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Postoperative outcomes of combined interpectoral–pectoserratus versus combined deep–superficial serratus anterior plane blocks in minimally invasive coronary artery bypass surgery: A prospective randomized study

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Alperen Kutay Yildirim, Mesher Ensarioglu, Ertan Demirdas & Kubilay Karabacak

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Postoperative Outcomes of Combined Interpectoral–Pectoserratus versus Combined Deep–Superficial Serratus Anterior Plane Blocks in Minimally Invasive Coronary Artery Bypass Surgery: A Prospective Randomized Study

Alperen Kutay Yildirim[1,*], Mesher Ensarioglu[2], Ertan Demirdas[3], and Kubilay Karabacak[3]

[1]Gulhane Training and Research Hospital, Department of Cardiovascular Surgery, Ankara, 06010, Turkey; drayildirim@yahoo.com
[2]Gulhane Training and Research Hospital, Department of Anesthesiology and Reanimation, Ankara, 06010, Turkey; meshercapras@gmail.com
[3]University of Health Sciences, Gulhane Training and Research Hospital, Department of Cardiovascular Surgery, Ankara, 06010, Turkey; dr.ertandemirdas@gmail.com (E.D.); kubilaykarabacak@yahoo.com (K.K.)
[*]Correspondence: Alperen Kutay Yildirim, Gulhane Training and Research Hospital, Department of Cardiovascular Surgery, Ankara, 06010, Turkey; drayildirim@yahoo.com

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ABSTRACT

Background/Objectives: Minimally invasive coronary artery bypass grafting (MICS-CABG) and minimally invasive direct coronary artery bypass (MIDCAB) reduce surgical trauma compared with sternotomy but remain associated with significant postoperative pain that may delay recovery and contribute to complications. Although regional analgesic techniques are increasingly used to reduce opioid requirements, comparative data on different block strategies are limited. This study evaluated the effects of combined interpectoral–pectoserratus and combined deep–superficial serratus anterior plane blocks on postoperative pain, analgesic consumption, recovery quality, and clinical outcomes. **Methods:** In this prospective randomized single-center clinical study, 180 patients undergoing MICS-CABG or MIDCAB were randomized into three groups: combined interpectoral–pectoserratus plane block (Group P, n=60), combined deep–superficial serratus anterior plane block (Group S, n=60), and control (n=60). All blocks were ultrasound guided and performed by experienced anesthesiologists. Pain intensity was assessed using the visual analog scale (VAS) at 6, 12, 24, and 48 h after extubation. Quality of recovery was evaluated using the QoR-40 questionnaire preoperatively and on postoperative days 1 and 2. Secondary outcomes included time to first rescue analgesia, total analgesic consumption, extubation time, ICU and hospital length of stay, and postoperative complications. **Results:** VAS scores were significantly lower at all postoperative time points in both block groups compared with the control group, with no difference between block techniques. Time to first rescue analgesia was longer and total postoperative analgesic consumption was lower in both block groups. ICU and hospital stays were significantly shorter in patients receiving combined blocks. QoR-40 scores were better preserved throughout follow-up in both block groups. The incidence of atelectasis was lower in block groups, whereas other postoperative complications were infrequent and did not differ significantly between groups. **Conclusion:** Combined interpectoral–pectoserratus and combined deep–superficial serratus anterior plane blocks provide effective postoperative analgesia, reduce opioid requirements, enhance early recovery, and shorten ICU and hospital stays after minimally invasive CABG. Both techniques may represent practical opioid-sparing options for perioperative pain management in this setting. This study was also registered with the ISRCTN registry (ISRCTN32677289; first posted 16/02/2026).

Keywords: Coronary Artery Bypass; Minimally Invasive Surgical Procedures; Nerve Block; Postoperative Pain; Anesthesia, Regional; Quality of Life

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Introduction

Minimally invasive coronary bypass procedures, including minimally invasive direct coronary artery bypass (MIDCAB) and minimally invasive cardiac surgery coronary artery bypass grafting (MICS-CABG), use a left anterior mini-thoracotomy to reduce the sternotomy-related and support faster recovery[1–6]. Despite these advantages, the thoracotomy incision remains a clinically important source of postoperative pain. Pain related to intercostal and soft-tissue trauma, pleural irritation, and internal mammary artery harvesting may impair ventilation and coughing, delay mobilization, contribute to pulmonary complications, and prolong recovery[1,7–12]. Effective opioid-sparing analgesia is therefore central to enhanced recovery pathways after minimally invasive coronary surgery [13–15].

Systemic opioids remain a common component of postoperative pain management after minimally invasive cardiac surgery, but adverse effects such as respiratory depression, nausea, vomiting, sedation, and delayed mobilization may hinder early recovery[13,15]. Regional analgesic techniques can reduce opioid exposure and support multimodal analgesia in this setting. Thoracic epidural analgesia (TEA) is an established technique for thoracotomy-related pain[16,17]; however, its use in cardiac surgery is limited by perioperative anticoagulation and concerns regarding neuraxial complications[18,19]. Thoracic paravertebral block (TPVB) is an alternative, but its proximity to non-compressible thoracic structures makes it relatively invasive and may limit its use in anticoagulated cardiac surgical patients[19–21]. These limitations have increased interest in ultrasound-guided chest wall fascial plane blocks, which avoid neuraxial instrumentation and provide targeted anterolateral thoracic wall analgesia[14,22,23]. However, the most appropriate fascial plane block technique for this setting remains unclear [14,19].

Two clinically relevant chest wall fascial plane block strategies for anterior thoracotomy analgesia are the combined interpectoral–pectoserratus plane block and the serratus anterior plane block (SAPB)[14,19]. Both techniques target the sensory innervation of the anterolateral thoracic wall through distinct fascial planes with potentially overlapping analgesic coverage. The combined interpectoral–pectoserratus plane block is derived from the pectoral nerve block (PECS), originally described for breast surgery and later adapted for anterior chest wall analgesia[24]. It provides coverage by targeting the medial and lateral pectoral nerves, long thoracic nerve, and intercostobrachial nerves corresponding to the T2–T6 dermatomes through injections between the pectoralis major and minor muscles and between the pectoralis minor and serratus anterior muscles[25]. The SAPB targets the T2–T9 dermatomes of the anterolateral thoracic wall[16,23–25]. It is performed by depositing local anesthetic either in the fascial plane between the serratus anterior and latissimus dorsi muscles or deep to the serratus anterior muscle along the mid-axillary line[13,16,25]. Although superficial and deep SAPB approaches have been reported to provide comparable analgesic efficacy, combining both planes may broaden thoracic wall analgesic coverage[25].

Combined regional analgesic strategies for anterior thoracotomy have gained increasing attention; however, comparative data in minimally invasive coronary surgery remain limited, particularly regarding their performance relative to standard analgesic management[14,25–28]. Accordingly, this prospective randomized clinical study aimed to compare the analgesic efficacy of combined interpectoral–pectoserratus plane block, combined deep–superficial serratus anterior plane block, and standard analgesic management in patients undergoing minimally invasive coronary artery bypass grafting via left anterior thoracotomy. We hypothesized that, compared with standard analgesic management, the combined regional plane blocks would improve postoperative pain control, reduce additional analgesic requirements, preserve quality of recovery, and shorten hospital length of stay.

Methods

This prospective randomized clinical study was approved prior to patient enrollment by the Institutional Education Planning Coordination Unit (Reference number: 50687469.010.01.215313444, approval date: May 25, 2023) and the Prospective Clinical Research and Scientific Research Ethics Committee of the University of Health Sciences (Reference number: 46418926, project approval number: 2023-223, evaluation date: June 20, 2023). At the time of study initiation, prospective registration in a public clinical trial registry was not routinely required for investigator-initiated perioperative regional anesthesia studies at our institution; therefore, the study was retrospectively registered in the ISRCTN registry (ISRCTN32677289; first posted 16/02/2026) to ensure compliance with international trial registration standards. Patients and the public were not involved in the design, conduct, reporting, or dissemination of the study.

All eligible patients, undergoing surgical operation between July 2023 and November 2025 in Gulhane Training and Research Hospital, received detailed information regarding the study procedures and provided written and verbal informed consent prior to enrollment. The study population comprised adult patients undergoing MIDCAB and MICS-CABG. Inclusion criteria were age ≥18 years and provision of informed consent. Exclusion criteria included known allergy to local anesthetics, chronic analgesic use, a history of coagulopathy, infection at the injection site, peripheral neuropathy, and the presence of thoracic deformities. No important changes were made to the study protocol after commencement of the study. The primary and secondary outcomes were predefined prior to patient enrollment; however, certain operational definitions used in the analysis, including the definition of opioid consumption as the total rescue analgesic dosage administered during the postoperative observation period and postoperative complications as the occurrence of atrial fibrillation, pneumonia, or

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atelectasis during the postoperative hospitalization period, were specified during data analysis.

Participants were randomly assigned to three parallel groups in a 1:1:1 ratio: combined interpectoral–pectoserratus plane block, combined deep–superficial serratus anterior plane block, or standard analgesic management. The randomization sequence was generated by an independent investigator using a block randomization scheme to ensure balanced group allocation. The allocation list was generated before patient enrollment using the Sealed Envelope online randomization generator (www.sealedenvelope.com). Permuted block randomization with variable block sizes of 6 and 9 was used to ensure balanced allocation across the three study groups. Allocation concealment was maintained using sequentially numbered, sealed opaque envelopes prepared by an independent investigator. Following patient inclusion, the next envelope in sequence was opened by an investigator not involved in outcome assessment. Upon completion of surgery, treatment allocation was communicated to the anesthesiologist designated to perform the assigned regional block procedure, who subsequently prepared and performed the corresponding intervention when applicable. Consequently, the anesthesiologist performing the block became aware of group allocation at that stage, and blinding of the block-performing anesthesiologist was not feasible. However, intraoperative anesthesia followed a standardized protocol, with the primary anesthesia provider blinded to allocation. Although patients were informed about the study procedures, they were unaware of their group allocation, as the intervention was performed after induction of general anesthesia. Routine postoperative care in the intensive care unit (ICU) was provided by nursing staff, and full blinding was not feasible due to institutional patient record systems. However, postoperative pain assessment and analgesic management were performed by ICU clinicians who were blinded to treatment allocation. Investigators responsible for postoperative data collection were not involved in the allocation process. Therefore, outcome assessments were performed by blinded clinicians using predefined clinical parameters and patient-reported measures. Statistical analyses were conducted after completion of data collection.

Patients receiving a combined interpectoral–pectoserratus plane block were assigned to Group P, while patients receiving combined deep–superficial serratus anterior plane block were assigned to Group S. Patients who did not receive any regional plane block served as the control group. All regional blocks were administered by an anesthesiologist experienced in ultrasound-guided nerve blocks. The Quality of Recovery-40 (QoR-40) questionnaire, comprising 40 items rated on a 5-point Likert scale ranging from 1 (“none”) to 5 (“all the time”), was administered preoperatively and repeated on postoperative days 1 and 2.

All patients were monitored with five-lead electrocardiography, pulse oximetry, and noninvasive arterial pressure in accordance with the American Society of Anesthesiologists recommendations after preoperative evaluation. Intravenous cannulation was performed with a 16- to 18G angiocatheter, followed by sedation with 0.05 to 0.1 mg/kg midazolam. Invasive arterial pressure monitoring was performed under local anesthesia at the right radial artery with ultrasonographic guidance. Anesthesia induction was achieved with 1 mg/kg ketamine, 1 mg/kg propofol, 1 µg/kg fentanyl, and 0.5 mg/kg rocuronium bromide. After ensuring adequate muscle relaxation and sedation, patients were intubated with a left double-lumen tube (DLT). Mechanical ventilation was performed in volume control mode, with respiratory rate adjusted to maintain an end-tidal carbon dioxide between 30 and 35 mmHg. Anesthesia was maintained with 2% sevoflurane and a remifentanil infusion of 0.1-0.2 µg/kg/min, with a goal bispectral index of 40-60. A 7-Fr triple-lumen central venous catheter was placed after induction under ultrasound guidance to monitor central venous pressure. All coronary revascularization procedures were performed by the same cardiac surgical team through a left anterior thoracotomy at the third intercostal space, with an incision length of approximately 7 cm. In our practice, this access was used for both single-vessel LIMA-to-LAD revascularization (MIDCAB) and multivessel minimally invasive coronary revascularization (MICS-CABG); therefore, the principal difference between cases was only the extent of coronary grafting rather than the thoracic access itself. The number of grafted vessels was also recorded and compared across the study groups. Following completion of the surgical procedures, the assigned ultrasound-guided regional block techniques were performed.

In patients assigned to Group P, ultrasound-guided combined interpectoral–pectoserratus plane block was performed on the left anterior chest wall in the postoperative period. After identification of the pectoralis muscles under ultrasound at the infraclavicular level, the pectoral branch of the thoracoacromial artery was used as an anatomical landmark. A first injection of 15 mL of 0.25% bupivacaine was administered into the fascial plane between the pectoralis major and pectoralis minor muscles. The needle was then advanced to the plane between the pectoralis minor and serratus anterior muscles, where a second injection of 15 mL of 0.25% bupivacaine was delivered (Figure 1).

In patients assigned to Group S, ultrasound-guided combined deep–superficial serratus anterior plane blocks were performed on the left anterior chest wall. After identification of the fourth and fifth ribs along the mid-axillary line, the intercostal muscles, the serratus anterior muscle superficial to the ribs, and the latissimus dorsi muscle superficial to the serratus anterior were visualized. The thoracodorsal artery served as an additional anatomical landmark to facilitate identification of the superficial plane. Using an in-plane technique, the needle tip was positioned either superficial or deep to the serratus anterior muscle, depending on the block component. For the superficial block, the needle was advanced into the fascial plane between the latissimus dorsi (superiorly) and serratus anterior (inferiorly). For the deep serratus anterior plane block, the

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needle was advanced into the plane between the serratus anterior muscle and the underlying ribs and external intercostal muscles at the level of the fourth and fifth ribs (Figure 2). A total of 30 mL of 0.25% bupivacaine was administered across both planes.

For all patients, DLTs were replaced with standard intubation tubes after completion of blocks. Patients were later moved to the ICU for follow-up under intubation. Weaning was performed when adequate criteria were met, with no additional analgesic infusion given until extubation was performed.

During the postoperative period, patients were monitored in the ICU and evaluated using the visual analog scale (VAS) at 6, 12, 24, and 48 h after extubation, as primary outcome. VAS ranged from 0 to 100, with 0 indicating no pain and 100 indicating the most severe pain possible; patients were asked to rate their discomfort accordingly. All patients received intravenous paracetamol 1 g at 8-hour intervals postoperatively. If any patient had a VAS score greater than 40 during the postoperative period, a rescue analgesic injection of 100 mg tramadol IV was administered. In patients whose VAS score was 40 or higher despite the standard analgesic regimen and rescue analgesia, 50 mg of dexketoprofen was administered. The interval between tramadol injections was maintained at more than 4 hours.

Patients' files and hospital records were evaluated for demographic data, comorbidities, and postoperative complications. The total dosage of rescue analgesic used postoperatively, the time to the first rescue analgesic requirement, the presence of newly-onset atrial fibrillation during ICU stay, extubation times, ICU and total hospital stay durations were also recorded as secondary outcomes.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 31.0 (IBM Corp., Armonk, NY, USA). Distribution of the data was assessed using Kolmogorov–Smirnov tests and Q–Q plots. For parametric variables, continuous data were reported as means and standard deviations, while categorical variables were shown as counts and percentages.

Baseline demographic characteristics, comorbidities, operative variables, and postoperative complications were compared among the three groups. The Pearson Chi-square test was used to compare nominal variables, with further analysis planned using Phi and Cramer's V for statistically relevant parameters. ANOVA was used to compare means between groups, and when a significant overall difference was observed, post-hoc pairwise comparisons were performed using Bonferroni correction to control for multiple comparisons.

Repeated measurements of VAS and QoR-40 scores over time were analyzed using repeated-measures ANOVA. It should be noted that the study was powered to detect differences between each block group and the control group; it was not designed or powered to establish equivalence between Group P and Group S. Accordingly, non-significant differences between the two block groups should be interpreted as a lack of detected difference rather than evidence of equivalence.

Regarding study size, the required sample size was determined for repeated measures ANOVA as the statistical method requiring the most patients. Since there was no institutional pilot data available, the assumed effect size was based on published studies that evaluated chest wall plane blocks in thoracic and cardiac surgical populations. These studies reported moderate-to-large differences between groups in postoperative pain scores (η^2p ranging from 0.06 to 0.14)[23,29]. Therefore, a conservative moderate effect size (partial eta-squared η^2p of at least 0.06) was chosen for repeated-measures ANOVA with one between-subjects factor (three groups) and one within-subjects factor (four time points). Assuming a type I error rate of 0.05, 80% power, and a correlation of 0.5 between repeated measures, at least 54 patients per group were needed. To account for an expected 10% attrition rate, 60 patients per group were targeted, resulting in a total planned enrollment of 180 patients.

Results

A total of 192 patients undergoing minimally invasive cardiac surgery were assessed for eligibility. Four patients were excluded due to conversion to sternotomy, seven declined participation, and one was excluded due to perioperative mortality. The final study cohort consisted of 180 patients, with 60 patients assigned to each group. No patients were lost to follow-up during the study period (Figure 3).

Baseline demographic characteristics and comorbidities were comparable among the three groups, with no statistically significant differences observed in patient characteristics or major comorbid conditions (Table 1).

Operative characteristics and postoperative outcomes are summarized in Table 2. The number of grafted vessels, red blood cell transfusion requirements, intraoperative remifentanil use, and time to extubation were similar across groups. Surgery and anesthesia durations were longer in both block groups than in the control group, consistent with the additional time required for block administration. VAS scores were significantly lower at all postoperative time points in both Group P and Group S compared to the control, with no significant difference between the two block techniques (Figure 4). Time to first

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rescue analgesia was longer in both block groups than in controls. Overall rescue analgesic consumption was significantly reduced in both block groups during the first and second 24-hour postoperative periods. Preoperative QoR-40 scores were similar across all groups. After the surgery, both block groups maintained significantly higher QoR-40 scores than the control group at 24 and 48 hours, with no significant difference between Group P and Group S (Figure 5). Time to mobilization after extubation was significantly shorter in both block groups compared to the control group. ICU and hospital length of stay were also significantly reduced in Group P and Group S relative to controls.

Regarding postoperative complications, the incidence of atelectasis was significantly lower in the block groups compared with the control group. Rates of atrial fibrillation and pneumonia did not differ significantly between groups (Table 3).

Repeated-measures ANOVA showed significant main effects of time, group, and notable time × group interactions for both VAS and QoR-40 scores. For VAS, the time × group interaction had a large effect size. The between-subjects effect of group was also large. For QoR-40, a significant time × group interaction was found, with a large effect for the between-subjects group. In both cases, the control group showed worse scores at all postoperative assessments and did not catch up with the block groups by the end of follow-up (Table 4).

Bonferroni-corrected post-hoc pairwise comparisons confirmed significant differences between each block group and the control group at all measured time points for VAS scores, rescue analgesic consumption, QoR-40 scores, time to mobilization, ICU duration and hospital length of stay (Table 5, reporting mean differences with 95% confidence intervals and Cohen's d effect sizes). No statistically significant differences were found between Group P and Group S for any measured outcome.

Discussion

In this prospective randomized study, both combined interpectoral–pectoserratus plane block and combined deep–superficial serratus anterior plane block improved early postoperative analgesia compared with standard analgesic management in patients undergoing minimally invasive coronary revascularization via left anterior mini-thoracotomy. Both techniques were associated with lower postoperative pain scores, reduced rescue analgesic consumption, longer time to first rescue analgesia, better preservation of QoR-40 scores, earlier mobilization, and shorter ICU and hospital length of stay. Atelectasis was also less frequent in the block groups, whereas atrial fibrillation and pneumonia rates did not differ significantly among groups. No statistically significant difference was detected between the two active block techniques; however, this finding should be interpreted as a lack of detected difference rather than evidence of equivalence.

Chest wall fascial plane blocks, including pectoral and serratus-based techniques, have been widely evaluated in non-cardiac thoracic surgery[24,30–34]. Several studies have supported their analgesic and opioid-sparing effects. Tang et al. reported that SAPB reduced postoperative pain scores and opioid consumption after radical mastectomy compared with conventional analgesia[34]. Similarly, rhomboid intercostal and pectoral nerve blocks have been shown to reduce pain and opioid use while improving early recovery after breast surgery[35]. Gao et al. also demonstrated that serratus-based techniques reduced postoperative pain scores and opioid consumption.[36] However, studies comparing different block techniques have not consistently identified a superior approach. Alshawadfy et al. reported lower postoperative opioid consumption with deep SAPB than with PECS block[37], whereas Ozguner et al. observed lower tramadol requirements with combined SAPB than with pectoserratus plane block[28]. Other studies have reported comparable analgesic efficacy between SAPB and TPVB in terms of postoperative pain scores, although opioid or tramadol consumption differed between the techniques[38,39]. Ulger et al. likewise reported comparable efficacy between TPVB and combined SAPB, while highlighting the potential benefits of multi-site injection approaches[40]. The relative superiority of deep versus superficial SAPB also remains uncertain. Meng et al. found superficial SAPB to be associated with lower pain scores and reduced opioid consumption[41]. In contrast, a recent meta-analysis found no clear analgesic advantage of either approach[42]. Our findings are broadly consistent with the literature, showing that chest wall plane block strategies improve postoperative pain control and reduce analgesic requirements compared with standard management. However, unlike studies suggesting the superiority of one technique over another, we observed no significant difference between combined deep–superficial SAPB and combined interpectoral–pectoserratus plane block.

Evidence from cardiac surgery supports the use of regional analgesic techniques as part of multimodal, opioid-sparing perioperative care. TEA remains one of the most extensively studied techniques in this field and has been associated with reductions in perioperative myocardial infarction, respiratory complications, and atrial arrhythmias; however, concerns regarding epidural hematoma during systemic anticoagulation limit its routine use[18]. TPVB has been used as an alternative, with reports of effective postoperative pain control and early discharge after cardiac surgery [21], and similar postoperative VAS scores and opioid consumption compared with TEA in robot-assisted CABG[20]. Nevertheless, TPVB remains relatively invasive and may be technically challenging in anticoagulated cardiac surgical patients. These limitations have increased interest in chest wall fascial plane blocks as more practical opioid-sparing alternatives[14,43]. In this context, studies in minimally invasive cardiac procedures support serratus- and pectoral-based fascial plane blocks for mini-thoracotomy analgesia. SAPB, including combined deep–superficial approaches, has been associated with lower postoperative pain

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scores, reduced opioid or rescue analgesic consumption, shorter ICU and hospital stay, improved ICU recovery, and lower atelectasis rates after minimally invasive cardiac procedures[23,27,44–46]. Similarly, combined pectoserratus–interpectoral block has been shown to reduce 24-hour opioid consumption, lower pain scores at extubation, and improve the overall benefit of analgesia after MICS[47]. Consistent with these findings, both block groups in the present study demonstrated lower pain scores and rescue analgesic requirements, better QoR-40 recovery scores, earlier mobilization, shorter ICU and hospital length of stay, and a lower incidence of atelectasis compared with standard analgesic management.

Comparative studies suggest that different chest wall block combinations may provide effective thoracotomy analgesia when their sensory coverage matches the incision and pain distribution. Both SAPB and PECS II have been reported to provide effective postoperative thoracotomy analgesia in adult cardiac surgery, and different combined chest wall block strategies have produced similar analgesic outcomes in minimally invasive cardiac surgery[48,49]. This is consistent with the present finding that both combined interpectoral–pectoserratus plane block and combined deep–superficial SAPB improved pain scores and rescue analgesic requirements, while no statistically significant difference was detected between the two techniques. One possible explanation is that both approaches were designed as multi-plane blocks to enhance local anesthetic spread across complementary fascial compartments involved in mini-thoracotomy pain transmission, a concept supported by reports emphasizing broader fascial coverage through combined regional strategies[16]. However, not all serratus-based studies have shown consistent benefit, and neutral or less favorable outcomes have also been reported[50,51]. These discrepancies suggest that clinical efficacy may depend on surgical approach, baseline pain burden, block timing, fascial plane selection, and comparator treatment. Therefore, the absence of a detected difference between Group P and Group S should not be interpreted as evidence of equivalence, and further studies are needed to clarify the relative contribution of each block component.

Postoperative pain may contribute to postoperative pulmonary complications, particularly atelectasis (PPCs), by limiting deep breathing, effective coughing, respiratory physiotherapy, and early mobilization [7,11,12,52]. Previous studies support the link between effective analgesia and improved pulmonary outcomes. Tenenbein et al. reported that patients receiving TEA had significantly improved postoperative pulmonary function and a lower incidence of early atelectasis compared with controls[17]. Sun et al. also demonstrated lower pulmonary infection scores in patients receiving regional anesthesia compared with conventional analgesic strategies[22]. Consistent with these findings, the present study demonstrated a significantly lower incidence of atelectasis in patients receiving regional chest wall blocks, although pneumonia rates did not differ significantly between groups. These findings suggest that effective regional analgesia may reduce early pain-related pulmonary complications by improving respiratory mechanics, facilitating effective coughing and deep breathing, and promoting earlier mobilization. Although the overall incidence of postoperative pulmonary complications was low across all groups, likely reflecting standardized perioperative respiratory care and infection-prevention protocols, the reduction in atelectasis further supports the potential pulmonary benefits of chest wall plane blocks in MICS-CABG.

Postoperative atrial fibrillation (POAF) remains the most common complication following cardiac surgery[53]. The occurrence of POAF is clinically significant, as it is associated with prolonged hospitalization, increased healthcare costs, and a higher risk of thromboembolic events[54]. Effective regional analgesia may help reduce POAF by improving pain control and decreasing sympathetic activation. Consistent with this, previous studies have reported lower POAF rates with TEA and TPVB[55,56]. In contrast to these findings, the present study did not demonstrate a statistically significant difference in POAF incidence between the study groups. This may be primarily attributable to the relatively small sample size and the limited number of POAF events observed, which may have reduced the statistical power to detect potential differences. Nevertheless, although regional chest wall blocks significantly improved postoperative analgesia and recovery parameters in our cohort, their potential influence on POAF incidence remains uncertain and warrants further investigation in larger studies.

From a clinical perspective, the present findings support the use of ultrasound-guided chest wall plane blocks as part of multimodal analgesic pathways in minimally invasive coronary surgery. Effective postoperative pain control is particularly important in this setting because inadequate analgesia may impair respiratory function, hinder effective coughing and mobilization, and increase reliance on systemic opioids, all of which may adversely affect postoperative recovery in cardiac surgical patients[13,19,57–60]. In the present study, both combined interpectoral–pectoserratus plane block and combined deep–superficial serratus anterior plane block provided effective opioid-sparing analgesia during the early postoperative period, resulting in lower VAS scores, reduced rescue analgesic requirements, longer time to first rescue analgesia, earlier mobilization, improved QoR-40 recovery scores, shorter ICU and hospital stay, and a lower incidence of atelectasis compared with standard analgesic management. ICU stay was reduced by approximately 8–9 hours and total hospital stay by approximately 10–13 hours in the block groups. Although these absolute differences were modest, they may still be clinically meaningful in MICS-CABG, where recovery milestones are typically achieved over a short postoperative period. However, length-of-stay outcomes should be interpreted cautiously because they may also be influenced by institutional discharge practices and perioperative workflow factors. Further studies should evaluate whether these early recovery benefits translate into longer-term outcomes, including persistent postoperative pain and prolonged opioid use.

This study has several limitations that should be considered. First, both regional blocks were performed after completion of

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surgery; therefore, a pre-emptive analgesic effect could not be achieved, and intraoperative nociceptive modulation was not targeted. This may have limited the potential influence of the intervention on early postoperative pain dynamics. Second, because blocks were performed under general anesthesia, formal sensory testing and dermatomal mapping were not feasible, and block success had to be inferred from postoperative clinical outcomes rather than objectively confirmed. Third, a complete traditional blinding was not possible. The anesthesiologist performing the block was necessarily aware of group allocation; however intraoperative anesthesia was conducted according to standardized institutional protocol and primary anesthesia provider responsible for intraoperative management remained blinded to treatment assignment. No sham block was applied in the control group, which represents a potential source of performance and detection bias. Although patients were unaware of their group allocation because the interventions were performed under general anesthesia, the absence of a placebo procedure may have influenced both patient-reported outcomes, such as postoperative pain scores and QoR-40, and clinician-driven outcomes. Bedside nursing staff involved in routine patient care were also not formally blinded, owing to institutional workflow and documentation requirements. To minimize potential bias, decisions regarding postoperative care—including ventilatory management, postoperative pain assessment, and analgesic administration—were made by ICU clinicians blinded to treatment allocation, in accordance with predefined institutional protocols. In addition, investigators responsible for postoperative data collection and outcome assessment were independent of the allocation process and blinded to group assignment, which may have mitigated the impact of these limitations. Nevertheless, these potential sources of bias should be considered when interpreting the study findings. Fourth, the incidences of postoperative atrial fibrillation, pneumonia, atelectasis, and other complications were low, and the study was powered primarily for VAS and QoR-40 outcomes rather than complication endpoints; accordingly, it may have been underpowered to detect modest between-group differences in these secondary outcomes. Fifth, surgery and anesthesia durations were longer in the block groups because the ultrasound-guided blocks were performed within the operating-room workflow after completion of surgery and before transfer, and this additional intervention time was included in the recorded operative and anesthesia durations; however, residual confounding from unmeasured perioperative factors cannot be fully excluded. Finally, trial registration was retrospective, as registration in the public clinical trial registry was completed after patient enrollment and data collection had been finalized, which reduces methodological transparency. However, the study protocol had been prospectively developed and approved by the institutional ethics committee before study initiation, and the primary outcome—postoperative pain intensity assessed by VAS at predefined postoperative time points—remained unchanged from the original protocol, with no modification of the primary endpoint before registration. The secondary outcomes were also predefined and included opioid consumption, defined as the total rescue analgesic dosage administered during the postoperative observation period, rescue analgesic requirements, QoR-40 scores, ICU and hospital length of stay, and postoperative complications, defined as atrial fibrillation, pneumonia, or atelectasis during postoperative hospitalization; only certain operational definitions used in the analysis were clarified during data processing. In addition, although no statistically significant differences were observed between Group P and Group S across any measured outcome, the present study was not specifically designed or powered to test equivalence or non-inferiority between the two block techniques. Therefore, the comparable findings between the active block groups should be interpreted with caution, and a dedicated adequately powered equivalence or non-inferiority trial would be required to establish formal comparability.

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Conclusion

In this prospective randomized single-center study, both combined interpectoral–pectoserratus plane block and combined deep–superficial serratus anterior plane block improved postoperative analgesia and early recovery compared with standard analgesic management in MICS. No statistically significant difference was observed between the two active techniques, although the study was not designed to establish equivalence. Given the methodological limitations, these findings should be interpreted cautiously. Larger prospective studies are needed to confirm these results and further define the comparative role of these block techniques in perioperative care.

Data Availability

The full study protocol is provided as a related manuscript file and was made available for editorial and peer review. The datasets used and/or analyzed during the current study are not publicly available due to ethical restrictions and patient privacy considerations. However, they are available from the corresponding author on reasonable request, subject to approval by the Institutional Education Planning Coordination Unit, Prospective Clinical Research and Scientific Research Ethics Committee of the University of Health Sciences, and the hospital administration.

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Author contributions statement

Conceptualization, A.K.Y. and M.E.; data curation, A.K.Y., M.E., E.D. and K.K.; formal analysis, A.K.Y. and M.E.; investigation, A.K.Y. and M.E.; methodology, A.K.Y., E.D. and K.K.; project administration, A.K.Y. and K.K.; supervision, E.D. and K.K.; validation, M.E., E.D. and K.K; writing—original draft, A.K.Y. and M.E.; and writing—review and editing, A.K.Y., M.E., E.D. and K.K. All authors have read and agreed to the published version of the manuscript.

Declarations

Competing Interests

The authors declare no conflicts of interest.

Ethical Approval

The study was conducted in accordance with the Declaration of Helsinki. Following approval by the Institutional Education Planning Coordination Unit (Reference number: 50687469.010.01.215313444, approval date: May 25, 2023), the study protocol was reviewed and approved by the Prospective Clinical Research and Scientific Research Ethics Committee of the University of Health Sciences (reference number: 46418926; project approval number: 2023-223; evaluation date: June 20, 2023).

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

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Additional information

Correspondence and requests for materials should be addressed to A.K.Y.

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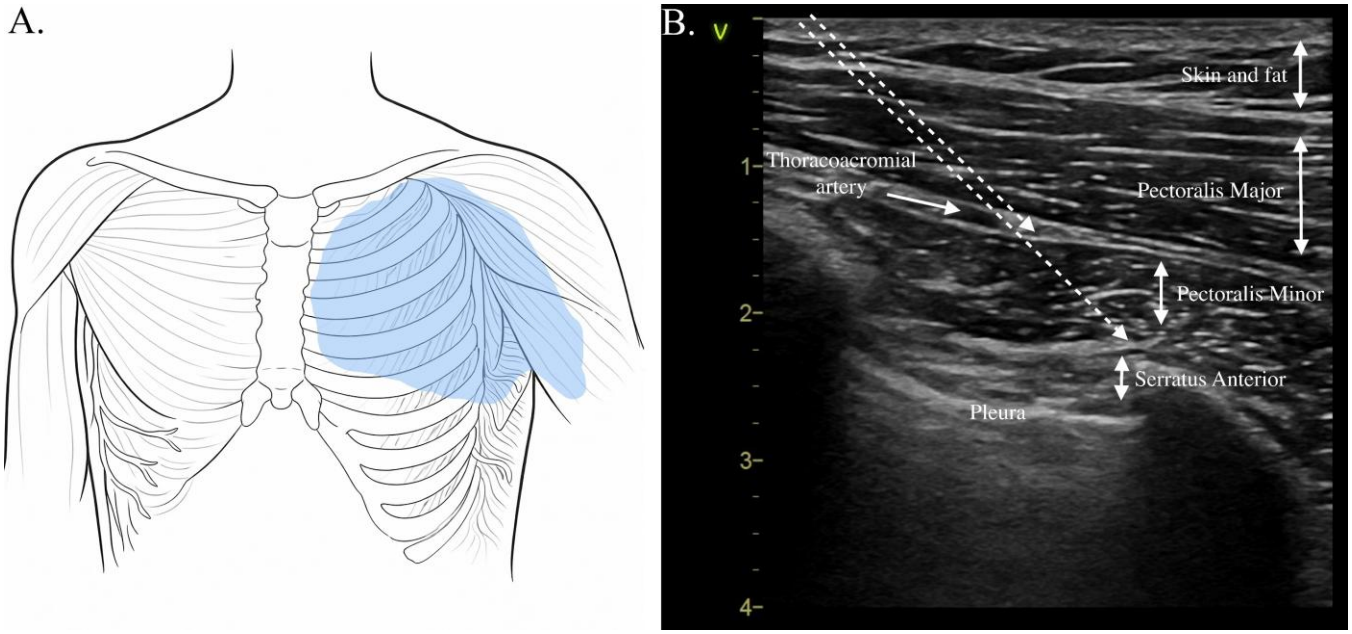


Figure 1. Ultrasound-guided combined interpectoral and pectoserratus plane block. (A) Simplified anatomical illustration of the anterior and anterolateral chest wall highlighting the target region and expected dermatomal coverage of the combined interpectoral–pectoserratus plane block. (B) Ultrasound image obtained at the infraclavicular level demonstrating the pectoralis major, pectoralis minor, and serratus anterior muscles, as well as the pleura. The in-plane needle trajectory is indicated by a dotted line, with local anesthetic deposited in the fascial plane between the pectoralis major and pectoralis minor muscles (interpectoral plane), using the pectoral branch of the thoracoacromial artery as an anatomical landmark prior to advancement toward the pectoserratus plane.

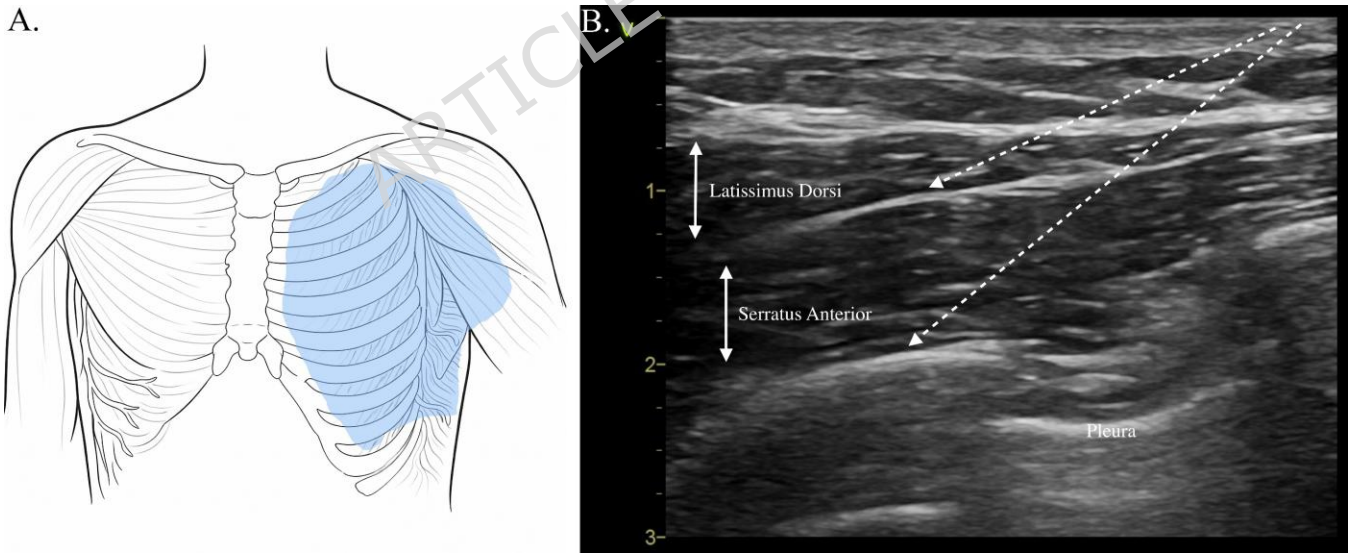


Figure 2. Ultrasound-guided combined deep–superficial serratus anterior plane blocks. (A) Simplified anatomical illustration of the anterolateral chest wall highlighting the target region and expected dermatomal coverage of combined superficial and deep serratus anterior plane blocks (T2–T9). (B) Ultrasound image obtained at the mid-axillary line over the fourth and fifth ribs demonstrating the latissimus dorsi and serratus anterior muscles in relation to the pleura. The in-plane needle trajectory is indicated by dotted lines. For the superficial serratus anterior plane block, local anesthetic is deposited in the fascial plane between the latissimus dorsi (superficial) and serratus anterior (deep) muscles. For the deep block, the needle is advanced to the plane between the serratus anterior muscle and the underlying ribs and external intercostal muscles.

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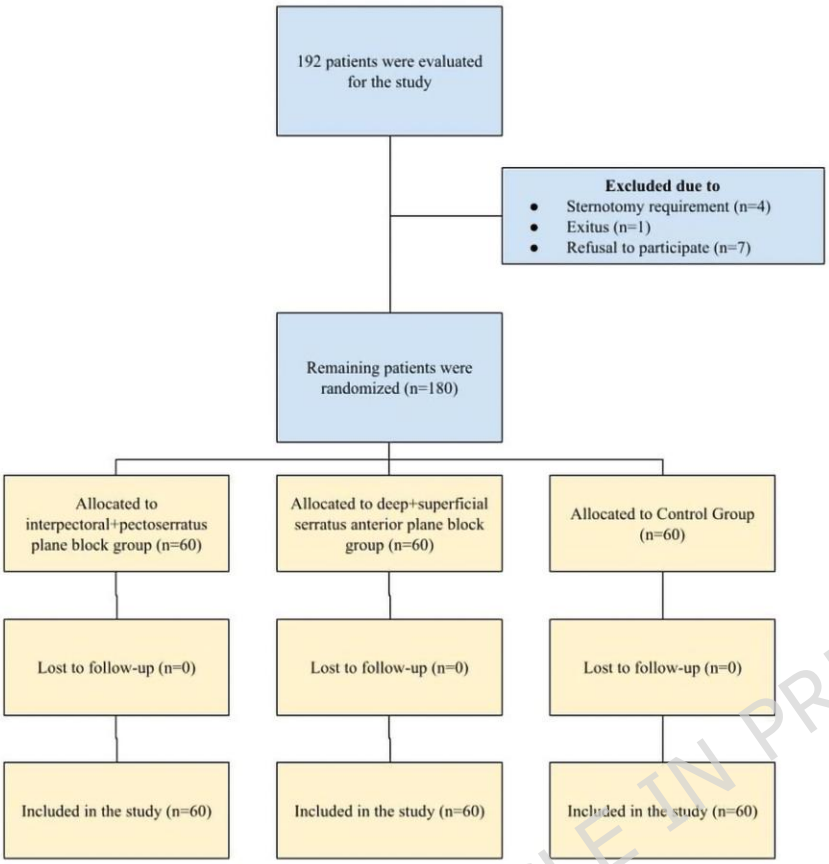


Figure 3. Patient Selection Flow-Chart. Flow diagram showing patient enrollment, exclusions, group allocation, and final analysis.

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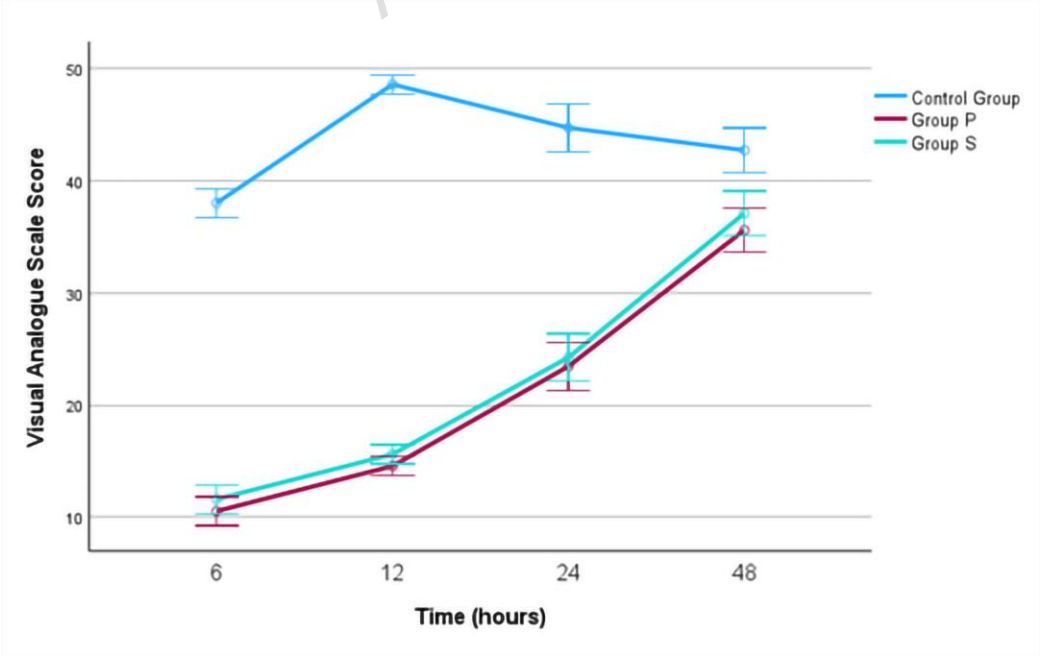


Figure 4. Visual analog scale (VAS) scores during postoperative follow-up. Mean VAS scores measured at 6, 12, 24, and 48 hours after extubation are shown for the control group, Group P (combined interpectoral pectoserratus plane block), and

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Group S (combined deep–superficial serratus anterior plane block). Both block groups demonstrated significantly lower pain scores at all time points compared with the control group, with no significant difference between Group P and Group S.

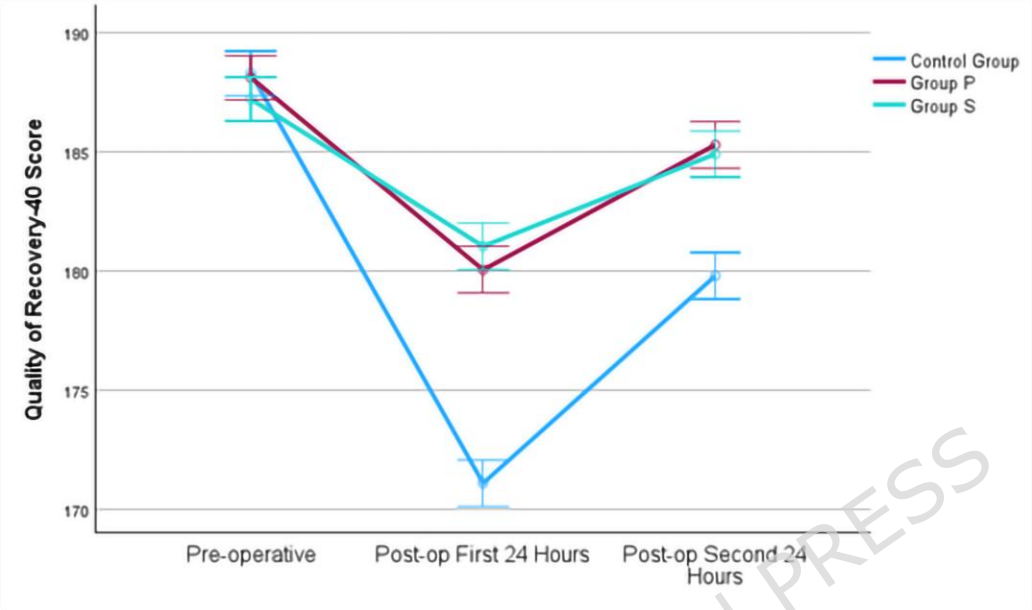


Figure 5. Quality of Recovery-40 (QoR-40) scores during postoperative follow-up. Mean QoR-40 scores assessed preoperatively and at 24 and 48 hours postoperatively are shown for the control group, Group P (combined interpectoral–pectoserratus plane block), and Group S (combined deep–superficial serratus anterior plane block). Both block groups demonstrated significantly higher postoperative QoR-40 scores compared with the control group, with no significant difference between Group P and Group S.

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Parameters (n, %)		Control Group	Group P	Group S	Total	P Value
Age (years, SD)		57.08 (7.89)	57.96 (9.08)	58.16 (8.87)	57.73 (8.59)	0.766
Sex	Female	16 (26.7)	17 (28.3)	18 (30)	51 (28.3)	0.921
	Male	44 (73.3)	43 (71.7)	42 (70)	129 (71.7)	
Smoking History	Nonsmoker	24 (40)	28 (46.7)	34 (56.7)	86 (47.8)	0.184
	Ex or Active Smoker	36 (60)	32 (53.3)	26 (43.3)	94 (52.2)	
Hypertension	None	40 (66.7)	34 (56.7)	45 (75)	119 (66.1)	0.105
	Present	20 (33.3)	26 (43.3)	15 (25)	61 (33.9)	
Diabetes Mellitus	None	48 (80)	45 (75)	51 (85)	144 (80)	0.392
	Present	12 (20)	15 (25)	9 (15)	36 (20)	
Hyperlipidemia	None	48 (80)	51 (85)	48 (80)	147 (81.7)	0.716
	Present	12 (20)	9 (15)	12 (20)	33 (18.3)	
Myocardial Infarction History	None	46 (76.7)	48 (80)	46 (76.7)	140 (77.8)	0.879
	Present	14 (23.3)	12 (20)	14 (23.3)	40 (22.2)	
PCI History	None	45 (75)	46 (76.7)	46 (76.7)	137 (76.1)	0.97
	Present	15 (25)	14 (23.3)	14 (23.3)	43 (23.9)	

Table 1. Demographic Characteristics. Data are presented as n (percentage) or mean ± standard deviation, SD: Standard Deviation, Group P: Patients undergoing combined interpectoral–pectoserratus plane block, Group S: Patients undergoing combined deep–superficial serratus anterior plane block. PCI: Percutaneous coronary intervention.

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Parameters (mean, SD)	Control Group	Group P	Group S	P Value
CABGx	2.52 (0.50)	2.6 (0.64)	2.58 (0.62)	0.717
Duration of Operation (min)	226.25 (19.51)	241.05 (23.8)	240.13 (25.85)	0.001
Duration of Anesthesia (min)	356.92 (27.2)	377 (24.64)	377.93 (26.75)	0.001
Amount of pRBC given (unit)	1.68 (0.54)	1.62 (0.58)	1.6 (0.56)	0.69
Total Intraoperative Remifentanil Dosage (µg)	1492.7 (171.17)	1499.7 (167.25)	1520.35 (163.82)	0.643
Time to Mobilization After Extubation	142.37 (5.97)	99 (7.77)	100.13 (7.26)	0.001
Duration Until Extubation (min)	167 (16.07)	168.8 (18.31)	169.62 (19.56)	0.719
Postoperative ICU Duration (day)	1.65 (0.63)	1.27 (0.45)	1.32 (0.47)	0.001
Postoperative Hospital Length of Stay (day)	6.33 (0.86)	5.9 (0.3)	5.8 (0.4)	0.001
Time to First Rescue Dosage (min)	195.22 (70.46)	663.27 (132.46)	639.05 (136.83)	0.001
VAS Score				
6 hours	38 (8.54)	10.55 (1.11)	11.62 (1.45)	0.001
12 hours	48.57 (4.19)	14.57 (2.87)	15.62 (2.76)	0.001
24 hours	44.7 (10.63)	23.45 (6.72)	24.25 (7.1)	0.001
48 hours	42.7 (9.33)	35.58 (6.93)	37.08 (6.87)	0.001
Total Rescue Analgesic Dosage				
First 24 Hours	233.47 (25.38)	148.62 (16.45)	145.57 (14.59)	0.001
Second 24 Hours	217.08 (19.28)	130.37 (15.57)	132.53 (14.13)	0.001
QoR-40 Score				
Pre-operative	188.28 (3.57)	188.1 (3.74)	187.2 (3.54)	0.216
Post Operative 24 hours	171.12 (4.38)	180.05 (3.63)	181.03 (3.32)	0.001
Post Operative 48 hours	179.8 (3.85)	185.28 (4)	184.9 (3.54)	0.001

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Table 2. Intraoperative Evaluation, Postoperative Outcomes and Scoring Results. Data are presented as mean ± standard deviation, SD: Standard Deviation, Group P: Patients undergoing combined interpectoral–pectoserratus plane block, Group S: Patients undergoing combined deep–superficial serratus anterior plane block, CABGx: Number of vessels grafted during coronary arterial bypass grafting, VAS: Visual analog scale, QoR-40: Quality of Recovery-40 questionnaire, pRBC: Packed red blood cells, ICU: Intensive Care Unit.

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Post Operative Complications (n, %)		Control Group	Group P	Group S	Total	P Value
Atrial Fibrillation	None	51 (85)	57 (95)	53 (88.3)	161 (89.4)	0.193
	Present	9 (15)	3 (5)	7 (11.7)	19 (10.6)	
Pneumonia	None	55 (91.7)	59 (98.3)	58 (96.7)	172 (95.6)	0.183
	Present	5 (8.3)	1 (1.7)	2 (3.3)	8 (4.4)	
Atelectasis	None	53 (88.3)	59 (98.3)	58 (96.7)	170 (94.4)	0.038
	Present	7 (11.7)	1 (1.7)	2 (3.3)	10 (5.6)	

Table 3. Postoperative Complications. Data are presented as n (percentage) or mean ± standard deviation, SD: Standard Deviation, Group P: Patients undergoing combined interpectoral–pectoserratus plane block, Group S: Patients undergoing combined deep–superficial serratus anterior plane block

Parameters	df	F	P value	η^2p
VAS				
Within-subjects effects				
VAS (Time)	2.073, 366.99	461.937	0.001	0.723
VAS × Groups	4.417, 366.99	114.445	0.001	0.564
Between-subjects effects				
Groups	2, 177	397.726	0.001	0.818
QoR-40				
Within-subjects effects				
QoR-40 (Time)	1.520, 268.998	36.034	0.001	0.657
QoR-40 × Groups	3.040, 268.998	36.034	0.001	0.289
Between-subjects effects				
Groups	2, 177	103.148	0.001	0.538

Table 4. Repeated-measures ANOVA results for pain and recovery scores. VAS: Visual analog scale, QoR-40: Quality of Recovery-40 questionnaire, * Sphericity was not assumed and Greenhouse-Geisser analysis was utilized. Df: Degrees of freedom and error. η^2p: Partial eta squared.

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Parameters	Comparison of Groups		Mean Difference	95% Confidence Interval		Std. Error	Cohen's D	P Value
				Lower Bound	Upper Bound			
VAS Score at 6 Hours	Control	Group P	27.45	25.22	29.68	0.921	4.51	0.001
		Group S	26.383	24.16	28.61	0.921	4.31	0.001
	Group P	Group S	-1.067	-3.29	1.16	0.921	0.83	0.745
VAS Score at 12 Hours	Control	Group P	34	32.53	35.47	0.609	9.47	0.001
		Group S	32.95	31.48	34.42	0.609	9.29	0.001
	Group P	Group S	-1.050	-2.52	0.42	0.609	0.37	0.260
VAS Score at 24 Hours	Control	Group P	21.25	17.57	24.93	1.522	2.39	0.001
		Group S	20.45	16.77	24.13	1.522	2.26	0.001
	Group P	Group S	-0.800	-4.48	2.88	1.522	0.12	1.000
VAS Score at 48 Hours	Control	Group P	7.117	3.68	10.56	1.423	0.87	0.001
		Group S	5.617	2.18	9.06	1.423	0.69	0.001
	Group P	Group S	-1.500	-4.94	1.94	1.423	0.22	0.880
Time to First Rescue Dosage	Control	Group P	-468.05	-519.78	-416.32	21.404	4.41	0.001
		Group S	-443.833	-495.57	-392.10	21.404	4.08	0.001
	Group P	Group S	24.217	-27.52	75.95	21.404	0.18	0.778
Total Rescue Analgesic Dosage (First 24 Hours)	Control	Group P	84.85	76.30	93.40	3.539	3.97	0.001
		Group S	87.9	79.35	96.45	3.539	4.25	0.001
	Group P	Group S	3.050	-5.50	11.60	3.539	0.20	1.000
Total Rescue Analgesic Dosage (Second 24 Hours)	Control	Group P	86.717	79.45	93.98	3.007	4.95	0.001
		Group S	84.55	77.28	91.82	3.007	5.00	0.001
	Group P	Group S	-2.167	-9.43	5.10	3.007	0.15	1.000
QoR-40 Score (Post Operative 24 hours)	Control	Group P	-8.933	-10.61	-7.25	0.694	2.22	0.001
		Group S	-9.917	-11.60	-8.24	0.694	2.55	0.001
	Group P	Group S	-0.983	-2.66	0.70	0.694	0.28	0.476
QoR-40 Score (Post Operative 48 hours)	Control	Group P	-5.483	-7.16	-3.81	0.694	1.40	0.001
		Group S	-5.1	-6.78	-3.42	0.694	1.38	0.001
	Group P	Group S	0.383	-1.29	2.06	0.694	0.10	1.000
Time to Mobilization After Extubation	Control	Group P	43.367	40.26	46.47	1.285	6.26	0.001
		Group S	42.233	39.13	45.34	1.285	6.36	0.001
	Group P	Group S	-1.133	-4.24	1.97	1.285	0.15	1.000
Postoperative Intensive Care Unit Duration (day)	Control	Group P	0.383	0.15	0.61	0.095	0.69	0.001
		Group S	0.333	0.10	0.56	0.095	0.59	0.001
	Group P	Group S	-0.050	-0.28	0.18	0.095	0.11	1.000
Postoperative Hospital Length of Stay (day)	Control	Group P	0.433	0.18	0.69	0.105	0.67	0.001
		Group S	0.533	0.28	0.79	0.105	0.79	0.001
	Group P	Group S	0.100	-0.15	0.35	0.105	0.28	1.000

Table 5. Post hoc pairwise comparisons of pain scores, recovery scores, and perioperative outcomes. Group P: Patients undergoing combined interpectoral–pectoserratus plane block, Group S: Patients undergoing combined deep–superficial serratus

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anterior plane block, VAS: Visual analog scale, QoR-40: Quality of Recovery-40 questionnaire. Post Hoc analysis was performed by the Bonferroni correction. Values are reported as mean differences with 95% confidence intervals and standard errors. Cohen's d effect sizes are reported as absolute values; values of 0.2, 0.5, and 0.8 correspond to small, medium, and large effects, respectively.

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