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REVIEW

Pain Management in Minimally Invasive Cardiac Surgery: A Review of Current Clinical Evidence

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ABSTRACT

Compared with conventional sternotomy, minimally invasive cardiac surgery (MICS) is associated with significant advantages such as reduced tissue trauma, faster recovery, and shorter hospital stay. However, the management of postoperative pain caused by intercostal nerve injury, pleural irritation, and tissue retraction remains a major challenge. Despite the less invasive nature of MICS, patients often report experiencing pain similar to that experienced following conventional cardiac surgery, particularly during the acute postoperative period. Effective pain management is essential for optimizing recovery, reducing the consumption of opioids, and preventing the transition to chronic postsurgical pain. Regional anesthesia techniques play a key role in multimodal analgesia for MICS. Thoracic epidural analgesia exhibits strong analgesic efficacy; nevertheless, it remains underutilized owing to concerns regarding anticoagulation-related complications and hemodynamic instability. The thoracic paravertebral block is a safer alternative that provides comparable pain relief with fewer side effects. Similarly, ultrasound-guided fascial plane blocks, such as serratus anterior, parasternal intercostal, interpectoral + pectoserratus, and erector spinae plane blocks, have gained popularity owing to their safety and feasibility; however, the effectiveness of these blocks varies according to the surgical approach and type of incision. Systemic analgesia is an integral component of multimodal pain management in MICS. Despite the efficacy of opioids, a shift toward opioid-sparing strategies has been observed given the significant adverse effects associated with the use of opioids. Intravenous adjuncts such as dexmedetomidine, ketamine, and non-steroidal anti-inflammatory drugs can reduce opioid consumption and improve postoperative pain control. Despite advances in pain

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management, a single approach that can provide comprehensive analgesia for MICS remains to be established. A multimodal strategy that combines systemic and regional techniques must be developed to optimize pain management and long-term outcomes.

Keywords: Analgesia; Cardiac surgical procedures; Nerve block; Minimally invasive surgery

Key Summary Points

Critical gaps have been reported in standardizing surgical approaches that minimize tissue trauma and regional anesthesia techniques.

Therefore, this review aimed to summarize the existing literature regarding analgesia strategies for the management of pain following minimally invasive cardiac surgery.

The safety and feasibility of ultrasound-guided fascial plane blocks, such as serratus anterior, parasternal, pectoserratus + interpectoral, and erector spinae plane blocks, have been demonstrated; however, their effectiveness varies according to the surgical approach and type of incision.

Intravenous adjuncts such as dexmedetomidine, ketamine, and non-steroidal anti-inflammatory drugs can also reduce opioid consumption and improve postoperative pain control.

INTRODUCTION

The popularity of minimally invasive surgeries has increased with the introduction of fast-track surgery and enhanced recovery after surgery (ERAS) protocols. Compared with conventional sternotomy, minimally invasive cardiac surgery (MICS) is associated with advantages such as lesser tissue trauma; a faster recovery profile with a shorter length of intensive care unit (ICU) and hospital stays [1]; reduced odds of renal failure and prolonged intubation; and fewer blood transfusions, especially among older patients [2]. Notably, video- and robot-assisted MICS reduce the risk of infection and improve cosmetic outcomes by preserving the sternal integrity [3].

While MICS appears less invasive, patients undergoing this approach experience similar postoperative acute pain compared to conventional cardiac surgery; however, patients undergoing MICS have a faster rate of resolution especially by the third day. Acute pain, often described as tightness, originates from the anterior chest wall and internal mammary harvest areas in patients undergoing conventional sternotomy. In contrast, pain from MICS is described as sharp, localized, and often neuropathic in the lateral chest wall owing to intercostal involvement. Pain caused by MICS can be attributed to rib injury, pleural tissue damage, and intercostal nerve injury. The severity of postoperative pain is related to the degree of tissue retraction and disruption, rather than to the size of the incision [4, 5]. Poor management of acute pain leads to higher consumption of opioids, longer ICU stay, and transition to persistent postsurgical pain (PPSP) [6]. Despite the benefits of MICS over conventional surgery with respect to early mobilization, faster recovery, and reduced length of stay in ICU, up to 49% patients after MICS experience severe pain on deep breathing and coughing in the postoperative period, which impairs their pulmonary function. Moreover, patients reporting greater pain scores are less likely to engage in physiotherapy, resulting in a significant delay in functional recovery and return to activities of daily living [7]. PPSP affects 37% of patients in the first 6 months following cardiac surgery. The corresponding rate among patients who undergo MICS is 43% and 17% at 6 months and 2 years, respectively [8]. PPSP from a sternotomy tends to be musculoskeletal, whereas reported pain from MICS is neuropathic in nature [9].

Compared with conventional sternotomy, the acute postoperative pain associated with MICS is generally less severe; however, the results have not been consistent across studies. The complex mechanisms and multifactorial nature of the pain associated with MICS present significant challenges. Standard multimodal analgesics cannot target all mechanisms simultaneously, and widely accepted multimodal regimens have not been established for MICS [5]. The high incidence of PPSP among patients undergoing MICS suggests the insufficiency of current analgesic modalities and their inability to prevent central sensitization. Furthermore, critical gaps can be identified in areas such as standardizing surgical approaches that minimize tissue trauma and regional anesthesia techniques which prevent the transition from acute pain to PPSP and measuring its impact on functional outcomes. Commonly used regional anesthesia techniques for MICS include thoracic epidural analgesia (TEA), spinal analgesia (SPA), thoracic paravertebral block (TPVB), erector spinae plane (ESP) block, intercostal nerve (ICN) block, serratus anterior plane (SAP) block, superficial and deep parasternal intercostal plane blocks, and the interpectoral (IPP) + pectoserratus plane (PSP) block, among others—each offering unique benefits and limitations.

This review aimed to summarize the existing literature regarding analgesia strategies for the management of pain following MICS, with a particular focus on regional anesthesia techniques. The application methods and anatomical underpinnings of these approaches, supported by illustrative clinical examples, are outlined herein to highlight their practical implementation and effectiveness.

This article is based on previously conducted studies and does not contain any new studies with human participants or animals performed by any of the authors.

TYPES OF SURGERY AND INCISIONS

MICS encompasses a range of surgical approaches aimed at reducing tissue trauma, enhancing recovery, and improving postoperative outcomes. Right anterolateral minithoracotomy, performed through the fourth or fifth intercostal space, is predominantly utilized during mitral and tricuspid valve procedures and can be performed under direct vision or endoscopic (port access) or robotic guidance. The incision is initiated in the third intercostal space in some cases to facilitate double- or triple-valve intervention. Direct-vision techniques require the use of an invasive rib retractor, which can increase postoperative pain. In contrast, port access and robotic approaches eliminate the need for rib retraction (Fig. 1a) [10].

In contrast to conventional sternotomies, only a limited incision in the upper or lower portion of the sternum is made in hemisternotomies. Upper hemisternotomy, also known as J-sternotomy, is commonly performed during aortic valve and root procedures (Fig. 1b). Lower hemisternotomy or inferior partial sternotomy, primarily employed for mitral and tricuspid valve surgeries, atrial septal defects, patent foramen ovale repair, and cardiac tumor resections, is utilized less frequently. Notably, even a partial sternotomy cannot be classified as a minimally invasive approach.

Right anterior minithoracotomy is performed through the second or third intercostal space for aortic valve and root surgeries (Fig. 1c) [11]. Left anterolateral minithoracotomy incision has been utilized in coronary revascularization (Fig. 1d). An internal thoracic artery graft can be harvested via direct vision, endoscopic techniques, or robotic assistance during minimally invasive direct coronary artery bypass (MIDCAB). Total endoscopic coronary artery bypass and total endoscopic right anterior thoracotomy have been adopted increasingly in specialized centers for valve and atrial septal defect procedures [11, 12].

In addition to anatomical and surgical variations, the size of the incision has a significant effect on postoperative pain. The degree of invasiveness of MICS can be categorized into four levels. The first level includes an incision of 10–15 cm that facilitates direct visualization. The second level includes an incision of 4–6 cm incision that facilitates both direct visualization and video assistance. The third level includes an incision of 1.5–4 cm for video-directed and robot-assisted procedures. The fourth and the least invasive level includes an incision of < 1.5 cm for robotic telemanipulation and total endoscopic port-access techniques [13].

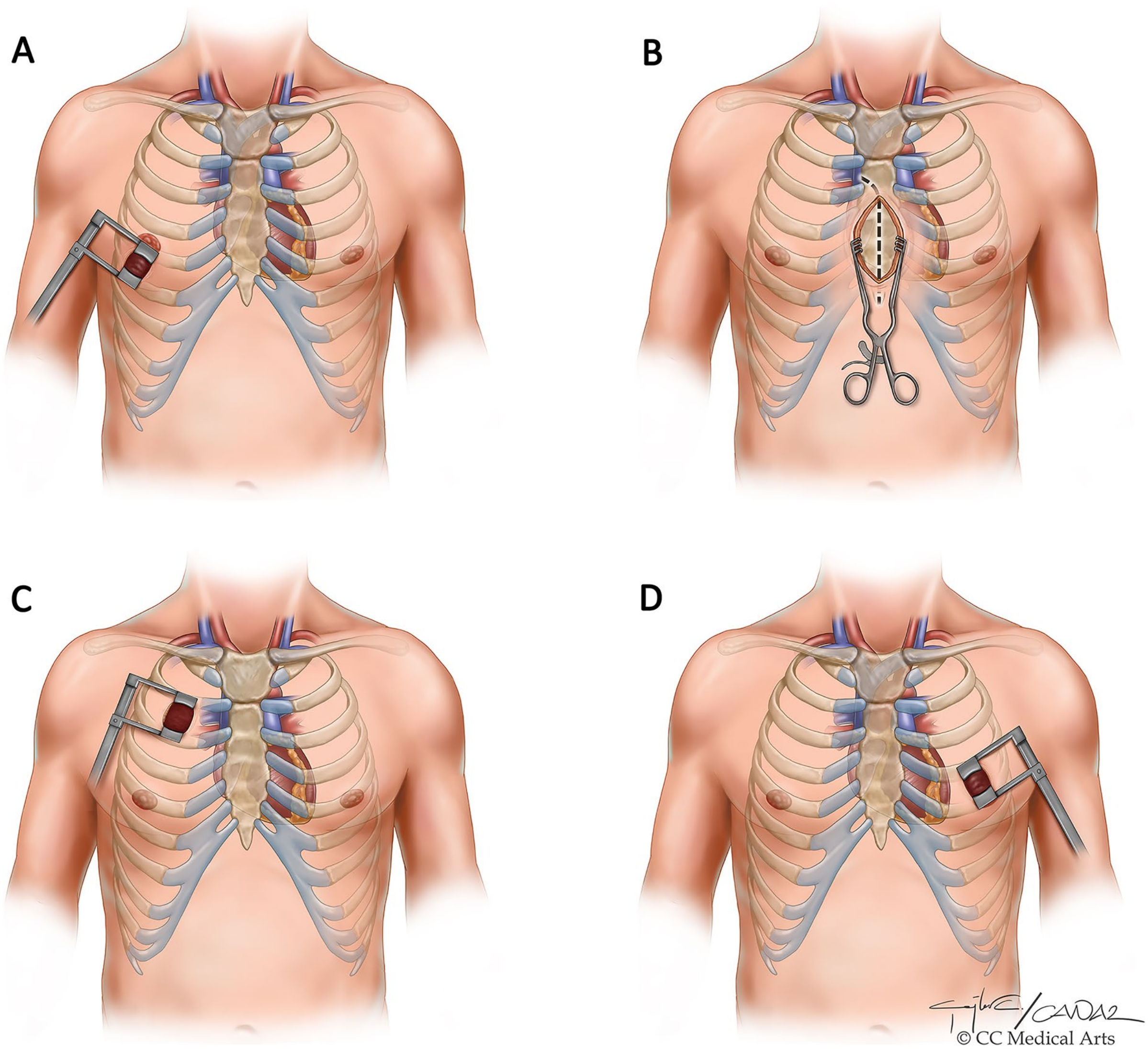

Fig. 1 Schematic illustration of the incision sites used in minimally invasive cardiac surgery. **a** Right anterolateral minithoracotomy. **b** Upper hemisternotomy. **c** Right anterior minithoracotomy. **d** Left anterolateral minithoracotomy

REGIONAL ANESTHESIA TECHNIQUES IN MICS

Thoracic Epidural Analgesia

Although first proposed for cardiac surgery in 1954, the first preoperative insertion of a thoracic epidural catheter for the neuraxial block was reported in 1976 [14, 15]. The progressive increase in the interest in TEA since then [15] can be attributed to the ability to provide significant pain control, improve postoperative respiratory function, shorten extubation duration, reduce ICU and hospital stays, and decrease postoperative complications [16]. TEA can suppress the surgical stress response through thoracic cardiac sympathectomy and by improving myocardial oxygen supply–demand balance, thereby enhancing patient outcomes [17]. Given that the other notable clinical benefits associated with TEA have not yet been conclusively demonstrated with fascial plane block techniques, it should be acknowledged that TEA remains an important option for cardiac surgery [18].

TEA enhances the outcomes following cardiac surgery; however, it is not without risks. Notably, concerns regarding the risk of epidural hematoma have limited its widespread use. Given the requirement for full heparinization, this risk is heightened in patients undergoing cardiac surgery. Thus, the benefits of epidural analgesia must be carefully balanced against the potential complications. However, the incidence of such serious events remains extremely rare [19, 20]. The risk of epidural hematoma and paralysis among patients undergoing cardiac surgery was approximately 1:7643 and 1:10,190, respectively, in a systematic review. However, this risk is concordant with that in anticoagulated patients [21]. Furthermore, this risk was comparable with that observed in other surgical procedures requiring epidural catheterization [18]. Nevertheless, isolated reports of epidural hematoma continue to emerge, emphasizing the importance of conducting a thorough preoperative evaluation of patients [22]. Vigilant postoperative neurological monitoring following the placement and removal of epidural catheters is imperative. However, the amount of heparin administered to patients undergoing MICS (1–1.5 mg/kg vs. 3–4 mg/kg in open cardiac surgery) is generally much lower than that administered to those undergoing conventional open-heart procedures. Thus, MICS represents a surgical subgroup at a low risk of developing epidural hematoma [23].

The risk of hemodynamic instability is another factor limiting the use of TEA in cardiac surgery. LA administered through the thoracic epidural route can block the afferent and efferent cardiac fibers emerging from the T1–T5 levels. This bilateral cardiac sympathetic blockade can result in significant hypotension [17]. A study involving 1720 patients revealed that the opioid requirement among patients who received TEA was lower than that among patients who did not receive TEA. Furthermore, the incidence of nausea and vomiting was lower among patients who received TEA. However, the higher incidence of hypotension (50% higher in the TEA group [24]), technical challenges associated with thoracic epidural catheter placement at the T4–5 or T5–6 levels, and the relatively high insertion failure rate (5.2–6.7%) have reduced interest in TEA [25].

MICS offers advantages in terms of two major concerns associated with TEA: epidural hematoma and hemodynamic instability. Thus, it is a viable option in cases involving midline incisions, such as ministernotomies. A study involving patients undergoing MIDCAB grafting who received TEA as an anesthetic technique revealed that patients who received TEA had shorter ICU and hospital stays and lower postoperative pain scores [26]. Similarly, a case series reported the success of TEA as an anesthetic technique in conscious patients undergoing minimally invasive aortic valve replacement and MIDCAB [27–29]. Another study involving patients undergoing transapical transcatheter aortic valve replacement under general anesthesia revealed that compared with intercostal blocks, TEA was more effective in reducing pain scores, respiratory complications, and short- and long-term mortality [30].

In summary, given its ability to provide reliable and effective pain control, TEA may be a suitable option for patients undergoing MICS. However, only a limited number of high-quality studies have evaluated its utility in MICS owing to its relatively low utilization in MICS. Thus, strong recommendations for its use remain limited. There is a need for well-designed, comprehensive studies to assess the efficacy, safety, and long-term impact of TEA on patient outcomes in the context of MICS.

Thoracic Paravertebral Block

The thoracic paravertebral space is a wedge-shaped potential space containing the spinal nerves and sympathetic chain that is laterally continuous with the intercostal space. TPVB involves the injection of a local anesthetic (LA) into an area near the spinal nerve as it exits the intervertebral foramen (Fig. 2). TPVB is a relatively simple procedure that can be performed without the risk of any significant complications or side effects, particularly under ultrasound guidance by experienced practitioners [31, 32]. Ipsilateral somatic and sympathetic blockade occurs across multiple thoracic

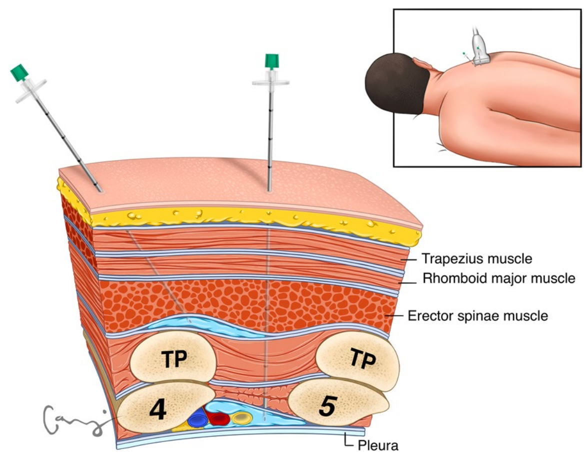

Fig. 2 Schematic illustration of ultrasound-guided erector spinae plane block and thoracic paravertebral block

dermatomes above and below the injection site following the injection of the LA [33]. A study investigating the spread of the LA after single-shot TPVB revealed that the anesthetic effect could extend into the epidural space, prevertebral region, and even to the contralateral side. LA spreads across approximately four vertebral levels; however, the sensory blockade covers a broader dermatomal distribution (7–8 segments) [34]. Another study on continuous TPVB reported that the sensory blockade extended across four segments [35].

The efficacy of TPVB is equivalent to that of TEA in terms of the management of postoperative pain; consequently, it is a popular alternative to TEA in cardiothoracic surgery [36, 37]. A meta-analysis reported that TPVB provides analgesic effects comparable with those of TEA while ensuring lower incidences of hypotension, nausea, vomiting, and urinary retention [38]. Another study comparing bilateral TPVB with general anesthesia alone revealed that TPVB facilitated earlier extubation and reduced opioid consumption [39]. Notably, in addition to its analgesic equivalence and the low incidence of side effects, TPVB is easier to master and perform. Furthermore, it is associated with a low risk of technical failure, dural puncture, and spinal cord injury due to epidural hematoma [37, 40, 41]. Thus, it is a feasible choice for MICS.

Depending on the type of surgery, unilateral TPVB may be sufficient in the context of MICS. The unilateral sympathetic blockade achieved with TPVB provides a more favorable side effect profile compared with that of TEA [32]. TPVB is a safe and effective choice for robot-assisted mitral valve repair cases [40, 42]. In addition to being incorporated into anesthesia protocols for MICS [42], TPVB has also been utilized in procedures such as transapical transcatheter aortic valve replacement. Retrospective studies have shown that TPVB reduces the extubation time and opioid requirements, decreases the incidence of atrial fibrillation, and preserves hemodynamic stability with no reported complications related to TPVB [43, 44]. Similarly, comparison of TPVB and TEA in MIDCAB and robot-assisted CABG revealed that TPVB was as effective as TEA in the management of postoperative pain [36, 45].

Thus, TPVB provides effective and safe pain control in patients undergoing MICS. Furthermore, it is technically easier to perform than TEA, and is associated with a lower risk of epidural hematoma, making it a preferable option over epidural techniques for MICS procedures that do not require complete heparinization. Nevertheless, further high-quality research must be conducted in the future to draw strong conclusions regarding its safety and efficacy, given the limited number of studies on TPVB in MICS.

Spinal Analgesia

SPA is commonly used for the management of postoperative pain. It can be performed using LA alone or in combination with intrathecal opioids. It is technically simple and has low risks of failure and complications. Morphine maintains its concentration in the cerebrospinal fluid for an extended period and exhibits greater rostral spread owing to its hydrophilic nature [46, 47]. This characteristic has made intrathecal morphine (ITM) administration the preferred option for SPA. ITM provides 24 h of analgesia without inducing sensorimotor or autonomic blockade [48]. It has also been used in cardiac surgeries for many years [49]. A recent meta-analysis demonstrated that ITM is associated with lower postoperative morphine consumption within the first 24 h following cardiac surgery [50].

Possible complications associated with ITM administration include pruritus and respiratory depression. Respiratory depression, particularly delayed respiratory depression, that develops following ITM administration is a significant concern for anesthesiologists. However, some studies have reported that ITM administration did not prolong postoperative extubation time or lead to respiratory depression [50]. Nevertheless, close monitoring is recommended when neuraxial opioids are administered alongside systemic opioids, sedatives, hypnotics, or magnesium [51]. Although rare, spinal hematoma, which can result in severe and irreversible neurological damage, is another potential complication. ITM administration is generally considered to have an acceptable risk–benefit ratio in cardiac surgery despite these risks [50, 52]. A literature review indicates that ITM administration also exhibits opioid-sparing effects in MICS. Notably, ITM administration (5 µg/kg) reduced postoperative opioid consumption by approximately 50% while maintaining analgesic efficacy for up to 48 h in a randomized controlled trial [53]. Another study reported that even lower doses (1.5 µg/kg) provided sufficient analgesia without prolonging extubation time [54]. Thus, SPA is a safe and effective treatment option for patients undergoing MICS. Further studies must be conducted in the future to provide strong recommendations for its use.

Intercostal Nerve Block

ICN block involves the injection of an LA into the intercostal nerves to alleviate pain in the surgical incision dermatomes. ICN block is typically administered at, above, and below the incision level to ensure adequate coverage. Repeated injections or continuous infusion via catheter placement is preferred for the effective management of postoperative pain, given the short duration of action [55]. Studies have demonstrated the efficacy of ICN block in the management of postoperative analgesia, particularly in the management of post-thoracotomy pain [56]. It reduces analgesic requirements in MICS procedures such as mitral valve repair [5] and MIDCAB [57]. A potential disadvantage, especially when compared to paravertebral or thoracic epidural blocks, is the need to perform multiple injections to achieve multilevel or bilateral coverage.

ULTRASOUND-GUIDED FASCIAL PLANE BLOCKS FOR MICS

Serratus Anterior Plane Block

SAP block, which targets the T2–T9 dermatomes of the anterolateral thorax, is performed by injecting the LA into the fascial plane between the latissimus dorsi and serratus anterior muscles or deep into the serratus anterior muscle along the mid-axillary line (Fig. 3). Both approaches provide comparable analgesic efficacy [58, 59].

Previous studies have demonstrated the analgesic efficacy of the SAP block following video-assisted thoracoscopic surgery, with some studies reporting reduced opioid consumption and improved respiratory function [60]. A continuous SAP block can effectively manage postoperative pain following mitral valve surgery; however, it has no significant effect on the ICU stay or overall hospitalization duration [61]. Nevertheless, the SAP block provides effective analgesia while reducing opioid requirements, ICU stay, and hospital length of stay in patients undergoing MICS, most of whom underwent aortic valve replacement [62]. Furthermore, the SAP block is a safe and effective analgesic technique in patients undergoing MICS, even among those receiving anticoagulation therapy [63].

Interpectoral Plane + Pectoserratus Plane Block

The IPP + PSP block (previously known as PECS-II block) provides analgesia to the anterolateral thoracic region, in particular the T3–T6 dermatomes, medial and lateral pectoral nerves, long thoracic nerve, and intercostobrachial nerve. This block involves two injections—first between the pectoralis major and minor, and second between the pectoralis minor and serratus anterior muscles (Fig. 4). The IPP + PSP block has demonstrated efficacy in reducing

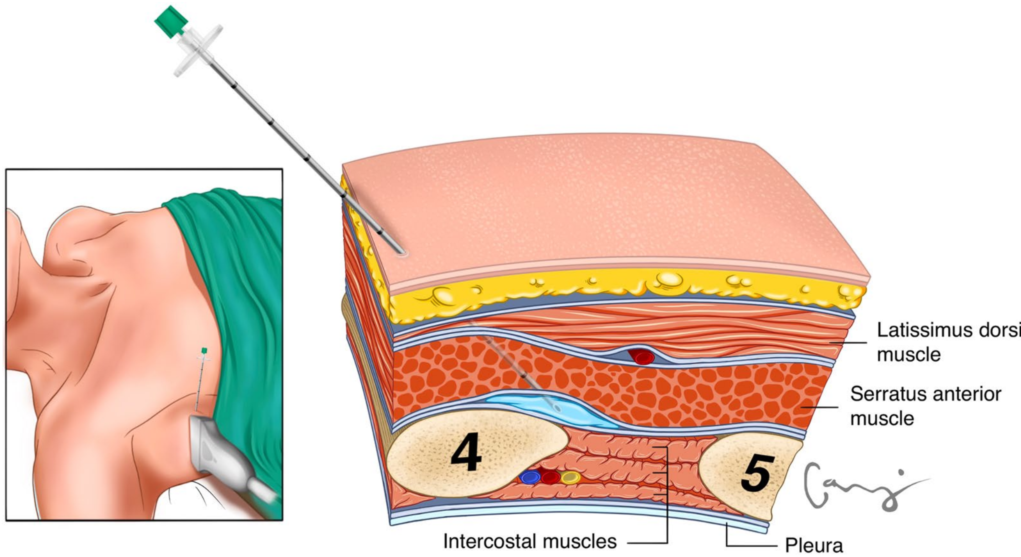

Fig. 3 Schematic illustration of the ultrasound-guided serratus anterior plane block

pain scores and opioid consumption within the first 24 h after minimally invasive thoracic surgery [64]. The combination of SAPB and IPP + PSP blocks provides effective postoperative analgesia and decreases opioid requirements in MICS [65]. In addition, the IPP + PSP block is a safe and effective analgesic technique for patients undergoing robotic mitral valve surgery [66].

Erector Spinae Plane Block

Widely used for the management of acute postoperative pain following breast, thoracic,

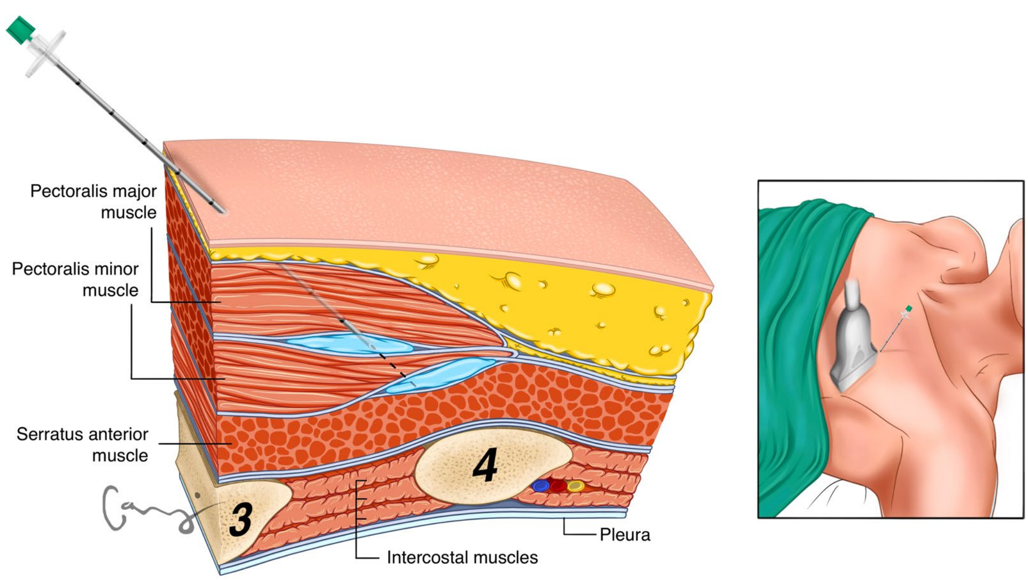

Fig. 4 Schematic illustration of the ultrasound-guided interpectoral + pectoserratus plane block

spinal, and abdominal surgery, the erector spinae plane (ESP) block, a fascial plane block first described by Forero et al., has gained popularity in cardiac surgery. This block, which provides effective analgesia to the anterior, lateral, and posterior chest walls, involves the injection of the LA at the T4 or T5 levels ventral to the erector spinae muscle to facilitate the spread of the LA across the T2–T9 levels (Fig. 2) [67]. The ESP block provides visceral and somatic multidermatomal sensory chest wall analgesia by blocking the dorsal and ventral branches of the spinal nerves, thereby reducing the requirement for systemic opioids and facilitating postoperative rehabilitation [68]. Magnetic resonance imaging and dissection studies have demonstrated significant craniocaudal spread of the LA to the lateral cutaneous branches of the intercostal nerves [69]. However, some cadaveric studies have reported inconsistent and unpredictable anesthetic spread in the paravertebral region, which is often limited to the dorsal ramus rather than the ventral ramus [70, 71]. This inconsistency may be attributed to the variable sensory coverage of the ESP block in the anterior thorax. The ESP block may provide effective analgesia for lateral incisions in MICS; however, its efficacy for anterior incisions remains limited. Notably, Dost et al. demonstrated that combining an ESP block with a superficial parasternal intercostal plane block could enhance analgesic effectiveness in open cardiac surgery [72].

Given its ease of application, classification as a superficial nerve block [73], and suitability for catheterization for continuous analgesia, the ESP block has gained attention in thoracic and cardiac surgery. A recent meta-analysis revealed that the ESP block was the most effective ultrasound-guided regional anesthesia technique for reducing the postoperative consumption of opioid following cardiac surgery [74]. Lin et al. reported improvements in the QoR-15 scores and a reduction in analgesic consumption (30%), propofol use, and the need for rescue analgesics in MICS with the use of continuous ESP block [75]. Hoogma et al. compared continuous and intermittent bolus ESP blocks in two separate studies using a catheter for the continuous block and reported that the ESP block was not an effective analgesic technique for MICS in either study [76, 77]. In contrast, Xin et al. reported a significant reduction in pain scores, opioid consumption, tracheal extubation time, and ICU discharge time within the first 18 h following MICS after performing single-shot ESP block [78]. Borys et al. reported no significant difference between the single-shot ESP block and control groups in terms of postoperative oxycodone consumption in a study involving patients undergoing valve repair. However, the ICU stay was shorter in the ESP group [79]. Moll et al. demonstrated that PVB is more effective than a single-shot ESP block in robotic MICS procedures [80]. Recently, Xin et al. conducted a randomized controlled trial evaluating the combined use of ultrasound-guided ESP block and SAP block for postoperative pain management in patients undergoing CABG via minithoracotomy [81]. The combination significantly reduced postoperative opioid consumption and pain scores compared with systemic analgesia alone, while also improving the overall quality of recovery. These findings support the potential additive or synergistic effect of combining fascial plane blocks in MICS to optimize analgesic outcomes.

Superficial and Deep Parasternal Intercostal Plane Blocks

Superficial and deep parasternal intercostal plane blocks are fascial plane blocks targeting the anterior cutaneous branches of the T2–T6 spinal nerve. First described for breast surgery, superficial and deep parasternal intercostal plane blocks have been widely used for the management of postoperative pain following median sternotomy in open-heart surgery [82, 83]. These blocks involve the injection of the LA above or below the intercostal muscle (Fig. 5). The LA is deposited between the pectoralis major and intercostal muscles in the superficial parasternal intercostal plane block. In contrast, the LA is deposited deep in the internal intercostal muscle, near the transversus thoracis muscle and closer to the pleura in the deep parasternal intercostal plane block. The increasing use of ultrasound guidance and the limitations of neuraxial

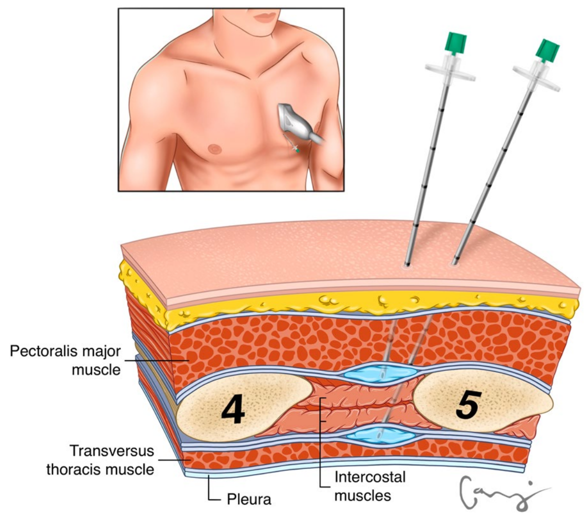

Fig. 5 Schematic illustration of the ultrasound-guided superficial and deep parasternal intercostal plane blocks

anesthesia in patients undergoing intraoperative heparinization have led to parasternal blocks emerging as safer and technically simpler alternatives to anterior chest wall analgesia in cardiac surgery [84]. Parasternal intercostal plane blocks may play an important role in multimodal analgesic strategies for MICS given the multiple sources of pain associated with cardiac surgery, including surgical incisions, sternal retraction, rib fractures, and chest drains [85]. These blocks may effectively target a significant component of postoperative pain in patients undergoing procedures involving anterior thoracic or parasternal incisions. However, the current evidence supporting their use in MICS, primarily comprising case reports, is limited. Thus, further high-quality clinical studies must be conducted in the future to establish their efficacy and safety [86]. From a technical standpoint, superficial and deep parasternal blocks have comparable analgesic effects. Nevertheless, the superficial parasternal block is generally preferred owing to the lower risk of injury to the internal thoracic artery, which lies deeper beneath the intercostal muscles [87]. Although a potential technique for achieving effective anterior chest wall analgesia, the uncertainty regarding the lateral spread of the LA is a major limitation of parasternal blocks in the context of MICS. No robust anatomical mapping studies have yet clarified this aspect. Therefore, their efficacy for lateral thoracic incisions or port sites commonly used in MICS remains questionable despite being a reasonable option for procedures involving anterior thoracic incisions such as hemisternotomy.

SYSTEMIC ANALGESIA IN MICS

Opioids have been widely used in cardiac surgery for the management of pain and the prevention of sympathetic activation in response to nociceptive stimuli. However, prolonged use of opioids results in serious adverse effects, such as gastrointestinal motility disorders, nausea and vomiting, urinary retention, hyperalgesia, postoperative cognitive dysfunction and delirium, central inhibition leading to respiratory depression, and an increased risk of pneumonia [88]. Opioid-related adverse events, reported in 40% of patients undergoing cardiac surgery, prolong hospital and ICU stays. Furthermore, they are associated with a greater risk of mortality [89]. Opioid dependence is another significant concern, with 10–13% of patients continuing persistent opioid use following cardiac surgery [90, 91]. Consequently, the Enhanced Recovery After Cardiac Surgery guidelines strongly recommend implementing multimodal opioid-sparing analgesia strategy [92–94].

Multimodal analgesia uses combinations of drugs and various analgesic techniques to block the harmful pathophysiological responses associated with nociception through different mechanisms. A comprehensive perioperative plan must be initiated preoperatively by screening patients for history of pain and current or recent analgesic use. The multimodal analgesia technique involves the preoperative administration of paracetamol (in the absence of severe liver disease), intraoperative application of fascial plane blocks, and use of non-opioid agents, given their utility in maintaining anesthesia and reducing opioid requirements [94–96]. Similarly, the use of various non-opioid medications as the first-line treatment for pain management must be prioritized in the postoperative period. Inadequate pain control should not be permitted in cases of persistent moderate to severe pain. A long-acting opioid such as hydromorphone may be used at low initial doses with careful titration in such cases [94]. Similar to that in conventional cardiac surgery, non-opioid pharmacological agents and specific nerve blocks have been recommended as multimodal analgesic strategies for MICS [97, 98].

INTRAVENOUS ADJUNCTS IN MICS

Previous studies have investigated the utility of using intravenous analgesics such as dexmedetomidine, ketamine, and lidocaine as a part of multimodal analgesia in cardiac surgery to reduce opioid consumption and improve postoperative analgesia. However, studies investigating the utility of using non-opioid pharmacological agents in MISC are limited, and systemic adjunctive agents are considered to be applicable to MISC. Intravenous infusion of lidocaine systemically blocks peripheral neurons and suppresses inflammation, thereby exerting an analgesic effect. Notably, intravenous infusion of lidocaine reduces postoperative pain and opioid consumption during non-cardiac surgeries [99]. However, its efficacy in cardiac surgery remains controversial and dose adjustments must be made to avoid systemic LA toxicity, particularly in cases wherein the patient is being withdrawn from cardiopulmonary bypass and cases wherein regional anesthesia is used [94]. Ketamine, an *N*-methyl-D-aspartate receptor antagonist, exerts sedative and analgesic effects. However, its standalone use in cardiac surgery is unlikely, given that it is associated with delirium and hallucinations. Nevertheless, low doses of ketamine, when combined with other agents (e.g., pregabalin and dexmedetomidine), have been associated with earlier extubation and reduced incidence of PPSP in the long term [100–102].

Dexmedetomidine, a selective alpha-2 adrenergic receptor agonist, exerts dose-dependent sedative, analgesic, and anxiolytic effects without inducing respiratory depression. In addition to inhibiting sympathetic activity in response to surgical stimulation, dexmedetomidine exerts myocardial protective effects against ischemia–reperfusion injury through potential anti-inflammatory and antiapoptotic mechanisms [103]. Dexmedetomidine-based opioid-free anesthesia has been associated with early extubation, reduced opioid requirements, and improved postoperative analgesia in patients undergoing cardiac surgery, provided that hypotension and bradycardia are well managed [94]. Notably, dexmedetomidine has demonstrated the potential to reduce delirium and agitation in the ICU [104, 105].

Gabapentinoids, including gabapentin and pregabalin, suppress central sensitization and neuropathic pain. Gabapentinoids potentially reduce perioperative opioid requirements by 20–30%. However, studies investigating the use of gabapentin in patients undergoing cardiac surgery have revealed no significant impact on postoperative pain, sleep quality, opioid consumption, or perceived recovery quality [106]. Gabapentin inconsistently reduced opioid consumption in another study; however, this reduction was associated with prolonged ventilation time [107]. Studies exploring the utility of pregabalin in cardiac surgery have reported reduced postoperative opioid consumption and lower rates of confusion [108, 109]. Preoperative and postoperative administration of pregabalin have also been linked to a reduction in the prevalence of PPSP at 3 and 6 months after cardiac surgery [101]. However, a recent meta-analysis investigating the utility of gabapentin and pregabalin in cardiac surgery concluded that clinical evidence to support their routine use is insufficient [110].

Nonsteroidal anti-inflammatory drugs (NSAIDs), which are crucial components of multimodal pain management in non-cardiac surgery, provide analgesia by suppressing peripheral inflammation. The perioperative use of NSAIDs is associated with reduced opioid consumption, lower pain scores, and shorter extubation times in patients undergoing cardiac surgery [111, 112]. However, concerns regarding its potential to increase the risk of acute kidney injury and impair platelet aggregation persist. The use of NSAIDs in cardiac surgery was not associated with an increased risk of mortality, gastrointestinal ulcers, bleeding, or acute kidney injury in some studies [113, 114]. Although widely used by anesthesiologists (with preference rates ranging from 44% to 87% depending on the surgical type), high-dose or prolonged use of NSAIDs is not advisable, particularly in older or high-risk patients [115]. The US Food and Drug Administration has issued an official warning regarding the use of NSAIDs among patients undergoing coronary revascularization owing to the risk of thrombotic cardiovascular complications [116]. Thus, NSAIDs must be used selectively for a short-term duration (48–72 h) following careful risk–benefit assessment.

Acetaminophen, a centrally acting analgesic, reduces acute pain and opioid consumption during cardiac surgery [117, 118]. However, the perioperative use of acetaminophen was not associated with a reduced incidence of PPSP at 90 days after cardiac surgery [119]. Notably, its use is limited in patients with liver disease owing to the risk of hepatotoxicity.

CONCLUSION

Effective pain management in MICS plays a crucial role in optimizing recovery, reducing opioid consumption, and preventing chronic postsurgical pain. MICS offers advantages over conventional sternotomy; however, postoperative pain caused by intercostal nerve injury, pleural irritation, and tissue retraction remains a significant challenge. Given the multifactorial nature of the pain associated with MICS, a multimodal analgesic approach is necessary to integrate systemic analgesics, regional anesthesia techniques, and intravenous adjuncts. Regional techniques such as TEA and TPVB provide effective pain relief; however, the use of TEA is limited by concerns regarding heparinization-related complications. Fascial plane blocks, such as ESP, SAP, IPP + PSP, and parasternal blocks, are safer alternatives with variable efficacies depending on the incision type and surgical approach. Systemic adjuncts such as dexmedetomidine, ketamine, and NSAIDs contribute to opioid-sparing strategies; however, their use must be individualized based on patient risk factors.

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Declarations

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