the incision or injury as possible. Blockage of three to five adjacent intercostal nerves may be required to achieve a complete block of one dermatome owing to the interconnections between spinal nerves and overlap in the innervation of dermatomes. This can be achieved by multiple blocks or a single injection of a larger volume of LA. More medial access for placement of a TPVB may decrease the risk of pleural puncture. However, more medial placement may raise the risk of neuraxial complications such as excessive epidural spread, accidental dural puncture (with or without spinal block), as well as increased the

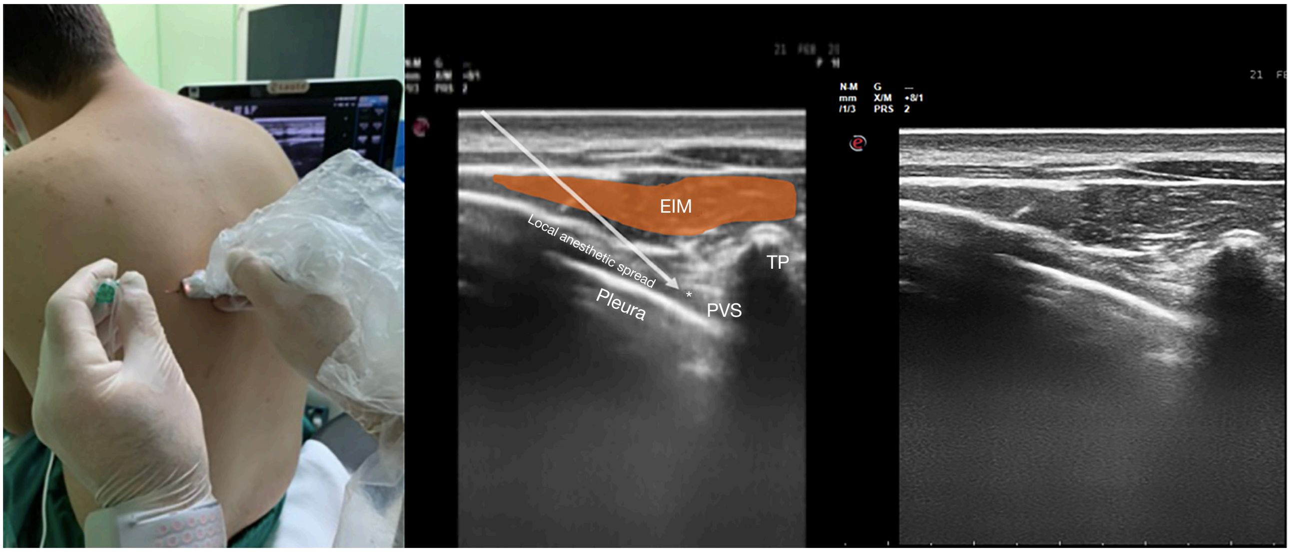

Figure 2 Patient position and sonoanatomy of the paravertebral block. This image is published with the patient/participant's consent. *, needle tip place. EIM, external intercostal muscle; TP, transverse process; PVS, paravertebral space.

chance of anterior catheter migration into the mediastinum. Furthermore, the application of high volumes of LA and high pressure during injection increases the likelihood of epidural spread (38).

TPVS communicates medially with the epidural space, laterally with the intercostal space, and cranially with the cervical paravertebral space. There is controversy over the caudal extent of the TPVS below T_{12}. Some cadaveric studies have found low dye diffusion from injections below the arcuate ligament into the TPVS, while others have found no spread at all (39-41). There are cavities in the superior costotransverse ligament, which form most of the dorsal border of the TPVS, which may allow LA to diffuse into the paravertebral space from more superficial injections [e.g., erector spinae plane (ESP) blocks].

A recent meta-analysis compared TPVB and TEA in patients having thoracoscopic surgery and reported minor, but clinically unimportant short-term benefits of TPVB over TEA. Furthermore, TPVB can be safely used in patients with coagulation dysfunction, spinal deformity, infection or in patients with contraindications against TEA like high risk of hypotension (42).

Epidural block

Thoracic epidural anesthesia (TEA) is a form of neuraxial anesthesia in which LA, often combined with adjunct medication, is injected into the epidural space at the levels of the thoracic vertebrae. TEA is an effective and versatile technique frequently used for perioperative analgesia in patients requiring thoracic surgery. If required for patients in whom a general anesthetic is contraindicated, TEA can also be used as a regional anesthetic strategy in awake or sedated patients.

The epidural space is a potential space that exists between the dura mater and ligamentum flavum. This space can be accessed with a needle to inject the medication, or, more commonly, a catheter can be threaded through the needle and left in the space to infuse medication that bathes the spinal roots as they emerge from the spinal column. Typically, a thoracic epidural placed above the T_5 vertebrae is denoted as a high thoracic epidural, while access between T_5 and T_{12} denotes a lower thoracic epidural (43).

The main indications for epidural blocks are thoracic surgery, including thoracotomy, video-assisted thoracoscopy, rib resection (44), as well as trauma patients with rib and chest wall injury (45).

For some complex patients, such as those suffering from chronic pain, opiate sensitivity, obstructive sleep apnea, respiratory depression, and pulmonary disease, TEA can be an ideal perioperative analgesic modality (46). TEA's potential to significantly reduce the dose of opiate analgesia required can be a key benefit for patients recovering from thoracotomy. This also includes lower rates of postoperative ileus (18). With the advent of ultrasound, never regional techniques depending on fascial planes have begun to supplement and, in some cases replace the TEA as the standard analgesic technique for patients undergoing thoracic surgery. Initial retrospective studies suggest potential noninferiority of fascial plane blocks to TEA (47). However, this study included video-assisted thoracoscopic surgery (VATS) or thoracotomy for wedge resection, lobectomy, esophagectomy, or pectus repair causing varying levels of postoperative pain. In addition, the number of cases included in the study was relatively small.

Also, unlike VATS, ESRA recommends TEA containing LA and opioid for 2–3 days or continuous TPVB with LA for pain management after thoracotomy. If these regional techniques are not feasible or are contraindicated, ESRA recommends systemic opioid and non-opioid analgesic with or without patient-controlled analgesia (48).

Ultrasound is also being used to place TEAs, though most recent randomized controlled trials do not show any significant advantages to ultrasound-assisted placement versus the traditional palpation technique (49).

Importantly, TEA can cause sympatholysis and subsequent drops in systemic vascular resistance. In patients with limited cardiovascular reserves, this can precipitate cardiovascular collapse. In patients with increased intracranial pressure (ICP), instilling the medication in the epidural space can compound ICP and cause herniation (50). While a functioning TEA provides effective analgesia for many surgical procedures, there are drawbacks during placement. Thoracic epidural placement can be technically challenging and stressful for awake patients. The most common adverse event following TEA placement is a nonfunctioning block (up to 30%) (51). Catheter migration or displacement can leave patients with unilateral or patchy blocks. During the sequence, vascular injury, paresthesia, and neural injury are serious complications, more common in patients with challenging anatomy.

Ultrasound-guided interfascial plane blocks

Most of the ultrasound-guided peripheral blocks for thoracic surgery are fascial plane blocks. Since the nerves involved are small and difficult to discern by imaging, the basic principle is to inject a significant volume of LAs (20–30 mL for adult, or 0.2–0.4 mL/kg for children) between the fascial planes to reach the nerves traveling between and adjacent to the fascial planes. The injected LAs may also spread to other compartments, such as the paravertebral area. The pattern and extent of spread are variables between individuals, resulting in variability of the amount of LA reaching and acting on the nerves. Therefore, sensory and motor blocks are always balanced, but individual variation can be expected (52).

Since the effectiveness of the fascial plane blocks depends on the extent of spread and LA volume, there is always a risk of LA toxicity due to systemic absorption. Therefore, maximum dose limits should be respected. As these blocks are primarily used for analgesic purposes, diluted LA concentrations can be used (bupivacaine 0.125%, 0.25%, ropivacaine 0.2%). If using a catheter for continuous infiltration, a loading dose of 20 mL or 0.2 mL/kg of dilute LA concentration (0.125% bupivacaine *vs.* 0.2% ropivacaine), followed by either 8–10 mL/h continuous infusion or intermittent doses of 10–15 mL every 1–3 h are recommended.

Infusion techniques used in chest wall blocks can be continuous infusion of LA or intermittent boluses of LA. It is recommended not to keep the catheters for longer than 48 h due to the risk of infection. In a study conducted in patients who underwent TPVB for postoperative analgesia after VATS, continuous infusion and programmed intermittent bolus infusion were compared, and postoperative pain and opioid use were found to be similar in both groups (53).

Fascial plane blocks are:

(I) Pectoral nerve blocks (PECS type I and II);
(II) Serratus plane block;
(III) Pecto-intercostal block;
(IV) Parasternal block;
(V) And erector spine plane (ESP) block.

Interfacial plane blocks of the chest wall can be used alone or in combination for surgical anesthesia and postoperative analgesia as an alternative to more invasive paravertebral and epidural blocks, depending on the surgical procedure and patient preference and co-morbidities (25,26,54). One of the problems with these blocks is the lack of sufficiently robust randomized, controlled trials comparing them to the gold standard epidural blocks or TPVB. Another problem is catheter positioning, as catheters can easily become dislodged by the movement of muscles and extremities.

Pectoral nerve blocks

The first description of a pectoral nerve block type I (PECS I) in breast surgery was published in 2011 (10). To achieve a PEC I block, a LA is injected into the tissue plane between the pectoralis major and minor muscles, thereby targeting

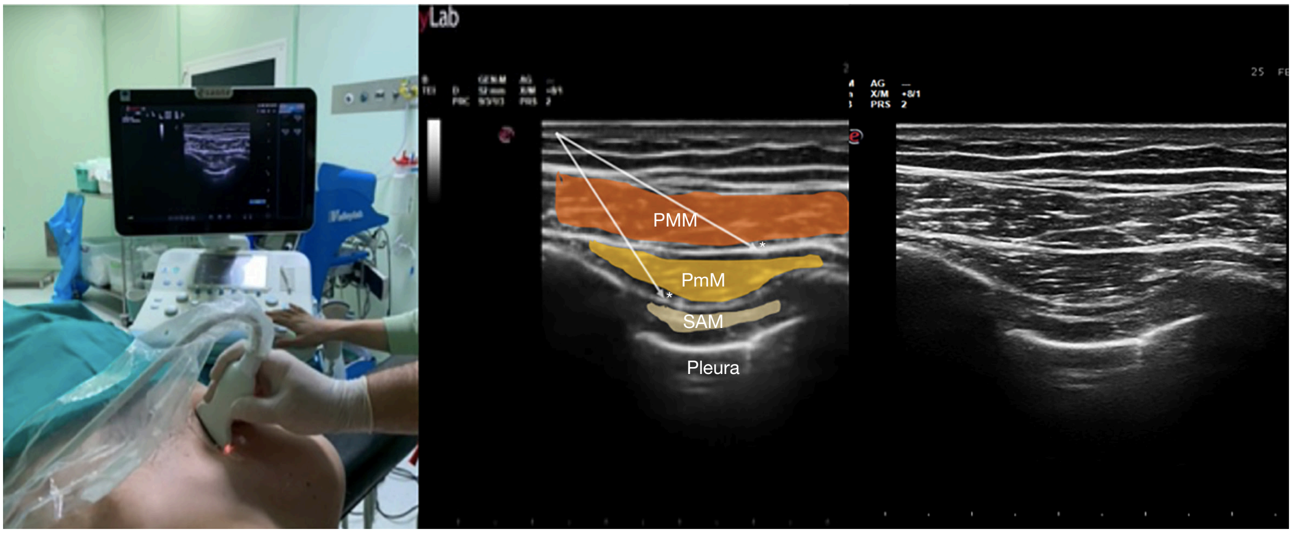

Figure 3 Patient position and sonoanatomy of the pectoral nerve block I and II. This image is published with the patient/participant's consent. *, needle tip place. PMM, pectoralis major muscle; PmM, pectoralis minor muscle; SAM, serratus anterior muscle.

the medial and lateral nerves arising from the brachial plexus (*Figure 3*).

PECS I block has a limited list of indications. Still, it is particularly useful for procedures that require dissection of the pectoralis major and minor muscles, such as lumpectomy, breast prosthesis, and sub-pectoral implantation (55).

There is an ongoing debate, if pectorals nerves are actually sensory nerves, rather than being proprioceptive nerves instead. In a randomized controlled study by Desroches *et al.*, there was a significant difference in adductor strength between volunteers who received placebo and LA in PECS I block, but no difference was found in dermatomal skin sensation tests (56).

However, nowadays, this block is mostly applied together with the PECS II block rather than alone. Apart from this, it can also be used with other chest wall blocks such as PECS I block, serratus anterior plane (SAP) block, transversus transthoracic muscle block, and ESP block for surgery involving the chest wall.

PECS II block includes LA injection into the plane between the pectoralis minor and serratus anterior muscles (*Figure 2*). The medial and lateral pectoral nerves, the lateral branches of the thoracic 3–6 intercostal nerves, and the long thoracic and thoracodorsal nerves are all targeted (26). Blocking the long thoracic and thoracodorsal nerves has a greater effect on the deep tissues of the chest. Indications for the PECS II block include: pectoral muscle dissection, thoracotomy, chest wall trauma, and minimally invasive procedures such as VATS, port catheter insertion or removal, and pacemaker placement (57,58) (*Table 2*).

PECS I and II blocks do not provide sensory blockage of the skin and subcutaneous tissues in the parasternal areas, as both do not involve the anterior branches of the intercostal nerves. The PECS II block may be used in conjunction with other interfascial chest wall blocks. Published reports describe its use in conjunction with an SAP block in the awake VATS (59). According to a recent meta-analysis, PECS II block and TPVB resulted in similar postoperative opioid consumption and similar postoperative pain scores after the first measurement (57).

Compared with other regional anesthesia techniques, the ability to perform this procedure in the supine position is a critical advantage. In a recently published study, PECS II block was used in VATS. It was reported that the block provides improved analgesia and reduces opioid consumption to an extent equivalent to TPVB. However, the fact that the postoperative rescue analgesic requirement was significantly higher in the PECS group may also have contributed to this result. In addition, the authors found that PECS II block provides better intraoperative hemodynamic stability compared to TPVB (60).

Serratus plane block

SAP block is performed by injecting a LA into a fascial

Table 2 Overview of specific regional techniques and specific indications and complications

Blocks type of the chest wall	Indications	Potential complications
Intercostal nerve block	Thoracotomy	Pneumothorax
	Video-assisted thoracic surgery	Local anesthetic systemic toxicity
	Rib fractures	
	Postherpetic neuralgia	
Pectoral nerve block I	Lumpectomy	Pneumothorax
	Sub-pectoral paresis	Vascular injury (cephalic vein/thoracoacromial artery)
	Sub-pectoral implantation	
Pectoral nerves block II	Anterior thoracotomies	Pneumothorax
	Pectoral muscle dissection	Vascular injury (cephalic vein/thoracoacromial artery)
	Sternotomy	Inadequate or failed block
	Minimally invasive cardiac surgeries	Temporary scapula of the wings
	Port catheter insertion or removal	
	Pacemaker placement	
	Chest wall pain caused by Herpes Zoster	
Serratus plane block	Video-assisted thoracic surgery	Pneumothorax
		Vascular damage
		Bleeding
	Rib fractures, rib contusions	Hematoma
	Minimally invasive cardiac surgery	Temporary wing scapula
Parasternal block	Median sternotomy	Pneumothorax
	Cardiac surgery	Vascular damage
		Bleeding
		Hematoma
		Sternal wound infection
Erector spinae plane block	Thoracotomy	Pneumothorax
	Video-assisted thoracic surgery	Sensory blockade
	Cardiac surgery	
Pecto-intercostal fascial block	Thymectomy	Pneumothorax
	Sternotomy	Intravenous injection
	Cardiac surgery	
	Thoracotomy	
	Video-assisted thoracic surgery	

Table 2 (*continued*)

Table 2 (*continued*)

Blocks type of the chest wall	Indications	Potential complications
Interpleural block	Thoracotomy	Pneumothorax
	Video-assisted thoracic surgery	Hemidiaphragm paralysis
	Multiple rib fractures	Horner syndrome
	Cancer pain	Hemothorax
	Post-herpetic neuralgia	Catheter migration
	Complex regional pain syndromes	Pleural effusion
		Bronchial trauma
		Bronchopleural fistula formation
Thoracic paravertebral block	Thoracotomy	Pneumothorax
	Video-assisted thoracic surgery	Epidural block, spinal block, or intrathecal spread
	Rib fractures	Neuraxial complications mild hypotension
Epidural block	Thoracotomy	Post puncture headache
		Transient neurological syndrome (symmetrical back pain, radiated to the buttocks and legs, without sensitive or motor component)
		Nerve injury with possible neuropathy—paresis is extremely rare
		Epidural hematoma
	Video-assisted thoracic surgery	Epidural abscess
	Cardiac surgery	Meningitis
	Rib fractures	Accidental intrathecal injection with total spinal anesthesia

plane above the serratus anterior muscles (*Figure 4*).

A LA injection targets the intercostal nerves' lateral cutaneous branches and muscular branches (9). It aims to provide analgesia to the anterolateral and posterior sides of the chest wall as an alternative to epidural block and TPVB. If this block is performed above the serratus anterior muscle, it numbs the anterolateral branch of the thoracic intercostal nerves between the serratus anterior and the latissimus dorsi, the serratus anterior nerve, and the thoracodorsal nerve. If the block is performed below the serratus anterior muscle, the lateral and anterior cutaneous branches of the thoracic intercostal nerves are blocked.

The superficial SAP block is anatomically a variation of PECS II, whereby the needle is placed more caudally and posteriorly (9). The evidence of whether a deep serratus plane block is more effective than the superficial one in analgesia of deep muscle and bone structures is unclear (19). However, the long thoracic and thoracodorsal nerves run in the fascial plane on the surface of the serratus anterior muscle and can be inadvertently blocked with a superficial SAP block. This condition can cause temporary paralysis of the long thoracic nerve (LTN) and result in the winged scapula.

A study conducted in healthy volunteers determined that sensory paresthesia occurred in dermatomes between T_{2-9}. A difference was found in the duration of analgesic effect between the superficial and the deep SAP blocks; if the LA was injected superficially into the SA muscle, the effective time was doubled.

Indications for SAP block include pain control after VATS and thoracotomy for lung resection (61-65) (*Table 2*).

Although SAP does not directly target the pectoral nerves, it has an effect similar to PECS II block and therefore provides sufficient analgesia in thoracic surgery (66). Effect can be topped by simultaneously blocking pectoral and intercostal nerves. Recently, a technique combining PECS II and SAP block has been described. Some randomized controlled studies reported,

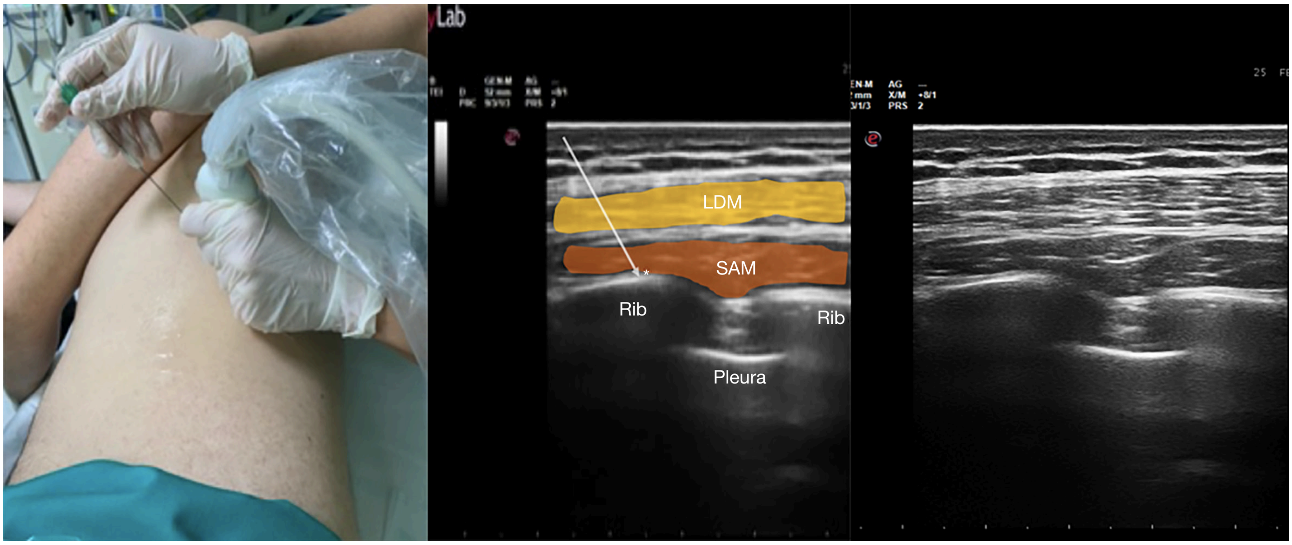

Figure 4 Patient position and sonoanatomy of the serratus anterior plane block. This image is published with the patient/participant's consent. *, needle tip place. LDM, latissimus dorsi muscle; SAM, serratus anterior muscle.

that the SAP block is as effective as the PVB.

Additionally, some studies including patients having pneumonectomy, lobectomy and wedge resection with thoracotomy and thoracoscopy reported that hemodynamics remained more stable in the SAP block group compared to patients receiving paravertebral and thoracic epidural blocks (64,67) (*Table 3*).

Additional advantages over thoracic epidural block and TPVB are the ability to perform them on supine patients, including in situations involving head and spine injuries and in the presence of coagulopathy. A disadvantage is the short duration of action, but this problem can be overcome by inserting a catheter for continuous or intermittent further application of LA.

The European Society of Regional Anesthesia (ESRA) recommends a PVB or an erector spina plane block as the first choice in the management of analgesia after VATS.
The SAP block can be considered as a second option, but TEA is not recommended in patients having VATS, but can be considered in patients having thoracotomy (69).

ESP block

ESP block was first described in 2016 as a treatment for chronic pain (70). Today, its application has expanded to help with postoperative pain control after surgery to the thorax. ESP block is performed by administering a LA to the fascial plane between the erector spinae muscle and the transverse process, and targets the dorsal and ventral nerves (*Figure 5*). The dorsal rami of the spinal nerves pass here and can be effectively blocked.

Blockage of the ventral rami and other branches can develop due to the anterior spread of LA to the paravertebral and epidural areas. Cadaveric and imaging studies have shown that LAs also spread to the paravertebral and epidural areas. The vertebral level to which the block will be applied should be determined based on the center of the area where analgesia will be provided (71).

After a single injection of LA, the spread can cover at least 3 and up to 6–8 vertebral levels. For this reason, it is often appropriate to apply a block at the T_4 or T_5 level (71,72). ESP blocks are used for thoracic (68) procedures when applied at T3-4 level (*Table 2*). A single shot ESP block provides analgesia for a limited time, but catheter insertion allows for continuous or repeat dosing and can provide prolonged analgesia.

The most significant advantage of the ESP block over the SAP and PECS blocks is that the dorsal rami and branches of the spinal nerves are blocked and it therefore also covers the posterior and lateral thorax. Sympathetic chain blockade is considered a component of ensuing visceral analgesia, although this has not been conclusively proven. A meta-analysis of 140 studies reported that ESP provides adequate analgesia in various surgical procedures (73). However, prospective randomized controlled clinical studies are needed to define the optimal volume of LA used, the mode

Table 3 Recent randomized clinical trials of block types

References	Procedure	Block type	Comparator intervention	Primary outcome	Result
Semyonov *et al.*, 2019, (61)	Thoracic surgery	SAPB	No block	Pain scores	Lower pain scores in SAP group in the first 8 h postoperatively, no difference after the 9th hour
Park *et al.*, 2018, (62)	VATS	SAPB	No block	Opioid use	Less opioid use in SAP group in the first 24 h
Finnerty *et al.*, 2020, (68)	Minimally invasive thoracic surgery	ESPB	SAPB	Quality of patient recovery	ESP provides superior quality of recovery at the 24th hour
Yildirim *et al.*, 2022, (60)	VATS	PECS II	TPVB	Opioid use	No difference
Baldinelli *et al.*, 2021, (63)	VATS	SAPB	ICNB	Pain scores	Lower pain scores in SAP group while coughing in 6, 12, 24 h postoperatively, no difference before the first 5 h and after 24 h
Chu *et al.*, 2020, (35)	VATS	TPVB	No block	Pain scores	Pain scores at rest at the 4th and 24th hours, on cough at the 4th hour were lower in PVB group
Li *et al.*, 2018, (36)	Thoracotomy	TPVB	No block	Pain scores	Lower acute pain scores, no difference chronic post-thoracotomy pain incidence
Kadomatsu *et al.*, 2018, (27)	VATS	ICNB	TPVB	Pain scores	Lower pain scores in ICNB group at the 48th h postoperatively, no differences before the 48th hour
Hanley *et al.*, 2020, (64)	VATS	SAPB	TPVB	Opioid use	Non-inferior opioid use in SAP group in the first 48 h
Vilvanathan *et al.*, 2020, (21)	Thoracotomy	ICNB	TEA	Pain scores	Lower pain scores in epidural group in 12 h postoperatively
Dikici *et al.*, 2022, (65)	VATS	SAPB	Infiltration block	Pain scores	Lower pain scores in SAP group in 12 h postoperatively

SAPB, serratus anterior plane block; SAP, serratus anterior plane; ESPB, erector spinae plane block; PECS II, pectoral nerve block II; TPVB, thoracic paravertebral block; TEA, thoracic epidural analgesia; ICNB, intercostal nerve block; VATS, video-assisted thoracic surgery.

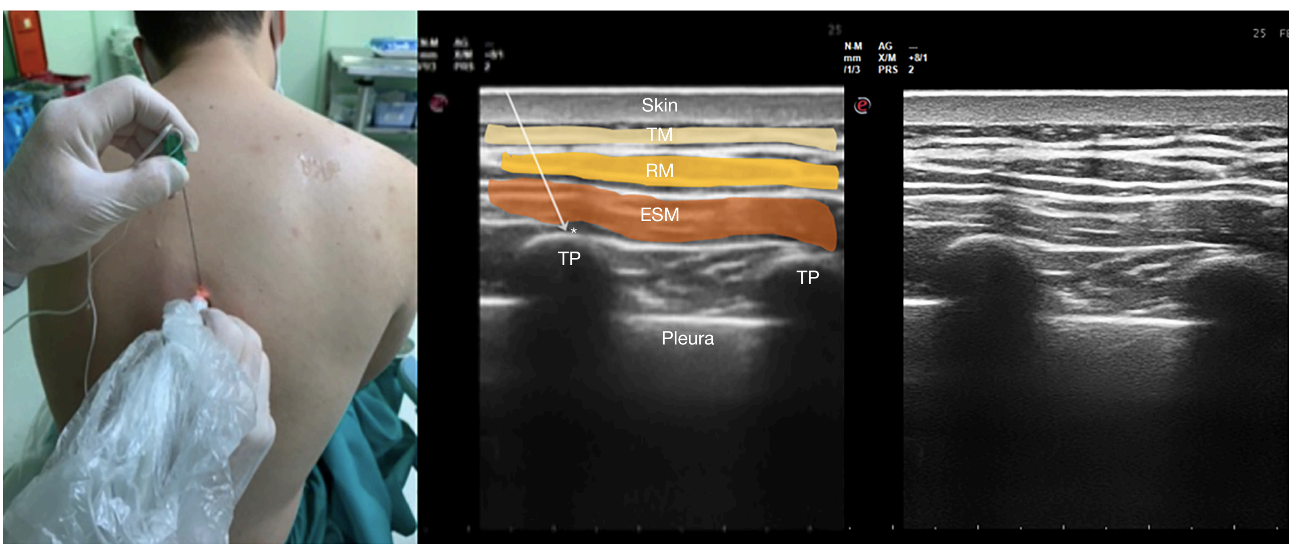

Figure 5 Patient position and sonoanatomy of the erector spinae plane block. This image is published with the patient/participant's consent. *, needle tip place. TM, trapezius muscle; RM, rhomboid major muscle; ESM, erector spinae muscle; TP, transverse process.

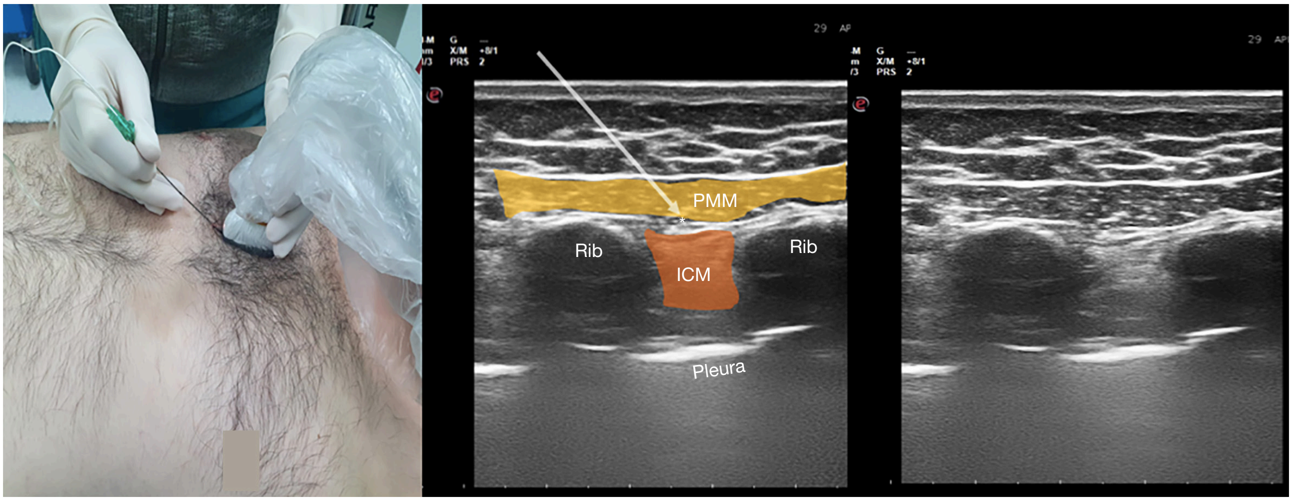

Figure 6 Ultrasound probe positioning and sonographic image of the pecto-intercostal fascial block. This image is published with the patient/participant's consent. *, needle tip place. PMM, pectoralis major muscle; ICM, intercostal muscle.

and frequency of LA administration, such as continuous infusion, intermittent bolus, single shot, and the subsequent number of dermatomes spread (74).

Pecto-intercostal fascial (PIF) block

PIF block injects LA between the pectoralis major and internal intercostal muscles (*Figure 6*). The anterior cutaneous branches of the intercostal nerves located in the fascial plane between these muscles are targeted (75).

This block was first described to treat postoperative pain in breast surgery. Subsequently, it was also used for various surgeries such as thymectomy and sternotomy, and the comparative results showed that this block could provide analgesia equivalent to a transversus thoracis muscle plane (TTP) block (76).

It has also been reported to produce an analgesic effect covering the T_1-T_6 dermatomes after sternotomy (77). It can provide adequate analgesia for four days with bilateral catheter placement and repeat or continuous application of LAs after thymectomy (78).

Although PIF block is a new development that requires additional research, it may offer the potential for a safer approach to regional anesthesia, particularly for medial parts of the anterior chest wall (79,80).

Interpleural block

Interpleural blockade was first published by Strömskag *et al.* to treat acute postoperative pain (81). It is a technique performed by LA injection into the intrapleural space between the visceral and parietal pleura to create the ipsilateral somatic block of thoracic dermatomes. In this technique, it is believed that the LA administered from a single intrapleural injection site reaches the intercostal nerves retrogradely (82). Interpleural blockade can treat unilateral surgical or nonsurgical pain originating in the chest or upper abdomen in both acute and chronic settings. It has been shown to provide analgesia for thoracotomy, multiple rib fractures, post-herpetic neuralgia, and complex regional pain syndromes (82-84).

Specific adverse events for interpleural blocks are paralysis of a hemidiaphragm and the full picture of Horner syndrome. Both are based on the proximity of the phrenic nerve and the upper thoracic sympathetic ganglia.

Limitations

This narrative review summarizes indications and clinical considerations of regional anesthetic techniques for patients having thoracic surgery. Findings of this review are only eligible to adult patients and cannot be extrapolated to special patient populations such as pediatric, obese and geriatric patients. The authors of this narrative review focused on the most commonly used regional anesthetic techniques for patients having thoracic surgery in their institutions, and did not discuss any further regional techniques used for other kind of surgeries. Furthermore, we limited our summary to widely used medications, and did not address newly introduced LA agents. Especially with the last, more research is needed to provide a better cost-benefit assessment.

Conclusions

In summary, sonoanatomy and the use of ultrasound in regional anesthesia have made it possible to safely and successfully perform interfascial plane blocks in patients undergoing thoracic surgery. Since fascial plan blocks are more superficial, they are easier to apply, which is one of the reasons for their increasing use and importance, often performed instead of thoracic epidural block and TPVB. Conversely, these epidural block and PVB for patients undergoing thoracic surgery are well established with proven effectiveness and a solid evidence base supporting their use. Therefore, to evolve clinical practice, high-quality studies comparing the novel blocks to the established standards are needed.

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