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Combined Superficial Parasternal Intercostal Plane and Rectus Sheath Blocks for Enhanced Recovery After Cardiac Surgery: A Randomized Controlled Trial

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Research Article

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Abstract

Background Pain after cardiac surgery via median sternotomy, arising from both the sternal incision and upper abdominal drains, impedes recovery. While the superficial parasternal intercostal plane (SPIP) block effectively addresses sternotomy pain, analgesia for the abdominal region remains challenging. We hypothesized that combining the SPIP block with a rectus sheath block (RSB) would provide comprehensive analgesia, thereby enhancing early recovery quality.

Methods: In this randomized controlled trial, 234 patients scheduled for median sternotomy cardiac surgery were randomly assigned to receive either bilateral SPIP and RSB with 0.3% ropivacaine or sham blocks with saline, both groups received the usual analgesic protocol. The primary outcome was the 48-hour postoperative quality of recovery, assessed using the QoR-15 scale. Secondary outcomes included QoR-15 scores at 72 hours postoperatively, postoperative pain scores, opioid consumption, ICU and hospital length of stay, time to extubation, time to first incentive spirometer use, time to first ambulation, and 6-minute walk test (6MWT) performance at discharge.

Results: The SPIP + RSB group exhibited significantly higher QoR-15 scores at 48 hours (89.2 ± 7.3 vs. 95.6 ± 7.5, respectively; 95% CI, -8.7 to -4.2, $P < 0.001$) and 72 hours (103.8 ± 7.9 vs. 110.7 ± 9.4, respectively; 95% CI, -9.6 to -4.3, $P < 0.001$) postoperatively compared to the control group. Patients receiving SPIP + RSB also reported significantly lower NRS pain scores at all assessed time points ($P < 0.05$), consumed less opioid analgesia within the first 48 hours, and experienced shorter time to exhaust, shorter ICU stay, and shorter hospital stay (all $P < 0.05$). Additionally, the SPIP + RSB group demonstrated earlier achievement of key recovery milestones, including earlier first ambulation and incentive spirometer exercises, as well as improved 6MWT performance at discharge (all $P < 0.05$). The incidence of postoperative delirium was similar between groups ($P = 0.496$), and no block-related adverse events were observed in either group.

Conclusions: Compared with sham block, the combination of ultrasound-guided SPIP and RSB significantly enhanced postoperative recovery quality, provided superior analgesic efficacy, and reduced opioid consumption following cardiac surgery.

Background

With continuous improvements in living standards and healthcare, the annual number of patients undergoing cardiac surgery has been steadily increasing [1]. Patients undergoing sternotomy for cardiac procedures frequently experience moderate to severe postoperative pain. Inadequate acute pain management following surgery may lead to increased risks of postoperative complications, higher incidence of cardiac adverse events, prolonged hospital stays, impaired early recovery quality, and elevated postoperative mortality [2–3]. Therefore, effective postoperative analgesia is essential to optimize recovery outcomes.

The development of advanced visualization techniques has established peripheral nerve blocks as a key component of multimodal analgesia due to their favorable safety and efficacy profiles [4, 5]. The superficial parasternal intercostal plane (SPIP) block is an effective and regional anesthesia technique for managing post-sternotomy pain. This technique involves depositing local anesthetic in the plane between the pectoralis major muscle (PAM) and the internal intercostal muscles (IIM), targeting the anterior cutaneous branches of the T2–T6 intercostal nerves to provide sensory blockade of the anterior chest wall [6]. Because the needle insertion remains superficial to the ribs, the risk of inadvertent pleural puncture or internal thoracic artery injury is minimized [7]. Additionally, the superficial injection site allows for easier ultrasound visualization in most patients, making the block relatively straightforward to perform. Clinical Studies confirm that the SPIP block provides effective analgesia and reduces opioid consumption [8–10].

However, post-cardiac surgery pain in the upper abdominal region is often overlooked and is primarily attributed to thoracic drainage tubes [11]. The analgesic coverage provided by the SPIP block is insufficient to address discomfort originating from the upper abdominal surgical site and drainage tube insertion points. Recent studies demonstrate that ultrasound-guided rectus sheath block (RSB) effectively alleviates upper abdominal postoperative pain, reduces opioid requirements, and facilitates early mobilization and coughing exercises [12, 13]. Combining the SPIP and RSB techniques can therefore provide continuous analgesic coverage for both the sternal incision and drainage tube regions, offering more comprehensive pain management, optimizing analgesic protocols, and ultimately accelerating early recovery in cardiac surgery patients.

Therefore, we designed this randomized, sham-controlled trial to test the hypothesis that the combination of ultrasound-guided SPIP and RSB, compared to sham blocks, would improve the quality of early postoperative recovery, assessed by the QoR-15 score at 48 hours, in patients undergoing cardiac surgery via median sternotomy.

Materials and methods

Design and patients This single-center randomized clinical trial was approved by the Ethics Committee of Xuzhou Central Hospital, China (Approval No.: XZXY-LJ-20200315-088). Written informed consent was obtained from all participants. The study protocol was prospectively registered at the Chinese Clinical Trial Registry (http://www.chictr.org.cn, Identifier: ChiCTR2200056745) on February 13, 2022. The study complies with the Declaration of Helsinki and the Consolidated Standards of Reporting Trials (CONSORT) statement [14].

Patients aged over 18 years with American Society of Anesthesiologists (ASA) physical status III- undergoing cardiac surgery via median sternotomy were eligible for participation. Exclusion criteria included: allergy to local anesthetics; psychiatric disorders; hematologic diseases; cognitive impairment (inability to assess the Verbal Numerical Rating Scale for pain); alcohol/drug abuse and/or daily opioid

use; severe hepatic or renal dysfunction; surgery cancellation; change in surgical approach; patient death; or patient/family request for study withdrawal.

Randomization and blinding Patients were randomized in a 1:1 ratio to either the experimental group (SPIP + RSB group) or saline group (control group) using a computer-generated randomization table. The randomization sequence was concealed in sequentially numbered, sealed, opaque envelopes, which were opened by an independent researcher responsible for preparing either 0.3% ropivacaine (for the SPIP + RSB group) or saline (for the control group) according to group assignment. Throughout the observation period, all participants, surgeons, anesthesiologists, and outcome assessors remained blinded to group allocation.

AnesthesiaAll patients underwent standard cardiac surgery monitoring including electrocardiography, oxygen saturation (SpO_2), invasive arterial blood pressure, central venous pressure, end-tidal carbon dioxide ($EtCO_2$), core temperature, and urine output. Anesthesia induction was achieved with midazolam (0.05–0.1 mg/kg), sufentanil (3–4 μg/kg), etomidate (0.3 mg/kg), and cisatracurium (0.3 mg/kg). Maintenance anesthesia consisted of sufentanil, propofol, and cisatracurium titrated to maintain bispectral index (BIS) values between 40 and 60 in both groups. Anesthetic doses and vasoactive agent titration were guided by hemodynamic variables and determined at the discretion of the attending anesthesiologist.

InterventionTwenty minutes prior to anesthesia induction, the anesthesiologist performed bilateral superficial parasternal intercostal nerve blocks using a high-frequency linear ultrasound transducer. The probe was positioned parasagittally 1–2 cm lateral to the sternum between the fourth and fifth intercostal spaces, where a 22-gauge, 80-mm peripheral nerve block needle was advanced in-plane from caudal to cephalad into the fascial plane between the pectoralis major and intercostal muscles. Needle tip placement was confirmed by test injection of 1–3 mL of 0.9% saline, with observation of appropriate inter-fascial spread under real-time ultrasound guidance. Subsequently, 20 mL of 0.3% ropivacaine with 1 mg dexamethasone (or saline) was injected per side, and successful blockade was confirmed by observed pleural displacement during injection [15, 16].

At the conclusion of surgery, the anesthesiologist performed bilateral rectus sheath blocks targeting the anterior cutaneous branches of the T6–T10 intercostal nerves by placing the ultrasound transducer transversely above the umbilicus and below the drainage tube. A peripheral nerve block needle was carefully advanced in-plane from lateral to medial through the anterior rectus sheath and rectus abdominis muscle until reaching the fascial plane between the rectus abdominis and posterior rectus sheath. Following negative aspiration, 10 mL of 0.3% ropivacaine (or saline) was injected, with successful blockade confirmed by fascial separation under ultrasound visualization. To ensure protocol adherence and minimize bias risk, all nerve blocks were performed exclusively by experienced anesthesiologists.

Postoperatively, patients were transferred to the intensive care unit (ICU) for extubation and further management, with analgesia provided as needed. All patients received patient-controlled intravenous

analgesia (PCIA) with sufentanil (2 μg/kg diluted in 0.9% saline to a total volume of 100 mL), programmed to deliver 0.5 mL per demand dose with a 15-minute lockout interval. All surgical procedures and cardiopulmonary bypass were performed by the same surgical team.

Outcomes assessment

The primary outcome was the Quality of Recovery-15 (QoR-15) score at 48 hours postoperatively, which assesses recovery quality following surgery and anesthesia through five patient-reported dimensions: pain, physical comfort, physical independence, psychological state, and emotional status. The QoR-15 total score ranges from 0 to 150, with higher scores indicating better recovery, and can be completed within 2–5 minutes by trained assessors[17]. The QoR-15 is internationally recommended as a validated endpoint for postoperative recovery due to its efficiency, reliability, and reproducibility, as endorsed by international consensus guidelines[18–20]

The secondary outcomes included the QoR-15 scores at 72 hours postoperatively; NRS pain scores within the first 48 hours postoperatively (assessed immediately after extubation, and at 12, 24, and 48 hours postoperatively); postoperative opioid consumption within 48 hours (converted to morphine equivalents); time to extubation and duration of hospitalization (ICU length of stay and total postoperative hospital stay); time to first exhaust, first incentive spirometer exercise, and first ambulation; and 6MWT performance at discharge. Additionally, vital signs, specifically heart rate (HR) and mean arterial pressure (MAP), were recorded at predefined time points: T0 (entry)), T1 (pre-incision), T2 (post-incision), T3 (post-sternotomy), and T4 (end of surgery). Opioid-related adverse events and nerve block-related complications were also documented.

Sample Size Calculation

The determination of the minimum sample size was based on the postoperative 48-hour QoR-15 scores of patients, where an 8-point difference has been widely recognized as the minimal clinically important difference (MCID) for perioperative interventions on the QoR-15 scale[22]; previous studies reported a mean QoR-15 score of 90 at 48 hours postoperatively in cardiac surgery patients, and assuming a clinically relevant increase to 98 points with a standard deviation of 15[22]. Using a significance level of $\alpha = 0.05$ and a power of 0.9, sample size calculations via PASS 15.0 statistical software (NCSS, LLC) determined that 75 participants were required per group. The sample size was further adjusted to 89 participants per group, accounting for an anticipated 15% dropout rate.

Statistical analysis

Statistical analyses were performed using SPSS 25.0 software to compare quantitative variables between groups. Normality of distribution was assessed using the Shapiro-Wilk test. Based on the distribution, group comparisons were conducted using the Student’s t-test for normally distributed data or the Mann-Whitney U test for non-normally distributed data. Categorical variables and proportions were

compared between groups using the chi-square test or Fisher's exact test, as appropriate. For repeated measures data, generalized estimating equations (GEE) were used to account for within-subject correlation, providing more precise estimates of the population-averaged parameters and their standard errors. A two-tailed test was applied for all statistical significance assessments, with a *P* value of < 0.05 considered statistically significant.

Results

Patients'characteristics

A total of 234 patients underwent initial screening. Subsequently, 56 patients were excluded due to failure to meet the inclusion criteria or other reasons. The remaining 178 patients were randomized to receive the study intervention. In the control group, 5 patients were excluded because of delayed extubation secondary to low cardiac output, withdrawal prior to study initiation, or death in the ICU. In the SPIP + RSB group, 4 patients were excluded due to the need for a second surgical intervention or withdrawal prior to study initiation. Consequently, 169 patients completed the study protocol and were included in the final analysis. The participant flow is detailed in Fig. 1. Baseline and demographic characteristics were well balanced between the two groups, as presented in Table 1.

Table 1. Patient Characteristics and Operative Details

Characteristic	Group control（n=84）	Group SPIP+RSB (n=85)	*p*-Value
Age,years	64.40±7.648	65.13±7.356	0.531
Sex(male/female)	48/36	53/32	0.532
BMI, kg/m2	22.97±3.17	23.36±2.83	0.401
ASA classification (III/Ⅱ)	52/32	50/35	0.683
NYHA classification (Ⅱ/Ⅲ/Ⅳ)	22/58/4	20/62/3	0.818
Type of surgery CABG/valve/ Combined	52/22/10	50/26/9	0.775
Operation with CPB,n(%)	37(44.0)	36(42.4)	0.877
Surgical time, min	252.62±44.10	260.95±45.87	0.230
Duration of CPB, min	110.62±13.13	115.67±15.88	0.143

Data are mean ± SD, number (proportion), or median (IQR).

Outcomes

Quality of Recovery-15 (QoR-15) scores are summarized in Table 2, and the distribution of QoR-15 scores is shown in Fig. 2. Statistically significant differences in QoR-15 scores were observed between the two groups at both 48 hours postoperatively (SPIP + RSB: 89.2 ± 7.3 vs. Control: 95.6 ± 7.5; 95% confidence interval [CI], -8.7 to -4.2; $P < 0.001$) and 72 hours postoperatively (SPIP + RSB: 110.7 ± 9.4 vs. Control: 103.8 ± 7.9; 95% CI, -9.6 to -4.3; $P < 0.001$). Analysis of the five QoR-15 dimensions revealed that at 48 hours postoperatively, the SPIP + RSB group had significantly higher scores than the control group in physical comfort ($P < 0.001$), pain ($P < 0.001$), and emotional state ($P = 0.001$). This superiority of the SPIP + RSB group persisted at 72 hours postoperatively for physical comfort ($P = 0.002$), pain ($P < 0.001$), and emotional state ($P < 0.001$).

Table 2
QoR-15 socres between two group

QoR-15 scores at 48h	**Group control (n = 84)**	**Group SPIP + RSB (n = 85)**	**Difference(95%CI)**	***P*-Value**
Physical comfort	27.4 ± 3.8	32.2 ± 4.7	-4.8(-6.1- -3.5)	< 0.001
Physical independence	2(1)	2(1)	0(0–0)	0.247
Physical support	18(1)	19(1)	0(0–0)	0.524
pain	14(1)	16(2)	-2(-2- -1)	< 0.001
Emotional status	27(3)	28(3.5)	-1(-2- 0)	0.001
Total QoR-15	89.2 ± 7.3	95.6 ± 7.5	-6.4(-8.7- -4.2)	< 0.001
QoR-15 scores at 72h				
Physical comfort	35.0 ± 4.6	37.1 ± 4.4	-2.2(-3.6- -0.8)	0.002
Physical independence	2(1)	2(1)	0(0–0)	0.428
Physical support	20(1)	20(1)	0(0–0)	0.784
Pain	17(2)	19(2)	-2(-2- -2)	< 0.001
Emotional status	32(4)	33(2.75)	-2(-3- -1)	< 0.001
Total QoR-15	103.8 ± 7.9	110.7 ± 9.4	-6.9(-9.6- -4.3)	< 0.001

Data are mean ± SD, median (IQR) SD standard deviation, IQR interquartile range, CI confidence interval

As demonstrated in Table 3, pain scores immediately following extubation were significantly lower in the SPIP + RSB group compared with the control group (*P* = 0.006). Likewise, the SPIP + RSB group reported progressively lower pain scores than the control group at 12 hours (*P* = 0.030), 24 hours (*P* = 0.010), and 48 hours (*P* = 0.037) postoperatively (Table 3). Consistent with these findings, cumulative 48-hour opioid consumption was significantly reduced in the SPIP + RSB group (62.1 ± 5.7 mg vs. 42.7 ± 6.6 mg; 95% CI, 17.4 to 21.2; P < 0.001; Table 3).

Table 3
Secondary outcomes.

Postoperative pain	**Group control (n = 84)**	**Group SPIP + RSB (n = 85)**	**Difference (95%CI)**	***P*-Value**
Immediately after extubation	4(1)	4(2)	1(0–1)	0.006
12 hours post-surgery	4(2)	3(2)	1(0–1)	0.030
24 hours post-surgery	2(2)	2(1)	1(0–1)	0.010
48 hours post-surgery	2(2)	1(1)	0(0–1)	0.037
Opioid consumption within 48h, mg	62.1 ± 5.7	42.7 ± 6.6	19.3(17.4–21.2)	< 0.001
Time to extubation,h	9.2 ± 1.8	8.7 ± 1.9	0.49(-0.07-1.07)	0.086
Duration of ICU stay,h	40.5 ± 3.1	38.5 ± 3.1	2.0(1.05–2.92)	< 0.001
Time to exhaust,h	33.1 ± 3.6	31.8.0 ± 3.4	1.3(0.27–2.39)	0.014
Time to first incentive spirometer exercises,h	32.0 ± 4.2	30.6 ± 3.8	1.4(0.15–2.57)	0.027
Time to first ambulation	61.2 ± 5.9	53.7 ± 4.5	7.4(5.8-9.0)	< 0.001
Duration of postoperative stay,days	14(3)	13(5.5)	1(0–2)	0.002
6MWT, meters	144.0 ± 8.4	160.5 ± 9.7	-16.5(-19.3–13.7)	< 0.001

Data are mean ± SD, median (IQR). SD standard deviation, IQR interquartile range, CI confidence interval

Although there was no significant difference in time to extubation between the two groups (*P* = 0.086), patients who received SPIP + RSB had significantly shorter intensive care unit (ICU) stays (*P* < 0.001) and a reduced total postoperative hospital length of stay (*P* = 0.002). Additionally, compared with the control

group, the SPIP + RSB group initiated incentive spirometer exercises ($P = 0.027$), exhaust ($P = 0.014$), and ambulation ($P < 0.001$) significantly earlier. At the time of discharge, the SPIP + RSB group also achieved a significantly greater 6-minute walk test (6MWT) distance than the control group ($P < 0.001$). Detailed comparisons of all postoperative outcome data are presented in Table 3.

No statistically significant differences in MAP were observed between the control and SPIP + RSB groups at time points T1 and T4 ($P > 0.05$). In contrast, the control group exhibited significantly higher MAP at T2 and T3 compared with the SPIP + RSB group ($P < 0.001$). Additionally, HR was significantly elevated in the control group at all time points (T1, T2, T3, and T4; $P < 0.001$). Detailed comparisons of HR and MAP are illustrated in Fig. 3.

The incidence of postoperative nausea and vomiting (PONV) ($P = 0.049$) and pulmonary complications ($P = 0.038$) was significantly lower in the SPIP + RSB group. No significant difference was observed in the rate of postoperative delirium between the groups ($P = 0.496$). Importantly, no nerve block-related adverse events were documented in either group during the study period. Detailed comparisons of all postoperative complications data are presented in Table 4.

Table 4
Postoperative complications and Adverse events

Postoperative delirium,n(%)	**Group control (n = 84)**	**Group SPIP + RSB (n = 85)**	***P*-Value**
	5(6.0)	**3(3.5)**	**0.496**
Nausea and vomiting,n(%)	13(15.5)	5(5.9)	0.049
Pulmonary complications,n(%)	15(17.9)	6(7.1)	0.038
Block-related complications, n (%)			
Pneumothorax	0	0	1
Hematoma	0	0	1
Local anesthetic systemic toxicity	0	0	1

Data are mean ± SD, median (IQR). SD standard deviation, IQR interquartile range, CI confidence interval

Discussion

This study demonstrates that the combination of ultrasound-guided SPIP and RSB significantly enhances the quality of early recovery after cardiac surgery, as evidenced by improved QoR-15 scores, reduced postoperative pain, decreased opioid consumption, earlier incentive spirometry use, and better performance in the 6MWT. These findings support the integration of regional anesthesia techniques within a multimodal analgesic framework in cardiac surgery.

Pain management after cardiac surgery presents unique challenges. The combined effect of anterior chest wall pain from sternotomy and upper abdominal discomfort from thoracic drainage tubes can significantly restrict respiratory [23]. Severe pain may also contribute to pathological anxiety, emotional disturbances, sleep deprivation, and is associated with an increased risk of delirium perioperative. [24, 25]. The SPIP block effectively covers the sternal incision area by anesthetizing the anterior cutaneous branches of the T2–T6 intercostal nerves. Complementing this, the rectus sheath block (RSB)—a technique with well-established analgesic efficacy in abdominal surgery—targets the T6–T10 branches, providing coverage for upper abdominal drainage-related pain [26, 27]. This synergistic effect was reflected in our study by significantly lower NRS pain scores at 12 to 48 hours postoperatively and reduced opioid consumption. Lower opioid use decreases the risk of side effects such as respiratory depression, nausea, and vomiting [28, 29], which aligns with the observed reduction in postoperative nausea and vomiting and pulmonary complications in the SPIP + RSB group. Although the incidence of delirium did not differ significantly between groups, fewer cases were reported in the SPIP + RSB group.

The improvement in recovery quality attributable to the combined block was reflected across multiple domains of the QoR-15 score, with notable enhancements in physical comfort and pain control, underscoring its specific benefits for cardiac surgery patients. Effective analgesia early after surgery is essential to encourage patient participation in breathing exercises and early mobilization, both of which are critical for preventing pulmonary complications and maintaining hemodynamic stability [30–32]. In this study, patients in the SPIP + RSB group initiated breathing exercises, flatus passage and ambulation earlier, demonstrated a significantly longer 6-minute walking distance at discharge, and exhibited improved cardiopulmonary reserve. These outcomes suggest a positive impact on overall functional status beyond pain reduction alone. Intraoperatively, attending anesthesiologists adjusted the anesthetic depth based on BIS values and clinical conditions, while heart rate HR and MAP were continuously monitored. During skin incision and sternotomy, the SPIP + RSB group showed lower HR and MAP variability relative to the control group, indicating that combined SPIP and RSB effectively maintained stable intraoperative hemodynamics. Although no significant difference was observed in the duration of mechanical ventilation between groups, patients receiving the combined block experienced easier spontaneous breathing after extubation, likely due to improved pain control reducing respiratory muscle effort and oxygen consumption. This effect may provide particular clinical benefit for patients with impaired cardiac function by indirectly supporting myocardial protection [33].

The combination of SPIP and RSB for cardiac surgery creates a continuous analgesic band from the sternum to the upper abdomen. The clinical value of this approach is demonstrated by the observed reductions in both ICU and total hospital length of stay, outcomes that align closely with the principles of Enhanced Recovery After Cardiac Surgery (ERACS) [34]. ERAPS emphasizes multimodal interventions to reduce surgical stress. As a core element of this strategy, regional anesthesia not only attenuates the stress response directly through effective analgesia but also facilitates early mobilization and improves respiratory function. This creates a positive cycle that ultimately accelerates the overall recovery process.

Although thoracic paravertebral block (TPVB) provides a comparable analgesic range and is commonly used for post-cardiac surgery pain relief, its procedure-related risk of pneumothorax can be life-threatening in patients undergoing cardiopulmonary bypass [35, 36]. In contrast, both the SPIP and RSB are superficial blocks. No block-related adverse events were observed in this study, confirming their safety advantage in cardiac surgery, where systemic anticoagulation is routinely used.

Several limitations of this study should be acknowledged. First, as a single-center trial, the results may be influenced by local clinical practices, which could limit their generalizability. Second, although the QoR-15 score reflects early recovery quality, it does not assess long-term outcomes such as quality of life at three months postoperatively. Larger multicenter trials are needed to validate these findings in broader populations and to evaluate long-term effects. Despite these limitations, this study provides valuable clinical evidence supporting the combined use of SPIP and RSB as a preferred analgesic strategy for patients undergoing cardiac surgery via sternotomy.

Conclusions

The combination of SPIP and RSB provides precise coverage of the anatomical sources of pain after cardiac surgery, significantly enhancing early recovery quality. This combined regional technique is both safe and effective, representing a valuable component of multimodal analgesic management to promote recovery after cardiac surgery.

Abbreviations

BMI Body mass index;

NYHA New York Heart Association;

CABG Coronary artery bypass graft;

CPB Cardiopulmonary Bypass;

SPIP Superficial parasternal intercostal plane;

RSB Rectus sheath block;

QoR-15 Quality of Recovery-15.

ICU Intensive Care Unit;

6MWT 6-minute walk test;

Declarations

Authorship contributions

Conceptualization, Y. Qi and L.W. Wang; methodology, R.G. Wang and L. Yan; investigation, M.Y. Zhou, Y.H. Zhang, R.G. Wang, L. Yan and Q. Liu; data curation, Q. Liu; validation, Z. Zhang; formal analysis, Z. Zhang; writing—original draft preparation, M.Y. Zhou and Y.H. Zhang; writing—review and editing, Y. Qi and L.W. Wang. All authors have read and agreed to the published version of the manuscript.

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Data availability

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate

This study received approval from the institutional research ethics committee of Xuzhou Central Hospital, China (No. XZXY-LJ-20200315-088). Written informed consent was obtained from all participants prior to their involvement. The study was conducted in strict adherence to the Declaration of Helsinki. The study protocol was prospectively registered at the Chinese Clinical Trial Registry (http://www.chictr.org.cn, Identifier: ChiCTR2200056745) on February 13, 2022.

Consent for publication

Not applicable

Competing interests

The authors declare no competing interests.

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Figures

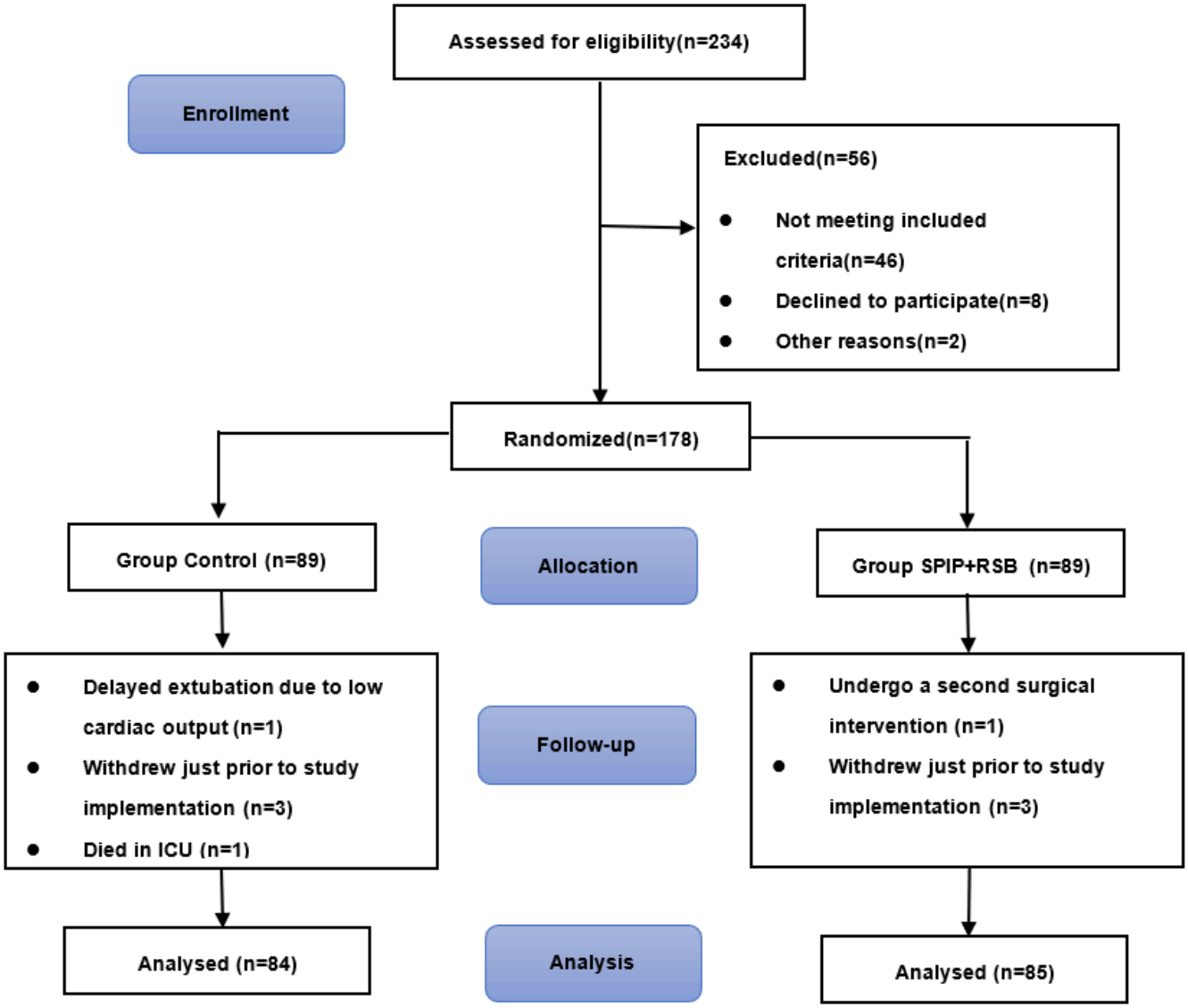


Figure 1

Flow diagram of subject enrolment and analysis.

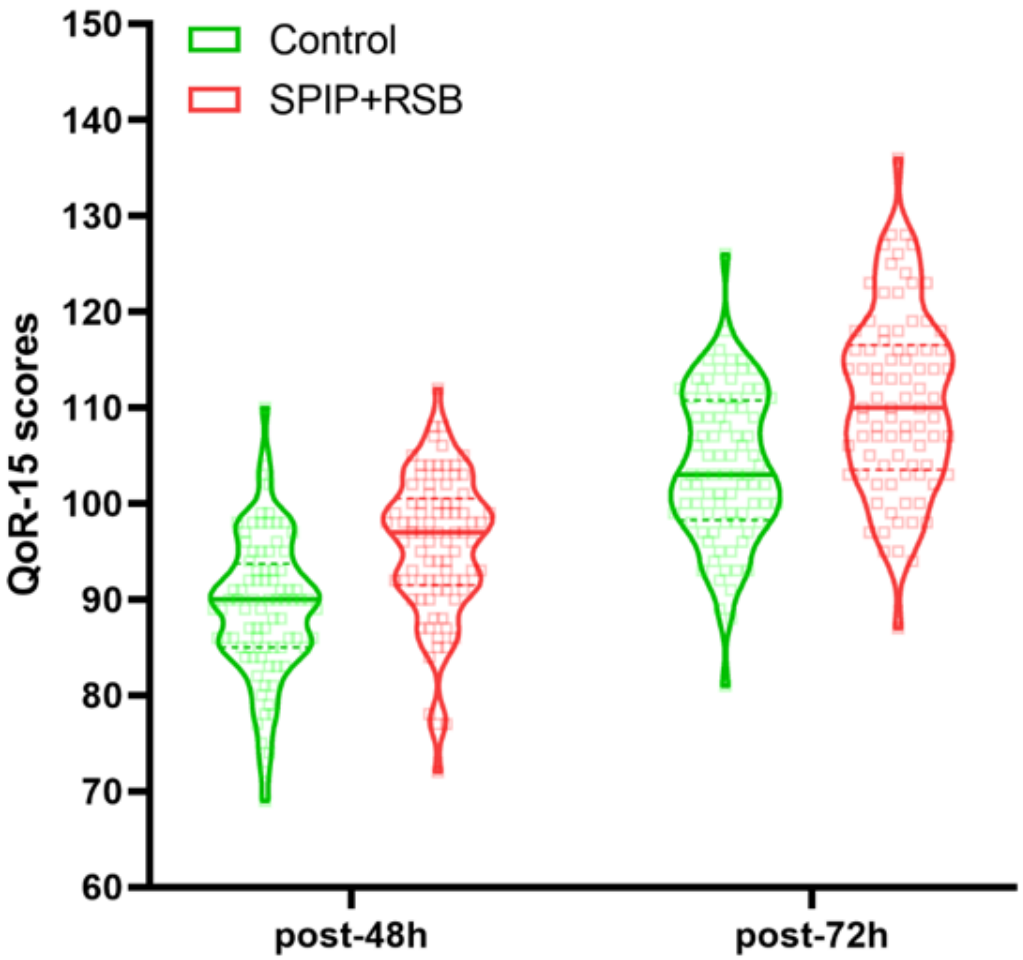


Figure 2

QoR-15 total by group and postoperative day. Violin plots show the QoR-15 distribution. Violin width indicates distribution density; the central lines represent the median and interquartile range of each group; individual data points are shown as square.

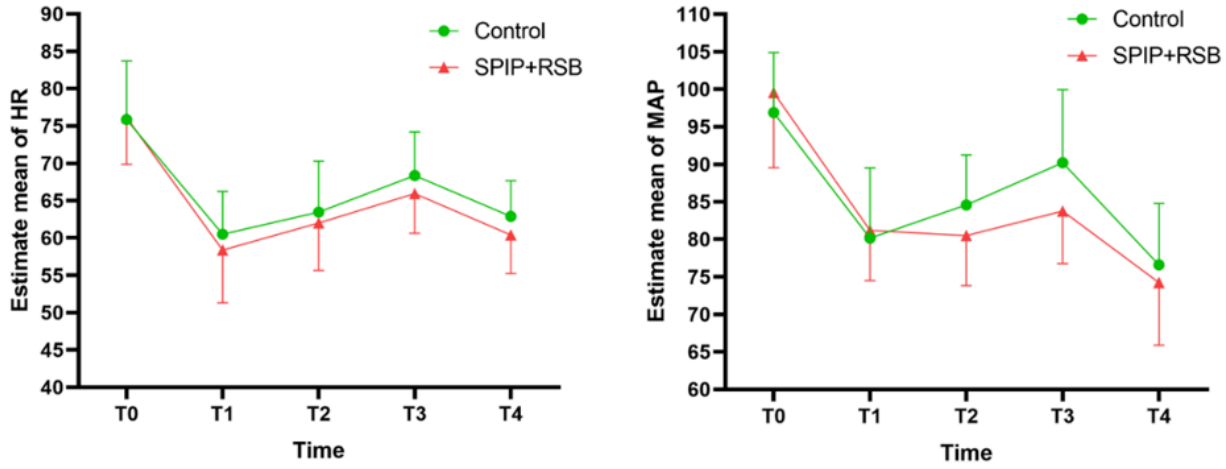


Figure 3

GEE-analyzed estimate mean of HR and MAP, T0(entry), T1 (pre-incision), T2 (post-incision), T3 (post-sternotomy), T4 (end of surgery).