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ORIGINAL RESEARCH

Ultrasound-Guided Erector Spinae Plane Block and Subcostal Transversus Abdominis Plane Block for Postoperative Analgesia in Laparoscopic Liver Resection: A Three-Arm Randomized Controlled Trial

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Background: Laparoscopic liver resection (LLR) is widely performed for the treatment of liver diseases. Effective postoperative pain control is essential, particularly in patients vulnerable to opioid-related complications due to impaired hepatic function. This study compared the analgesic efficacy and recovery outcomes of ultrasound-guided erector spinae plane block (ESPB) and subcostal transversus abdominis plane block (TAPB) in patients undergoing LLR.

Methods: In this single-center randomized controlled trial (ChiCTR2300078378), 120 patients scheduled for LLR were randomly allocated to receive ESPB, subcostal TAPB, or standard care (CON). The primary outcomes were postoperative pain scores at rest and during coughing. Secondary outcomes included cumulative opioid consumption, time to first patient-controlled intravenous analgesia (PCIA) activation, rescue analgesia use, and effective PCIA requests. Early recovery outcomes included time to ambulation, first flatus, length of hospital stay, Quality of Recovery-15 (QoR-15) scores, and adverse events.

Results: All 120 patients were included in the analysis. Significant time-by-group interactions were observed for postoperative NRS pain scores at rest and during coughing (P=0.004 and P = 0.003). At 2 hours postoperatively, the estimated mean differences in coughing NRS score were −1.03 points (95% CI, −1.60 to −0.45; P < 0.001) for subcostal TAPB versus CON and −1.15 points (95% CI, −1.73 to −0.57; P < 0.001) for ESPB versus CON. The estimated difference between ESPB and subcostal TAPB was −0.13 points (95% CI, −0.70 to 0.45; P = 1.000). Both blocks reduced cumulative opioid consumption, prolonged time to rescue analgesia, and decreased rescue analgesia events and effective PCIA demands. QoR-15 scores at 24 hours were higher in both block groups compared with control, whereas scores at 30 days were similar among groups. No significant between-group differences were observed in the recorded adverse events.

Conclusion: In this single-center randomized trial, both subcostal TAPB and ESPB provide effective opioid-sparing analgesia and improve early recovery after LLR. Neither technique demonstrated consistent superiority across postoperative pain trajectories, suggesting that either block can be incorporated into multimodal analgesia strategies for LLR.

Keywords: erector spinae plane block, transversus abdominis plane block, laparoscopic liver resection, opioid, analgesia

Introduction

Since its introduction by Gagner[1] in 1992, laparoscopic liver resection (LLR) has become widely utilized for the surgical management of intrahepatic bile duct stones, benign liver tumors, hepatocellular carcinoma (HCC), and metastatic liver disease. Accumulating evidence indicates that, compared with open hepatectomy, LLR is associated with favorable

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perioperative outcomes such as decreased intraoperative blood loss, lower surgical morbidity, shorter hospitalization, and accelerated postoperative recovery.[2] Despite these benefits, perioperative analgesic management and the quality of postoperative recovery remain important clinical challenges.[3]

Postoperative pain following laparoscopic liver resection is multifactorial, comprising visceral pain from hepatic manipulation, somatic pain arising from surgical incisions, and referred pain secondary to diaphragmatic irritation.[4] The interplay of these pain mechanisms presents a significant challenge in effective pain management.[5] Current analgesic approaches include systemic analgesics, local anesthetic infiltration, and various regional anesthesia techniques.[6] Although opioids remain a mainstay of analgesia after abdominal surgery, reduced functional liver volume and underlying hepatic dysfunction may impair their metabolism and increase the risk of adverse effects.[7,8] Opioid-induced sedation, nausea and vomiting, respiratory depression, and gastrointestinal dysfunction may impede early mobilization, oral intake, and return of bowel function. Opioid-sparing multimodal analgesia is therefore integral to enhanced recovery pathways for liver surgery, providing effective pain control while facilitating early mobilization, enteral nutrition, and timely functional recovery.[9]

Current guidelines for pain management following hepatectomy recommend local anesthetic infiltration or interfascial plane blocks as effective analgesic options. Nevertheless, the most appropriate fascial plane block for laparoscopic liver surgery remains a subject of debate. Transversus abdominis plane block (TAPB) is frequently incorporated into perioperative analgesic strategies for abdominal surgery, including as part of multimodal analgesia in laparoscopic procedures.[10] TAPB achieves somatic analgesia of the anterior abdominal wall through deposition of local anesthetic within a targeted abdominal wall interfascial compartment. The subcostal approach primarily targets the anterior rami supplying the upper abdominal wall and generally provides somatic analgesia across the upper abdominal dermatomes, with reported coverage extending approximately from T6 to T10 depending on the injection site and technique.[11] Previous studies have shown that TAPB effectively alleviates perioperative pain, reduces opioid consumption, and enhances patient satisfaction in laparoscopic surgery.[12] However, because its analgesic action is predominantly somatic, its effectiveness in controlling visceral nociception is less consistent.[13,14]

Erector spinae plane block (ESPB) has emerged as an alternative regional analgesic approach for thoracic and abdominal procedures since its initial clinical application.[15] Local anesthetic is deposited within the paraspinal fascial plane, allowing cranio–caudal spread across multiple thoracic segments. When performed at the T8 level, ESPB may provide multisegmental analgesia through fascial spread and possible extension toward the intercostal, paravertebral, and sympathetic pathways, although the extent of spread may vary among patients. This relatively straightforward technique may therefore be suitable for surgical procedures involving multiple thoracoabdominal dermatomes.[16,17] Previous studies suggest that ESPB may alleviate both somatic and visceral pain, potentially through extension of local anesthetic toward the paravertebral space, thereby improving the quality and duration of postoperative analgesia.[18,19]

Previous systematic reviews directly comparing ESPB with TAPB in abdominal surgery found that ESPB was associated with statistically lower postoperative pain scores and opioid consumption. However, the magnitude of these differences was generally small and did not consistently reach thresholds for clinical importance. Similar findings have been reported in randomized trials involving other laparoscopic abdominal procedures.[20,21] Nevertheless, the available evidence is derived predominantly from non-hepatic surgery, and its applicability to LLR remains uncertain because of the distinct combination of abdominal wall, visceral, and diaphragmatic pain following liver resection. Therefore, this randomized controlled trial aimed to compare postoperative analgesia, opioid consumption, and recovery outcomes among ultrasound-guided subcostal TAPB, ESPB or standard care without a regional block in patients undergoing LLR. We hypothesized that both TAPB and ESPB would improve postoperative analgesia and reduce opioid requirements compared with standard care. Given the proposed broader somatic and visceral analgesic coverage of ESPB, we also explored whether ESPB provided additional analgesic or recovery benefits compared with TAPB.

Methods

Study Design

Ethical approval for this single-center randomized controlled trial was granted by the Ethics Committee of the Second Affiliated Hospital of Anhui Medical University, Hefei, China (Approval No. YX2023-182(F1)). The trial was prospectively registered with the Chinese Clinical Trial Registry on December 6, 2023 (ChiCTR2300078378), with participant enrollment commencing on the same day. All participants provided written informed consent before enrollment.

Patient Recruitment

Adult patients scheduled for laparoscopic liver resection at the Second Affiliated Hospital of Anhui Medical University were screened for study participation. In accordance with the registered eligibility criteria, patients were eligible if they were aged 18–80 years, had an American Society of Anesthesiologists physical status of I–III, a body mass index of 18–30 kg/m^2, and Child–Pugh class A liver function. Patients with a history of mental illness, hearing impairment, or language impairment that could interfere with communication or postoperative outcome assessment were not eligible. Exclusion criteria included a history of abdominal surgery, preoperative chemotherapy or immunosuppressive therapy, allergy to local anesthetics or opioids, infection at the intended puncture site, coagulation dysfunction, severe dysfunction of the heart, lung, liver, or kidney, peripheral nervous system disease, and chronic pain or persistent analgesic use before surgery.

During post-enrollment data verification, five patients were identified as having Child–Pugh class B liver function. These patients had been inadvertently enrolled because they were misclassified as having Child–Pugh class A liver function during eligibility screening. All five patients were clinically stable and had been considered suitable for laparoscopic liver resection and regional anesthesia based on routine preoperative surgical and anesthetic assessment. No patients with Child–Pugh class C liver function or severe hepatic dysfunction were enrolled. Because the trial registry specified Child–Pugh class A liver function as an eligibility criterion, the inclusion of these five patients was treated as an eligibility-related protocol deviation. A sensitivity analysis was subsequently performed after excluding them.

Blind and Randomization

Patients were randomly assigned in a 1:1:1 ratio to receive ultrasound-guided ESPB (ESPB group), subcostal TAPB (TAPB group), or no block (CON group) using computer-generated randomization (SPSS version 26.0; IBM, Armonk, NY, USA). The randomization list was prepared by an independent assistant not involved in the study, and group allocations were concealed in sealed, opaque, sequentially numbered envelopes. All participants were transferred to the pre-anesthesia holding area before surgery, where routine preoperative preparation was completed and peripheral venous and arterial access was established. An independent consultant anesthesiologist with experience in more than 200 TAPB and ESPB procedures, but otherwise uninvolved in the trial, opened the envelope immediately before performing the assigned block. Surgeons and attending anesthesiologists remained blinded during surgery; postoperative care nurses and outcome assessors remained blinded throughout follow-up, and statistical analysts remained blinded until completion of the analyses. Complete participant blinding could not be ensured because of the nature of the interventions.

Analgesic Technique

After arrival in the preoperative area, intravenous access was secured and patients received premedication with midazolam (0.02 mg/kg) and sufentanil (0.1 μg/kg). Patients were managed with standard intraoperative monitoring, including heart rate, electrocardiography, noninvasive blood pressure, and pulse oximetry, together with invasive monitoring via radial arterial and right internal jugular venous catheterization for hemodynamic assessment. Ultrasound-guided TAPB or ESPB was then performed according to the allocated group. In this study, bilateral subcostal TAPB was used to provide perioperative analgesia for patients undergoing laparoscopic liver resection. With the patient supine, ultrasound was used to identify the relevant subcostal abdominal wall fascial plane, and a 22-gauge needle was advanced in-plane to the injection site. Correct needle placement was confirmed by negative aspiration and saline hydrodissection,

followed by injection of 20 mL of 0.33% ropivacaine on each side to achieve bilateral blockade. For patients allocated to the ESPB group, bilateral erector spinae plane blocks were performed at the T8 level. With the patient in the lateral decubitus position, ultrasound was used to identify the transverse process, and a 22-gauge needle was inserted in-plane to access the interfascial plane deep to the erector spinae muscle.[22] After confirmation of proper needle positioning, 20 mL of 0.33% ropivacaine was administered on each side to ensure bilateral analgesia. All blocks were performed by the same senior anesthesiologist. Although correct needle-tip position and local anesthetic spread within the intended fascial plane were confirmed under ultrasound guidance, systematic sensory mapping or dermatomal testing was not performed before induction.

General Anesthesia

Upon arrival in the operating room, standard monitoring was applied, including electrocardiography, pulse oximetry, mean arterial pressure, and bispectral index (BIS; VISTA monitoring system). General anesthesia was induced with intravenous midazolam, propofol, sufentanil, and rocuronium. Following tracheal intubation, mechanical ventilation was initiated using lung-protective settings, with tidal volumes of 6–8 mL/kg and end-tidal carbon dioxide maintained within the normal range. Anesthesia was maintained with sevoflurane inhalation combined with continuous infusions of propofol and remifentanil, titrated to achieve a BIS value between 40 and 60 throughout the procedure. Remifentanil infusion was titrated according to changes in heart rate and mean arterial pressure in response to surgical stimulation. Hemodynamic stability was preserved using fluids and vasoactive agents as needed to maintain heart rate and mean arterial pressure within 20% of baseline values. Neuromuscular blockade was maintained with a continuous infusion of cisatracurium at 1–2 μg/kg/min, guided by surgical requirements and clinical assessment. The cisatracurium infusion was discontinued approximately 30 min before the anticipated end of surgery. Nalbuphine (10 mg) was administered before surgical incision for preemptive analgesia, and granisetron was given near the end of surgery for prophylaxis against postoperative nausea and vomiting. No local anesthetic infiltration was performed at the trocar sites or specimen-extraction incision in any group.

Surgical Procedure

All operations were conducted under general anesthesia by surgeons with extensive experience in laparoscopic liver procedures.

Postoperative Analgesia and Management

After the surgery, all patients were transferred to the AICU for continued postoperative care and monitoring. Patient-controlled intravenous analgesia (PCIA) was administered according to the patient's requirements and continued for 48 hours post-initiation. All patients were provided with a standardized PCIA device immediately after surgery. The pump was preset to deliver a 2-mL bolus of sufentanil (1.5 μg/mL, total volume 100 mL) upon the first activation, followed by a continuous background infusion at 2 mL/h. Additional bolus doses of 1.2 μg were available at 15-minute lockout intervals. Patients were instructed to initiate PCIA when their NRS pain score (0 = no pain, 10 = worst imaginable pain) reached ≥4 or upon their own request. The device delivered a preset initial bolus upon first activation, and patients were encouraged to press the demand button again if pain persisted despite this initial dose. If three doses of sufentanil failed to relieve pain, 30 mg of pentazocine was administered intravenously as rescue analgesia. If pain persisted 30 minutes after pentazocine administration, an additional 50 mg bolus of intravenous tramadol was administered for further analgesia. Following transfer to the ward, patients continued PCIA and received intramuscular diclofenac sodium with lidocaine (75 mg) as rescue analgesia for breakthrough pain. After discontinuation of PCIA at 48 h postoperatively, the same rescue analgesic regimen was administered as needed until discharge.

The primary outcome was postoperative pain intensity assessed by the Numeric Rating Scale (NRS). The NRS pain scores during coughing and at rest were recorded at 2, 6, 12, 18, 24, and 48 hours postoperatively, as well as at discharge. The group difference in NRS pain score during coughing at 2 hours postoperatively was prespecified as a clinically relevant key time point for interpretation, reflecting early postoperative analgesic efficacy. Secondary outcomes comprised postoperative sufentanil consumption within the first 24 h, indicators of early recovery, and treatment-related

adverse events. The need for supplemental analgesia was assessed by the time to first opioid administration, duration of the initial rescue analgesic intervention, proportion of patients requiring rescue analgesia, and the total number of effective patient-controlled intravenous analgesia (PCIA) demands during the first 48 h after surgery. Early recovery was evaluated by the time to ambulation, time to first flatus, length of hospital stays, QoR-15 scores at 24 hours and 30 days post-surgery, and the occurrence of side effects such as PONV, itching, hypotension, respiratory depression, delirium and block-related complications during the follow-up period. Overall postoperative recovery was evaluated using the Quality of Recovery-15 (QoR-15) questionnaire, a patient-reported measure with total scores ranging from 0 to 150, where higher values reflect better recovery. The instrument captures multiple dimensions of postoperative health, encompassing pain, physical comfort, functional independence, psychological status, and emotional well-being, thereby providing a multidimensional overview of recovery quality. Postoperative nausea and vomiting (PONV) severity was graded on a five-point ordinal scale, with scores of 0 indicating no symptoms and increasing values representing progressively greater symptom severity, up to continuous vomiting at the highest score. Droperidol was administered for rescue treatment as needed for PONV management. Itching was defined as patient-reported pruritus that required treatment or interfered with comfort. Respiratory depression was defined as oxygen saturation below 90% despite supplemental nasal oxygen at 2 L/min, or a respiratory rate of fewer than 8 breaths per minute. Hypotension was defined as a mean arterial pressure below 60 mmHg requiring intravenous fluid administration or vasopressor support. Delirium was assessed during hospitalization using the Confusion Assessment Method (CAM), specifically the 3-Minute Diagnostic Interview for CAM-defined delirium (3D-CAM). A diagnosis was made according to established CAM criteria based on acute cognitive changes and inattention, with additional features supporting the diagnosis as appropriate.[23] Block-related complications were defined as adverse events directly attributable to the regional block, including local hematoma, vascular puncture, nerve injury symptoms (eg, persistent paresthesia, weakness), or local infection at the puncture site.

Statistical Analysis

The sample size was calculated using PASS software (version 15.0; PASS, NCSS, USA) for Windows. Although the primary outcome was postoperative pain intensity assessed at multiple time points, the NRS pain score during coughing at 2 hours postoperatively was prespecified as a clinically relevant and sensitive time point and was therefore used for sample size estimation. An unpublished pilot study conducted at our institution in 2023, including 13 patients in each group, provided the following preliminary estimates: the mean ± standard deviation (SD) of the NRS pain score during coughing at 2 h postoperatively was 4.46 ± 0.78 for the TAPB group, 4.38 ± 0.65 for the ESPB group, and 5.15 ± 0.90 for the CON group. Assuming a two-sided alpha level of 0.05, a statistical power of 90%, and allowing for a 20% dropout rate, the final required sample size was 40 patients per group, resulting in a total of 120 participants.

Statistical analyses were performed using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA). Data distribution was examined visually using histograms and quantile–quantile plots. Continuous variables are reported as mean with standard deviation or median with interquartile range, as appropriate. Between-group comparisons were conducted using analysis of variance for normally distributed data and the Kruskal–Wallis test for non-normally distributed data, with adjustment for multiple comparisons using the Bonferroni method. Categorical variables were analyzed using the chi-square test or Fisher's exact test when applicable. Longitudinal postoperative pain scores assessed by the numeric rating scale (NRS), both at rest and during coughing, were analyzed using linear mixed-effects models to explore differences in pain trajectories among groups. The models included intervention group, time, and their interaction as fixed effects, with patient-specific random intercepts to account for within-subject correlation. Post hoc pairwise comparisons were performed with Bonferroni adjustment when overall group effects were observed. No imputation was performed for missing outcome data. Outcomes with missing observations were analyzed using available cases. To assess the potential influence of the eligibility-related protocol deviation, a sensitivity analysis was performed after excluding the five patients with Child–Pugh class B liver function, and the same statistical methods were repeated in the remaining Child–Pugh class A population. All tests were two-sided, and $P < 0.05$ was considered statistically significant.

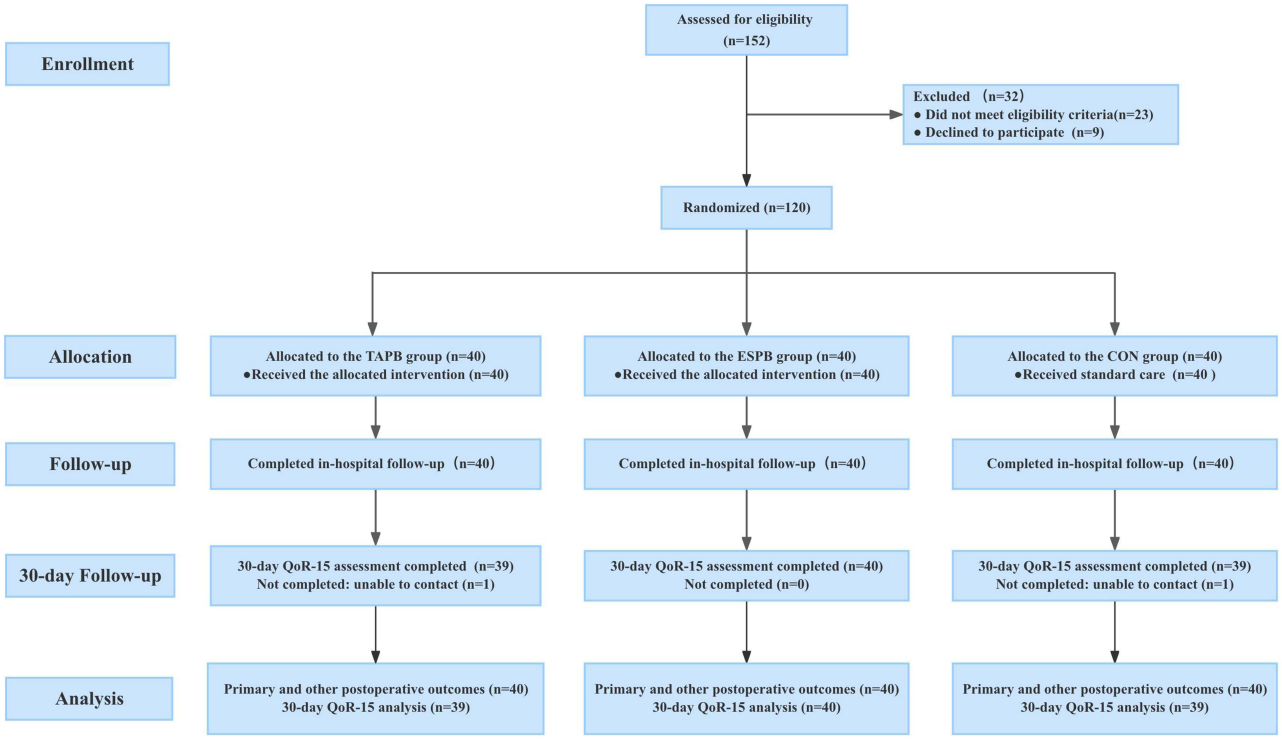

Figure 1 CONSORT flow diagram of participant recruitment, allocation, follow-up, and analysis. All 120 patients were included in the analysis of the primary outcomes. Two patients (1 in TAPB and 1 in CON) had missing 30-day QoR-15 data and were excluded only from this secondary analysis.
Abbreviations: TAPB, subcostal transversus abdominis plane block; ESPB, erector spinae plane block; CON, control.

Results

The participant flow throughout the trial is summarized in a CONSORT diagram (Figure 1). Among the 152 patients assessed for eligibility, 32 were excluded: 23 did not meet the eligibility criteria, and 9 declined to participate. The remaining 120 patients were randomized in a 1:1:1 ratio to the TAPB, ESPB, and CON groups, with 40 patients assigned to each group. All randomized participants were included in the primary and other postoperative outcome analyses. At the 30-day follow-up, two participants (one assigned to the TAPB group and one to the control group) were unavailable for assessment, resulting in 118 patients included in the final 30-day outcome analysis.

The three groups were comparable in sex, age, American Society of Anesthesiologists (ASA) physical status, body mass index (BMI), Child–Pugh scores, and number of resected liver segments (Table 1).

Primary Outcome

Postoperative NRS scores at rest and during coughing were recorded from 2 hours postoperatively until discharge. In the linear mixed-effects model, a significant group-by-time interactions were observed for NRS scores at rest ($P_{\text{time*group}}$ =0.004) and during coughing ($P_{\text{time*group}}$ =0.003), indicating that postoperative pain trajectories differed among the three groups (Figure 2).

Pairwise P values were adjusted for multiple comparisons using the Bonferroni method. At the prespecified 2-hour time point, the estimated mean differences in resting NRS score were −0.63 points (95% CI, −1.09 to −0.16; P = 0.004) for TAPB versus CON and −0.98 points (95% CI, −1.44 to −0.51; P <0.001) for ESPB versus CON. The corresponding differences in coughing NRS score were −1.03 points (95% CI, −1.60 to −0.45; P <0.001) and −1.15 points (95% CI, −1.73 to −0.57; P <0.001), respectively. Direct comparisons between ESPB and TAPB showed no significant difference at 2 hours for either resting NRS score (MD, −0.35; 95% CI, −0.81 to 0.11; P = 0.209) or coughing NRS score (MD, −0.13; 95% CI, −0.70 to 0.45; P = 1.000).

Table 1 Patients' Clinical and Demographic Characteristics

Parameters	TAPB (n=40)	ESPB (n=40)	CON (n=40)	*P*
Sex (male/female)	21/19	22/18	22/18	0.967
Age (years)	59.00 (53.50, 62.75)	57.00 (51.00, 68.00)	62.50 (55.25, 70.00)	0.083
ASA physical status				0.521
II	19	14	17	
III	21	26	23	
BMI (kg/m^2)	24.26 (22.77, 25.76)	23.54 (21.16, 25.62)	23.44 (21.17, 25.53)	0.285
Weight (kg)	64.45 (56.88, 72.00)	62.50 (54.25, 70.00)	60.00 (56.00, 69.00)	0.556
Child-Pugh score	5.00 (5.00, 5.00)	5.00 (5.00, 5.75)	5.00 (5.00, 5.00)	0.671
Child-Pugh classification				
A	40	38	37	0.232
B	0	2	3	
Diagnosis				0.791
Hepatocellular carcinoma	20	18	17	
Benign hepatic tumour	20	22	23	
Preoperative comorbidities (%)				
Hypertension	8 (20)	11 (27.5)	10 (25)	0.727
Diabetes mellitus	5 (12.5)	4 (10)	4 (10)	0.917
Coronary artery disease	1 (2.5)	1 (2.5)	2 (5.0)	0.772
The number of resected liver segments	2.00 (2.00, 2.00)	2.00 (2.00, 2.75)	2.00 (1.00, 2.75)	0.829

Note: Data are presented as median (interquartile range), mean ± standard deviation or n (%).
Abbreviations: TAPB, subcostal Transversus Abdominis Plane Block; ESPB, Erector Spinae Plane Block; CON, control; BMI, body mass index; ASA, American Society of Anesthesiologists.

During the early postoperative period, both block groups generally had lower resting and coughing NRS scores than the CON group. At 12 hours, an isolated difference in coughing NRS score was observed between ESPB and CON, whereas the difference between TAPB and CON was not significant. Because this finding occurred at only one assessment time point and neither block demonstrated consistent superiority across the overall postoperative pain trajectory, it should be interpreted cautiously.

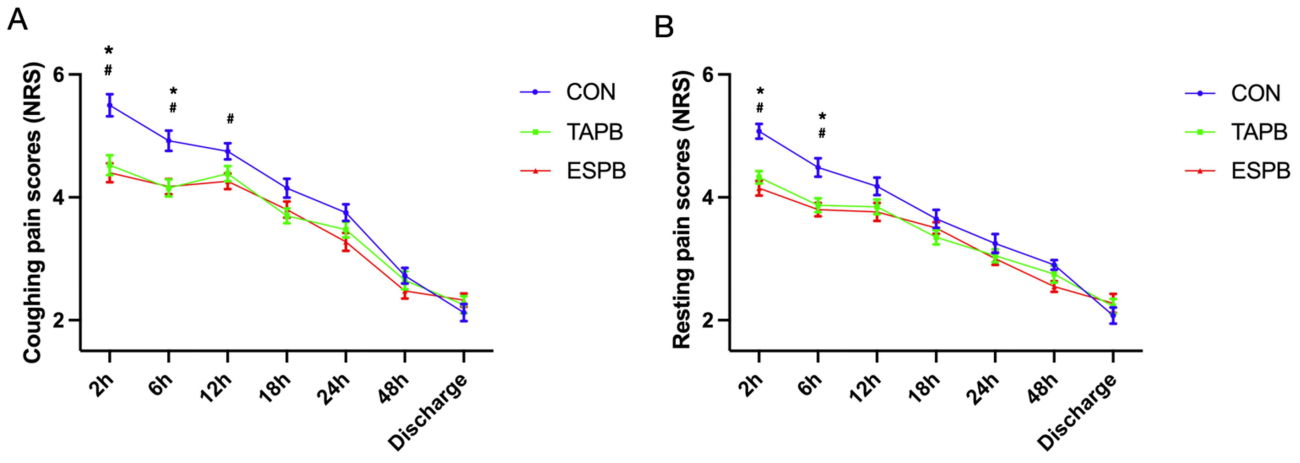

Figure 2 NRS scores of all patients during coughing (**A**) and at rest (**B**) after laparoscopic liver resection. Data are given as mean ± SEM; CON control, TAPB transversus abdominis plane block, ESPB erector spinae plane block, NRS scores from 0 to 10 points. Analysis was performed using linear mixed-effects models followed by Bonferroni's test. *$P < 0.05$, TAPB vs CON at the same time point. #$P < 0.05$, ESPB vs CON at the same time point.
Abbreviations: NRS, numerical rating scale; SEM, standard error of the mean; TAPB, subcostal transversus abdominis plane block; ESPB, erector spinae plane block; CON, control.

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Secondary Outcomes

A significant overall difference in sufentanil use was observed among the three groups at 24 h after surgery ($P < 0.001$). Following adjustment for multiple comparisons, patients receiving TAPB or ESPB required less sufentanil at 24 h than those in the control group (73.50 [72.00, 76.00] μg and 72.00 [69.25, 74.00] μg vs 88.50 [83.00, 91.00] μg; both $P < 0.001$). Sufentanil consumption did not differ significantly between the two regional block groups (Table 2).

The time to the first opioid was significantly longer in both the TAPB group (108.00 [76.25, 131.50]) and the ESPB group (97.50 [82.50, 117.75]) compared to the control group (50.00 [40.00, 56.00]) after Bonferroni correction ($P < 0.001$ for both comparisons). However, there were no significant differences between the two block groups (Table 2 and Figure 3). The duration of the first rescue analgesia treatment was longer in the TAPB and ESPB groups than in the CON group ($P < 0.001$ and $P = 0.005$, respectively), with no significant difference between the TAPB and ESPB groups ($P = 0.739$). The requirement for supplemental analgesia within the first 48 h after surgery was lower in patients receiving TAPB or ESPB than in those in the control group (18 vs 29 and 15 vs 29, respectively), whereas no difference was detected between the two block techniques. Similarly, the number of effective PCIA activations was reduced in both regional block groups compared with controls ($P < 0.001$). Pentazocine consumption was lower in the TAPB and ESPB groups than in the control group ($P = 0.001$), while tramadol use did not differ significantly among the three groups ($P = 0.349$). No significant differences were observed in analgesic requirements from 48 h postoperatively until hospital discharge ($P = 0.517$) (Table 2).

Intraoperative remifentanil requirements differed across the three groups, with patients receiving TAPB or ESPB requiring lower doses than those in the control group (2.83 [1.93, 4.06] mg vs 4.35 [3.24, 5.24] mg, $P = 0.002$; 3.14 [2.18, 4.30] mg vs 4.35 [3.24, 5.24] mg, $P = 0.013$). Intraoperative propofol and sufentanil requirements were comparable across the three groups, with no significant between-group differences observed for sufentanil consumption (Table 2).

The QoR-15 score at 24 hours postoperatively was significantly higher in both the TAPB group (116.00 [109.25, 127.25]) and the ESPB group (112.50 [99.25, 121.75]) compared to the CON group (99.00 [93.25, 113.75]; $P < 0.001$ and $P = 0.006$, respectively). In contrast, no significant differences were observed among the three groups in the preoperative QoR-15 scores or at 30 days postoperatively. The QoR-15 scores at 24 hours postoperatively were similar between the TAPB and ESPB groups, with no significant difference observed (Table 2).

No between-group differences were detected in secondary outcomes, including the use of vasoactive agents, operative duration, length of hospital stay, time to first flatus and ambulation, postoperative nausea and vomiting scores, itching, delirium, block-related complications, hypotension, or respiratory depression (Table 3).

Sensitivity Analysis

To assess the potential influence of the eligibility-related protocol deviation, a sensitivity analysis was performed after excluding the five patients with Child–Pugh class B liver function. The remaining Child–Pugh class A population included 115 patients: 40 in the TAPB group, 38 in the ESPB group, and 37 in the CON group. The postoperative NRS pain trajectories were consistent with the primary analysis. Mixed-effects models showed significant group-by-time interactions for coughing NRS scores ($P = 0.019$) and resting NRS scores ($P = 0.005$), indicating that the postoperative pain trajectories remained significantly different among the three groups. Key secondary outcomes, including postoperative sufentanil consumption, PCA activation, rescue analgesia, and 24-hour QoR-15 scores, were also generally consistent with the primary analysis. These results indicate that exclusion of the Child–Pugh class B patients did not materially alter the study conclusions (Supplementary Tables S1–S3, Supplementary Figure S1).

Discussion

In this randomized controlled trial, both ESPB and TAPB improved postoperative analgesia compared with the control condition in patients undergoing laparoscopic liver resection. Although the reductions in NRS pain scores reached statistical significance at several early postoperative time points, the absolute differences were modest and were not

Table 2 Intra-Operative and Postoperative Profiles

Outcome	TAPB	ESPB	CON	*P* value			
				TAPB VS ESPB vs CON	TAPB vs CON	ESPB vs CON	TAPB vs ESPB
Intra-Operative parameters							
Propofol consumption (mg)	787.00 (538.00, 978.75)	693.50 (488.50, 1004.75)	870.00 (647.75, 1046.50)	0.394			
Remifentanil consumption (mg)	2.83 (1.93, 4.06)	3.14 (2.18, 4.30)	4.35 (3.24, 5.24)	0.002	0.002	0.013	0.383
Sufentanil consumption (μg)	37.50 (30.00, 45.00)	40.00 (31.25, 48.75)	40.0 (30.0, 50.0)	0.382			
Vasoactive drugs, n	28	34	29	0.244			
Analgesia							
Coughing NRS score at 2 h, estimated mean (SE)	4.53 (0.17)	4.40 (0.17)	5.55 (0.17)	<0.001			
Cumulative sufentanil consumption at 24 h (μg)	73.50 (72.00, 76.00)	72.00 (69.25, 74.00)	88.50 (83.00, 91.00)	<0.001	<0.001	<0.001	0.128
Time to first opioid (min)	108.00 (76.25, 131.50)	97.50 (82.50, 117.75)	50.00 (40.00, 56.00)	<0.001	<0.001	<0.001	0.954
Duration of the first rescue analgesia treatment (min)	170.00 (144.25, 202.50)	165.00 (127.50, 245.00)	112.50 (99.50, 125.25)	<0.001	<0.001	0.005	0.739
Patients requiring additional analgesic postoperative 48h, n	18	15	29	0.004	0.012	0.002	0.496
Total number of effective PCIA	7.00 (6.00, 8.00)	6.00 (5.00, 8.00)	14.50 (13.25, 17.00)	<0.001	<0.001	<0.001	0.240
Pentazocine (mg)	0 (0, 0)	0 (0, 0)	0 (0, 30)	0.001	0.002	0.001	0.795
Tramadol (mg)	0 (0, 0)	0 (0, 0)	0 (0, 0)	0.349			
Postoperative analgesic consumption from 48 h to discharge (mg)	37.5 (0,150)	0 (0, 150)	112.5 (0,300)	0.517			
Postoperative parameters							
Duration of surgery (min)	248.50 (167.75, 309.00)	219.00 (154.25, 317.25)	261.00 (194.25, 314.00)	0.595			
Time to first ambulation (h)	51.00 (44.25, 58.00)	50.50 (45.00, 57.00)	57.00 (49.25, 62.75)	0.058			
Time to first flatus (h)	60.00 (52.00, 73.00)	62.50 (49.00, 75.25)	58.00 (47.50, 65.75)	0.287			
Length of hospital stay (d)	17.00 (12.25, 22.75)	15.00 (12.25, 19.00)	16.00 (10.00, 22.75)	0.774			
QoR-15 scores							
Preoperative	136.00 (129.25, 141.75)	132.00 (123.50, 140.00)	137.50 (129.25, 142.00)	0.203			
24h postoperatively	116.00 (109.25, 127.25)	112.50 (99.25, 121.75)	99.00 (93.25, 113.75)	<0.001	<0.001	0.006	0.163
30 days postoperatively	132.00 (129.00, 140.00)	134.50 (122.50, 141.00)	133.00 (122.00, 138.00)	0.468			

Notes: Data are presented as mean ± standard deviation, median (interquartile range), number (%), or estimated marginal mean (standard error), as appropriate. For coughing NRS score at 2 hours, the estimated MDs were −1.03 points (95% CI, −1.60 to −0.45; *P* <0.001) for TAPB versus CON, −1.15 points (95% CI, −1.73 to −0.57; *P* <0.001) for ESPB versus CON, and −0.13 points (95% CI, −0.70 to 0.45; *P* =1.000) for ESPB versus TAPB. Estimates were derived from the linear mixed-effects model. Pairwise P values were adjusted using the Bonferroni method.

Abbreviations: NRS, numeric rating scale; SE, standard error; CI, confidence interval; MD, mean difference; PCIA, patient-controlled intravenous analgesia; QoR-15, Quality of Recovery-15; TAPB, subcostal Transversus Abdominis Plane Block; ESPB, Erector Spinae Plane Block; CON, control.

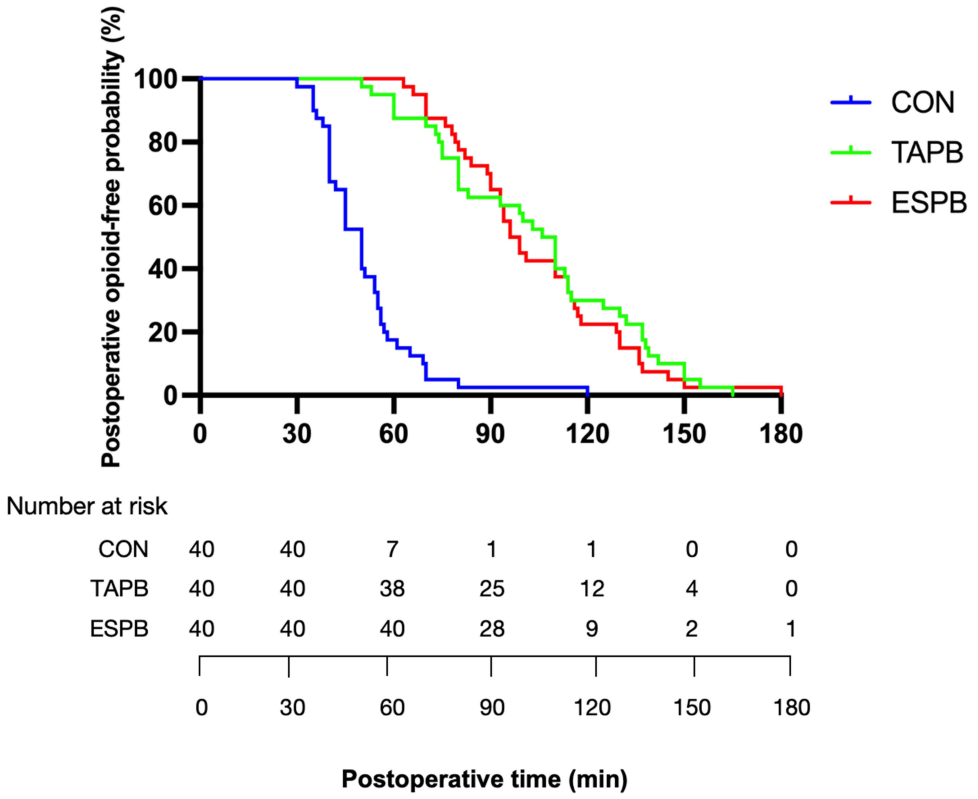

Figure 3 Kaplan–Meier survival curve representing the time to first sufentanil administration via PCIA. The time to first PCIA was significantly longer in the ESPB group and TAPB group than in the CON group after Bonferroni correction ($P < 0.001$; $P < 0.001$). There were no significant differences between the two block groups. The number of patients at risk is shown below the curves.
Abbreviations: PCIA, patient-controlled intravenous analgesia; ESPB, erector spinae plane block; TAPB, subcostal transversus abdominis plane block; CON, control.

consistently sustained throughout follow-up. Therefore, the clinical relevance of the pain-score differences alone should be interpreted cautiously. Nevertheless, both blocks were associated with lower postoperative opioid consumption, a longer time to first rescue analgesia, fewer rescue-analgesia events, and fewer effective PCIA demands. QoR-15 scores at 24 hours were also higher in both block groups than in the CON group. Collectively, these findings support complementary opioid-sparing and early recovery benefits, although neither block demonstrated consistent superiority across the overall postoperative pain trajectory.

These findings have practical implications for perioperative pain management in liver surgery. Hepatic resection reduces functional liver volume, whereas alterations in hepatic blood flow, surgical stress, and perioperative hepatic

Table 3 Postoperative Adverse Events

Adverse Events	TAPB	ESPB	CON	*P* value
				TAPB vs ESPB vs CON
PONV score	0 (0, 0)	0 (0, 0)	0 (0, 1)	0.053
Itching	1	0	1	0.601
Delirium	1	0	1	0.601
Block related complications	0	0	0	1.000
Hypotension	2	0	2	0.355
Respiratory depression	0	1	1	0.601

Note: Data are presented as median (interquartile range), mean ± standard deviation or n (%).
Abbreviations: TAPB, subcostal Transversus Abdominis Plane Block; ESPB, Erector Spinae Plane Block; CON, control; PONV, postoperative nausea and vomiting.

dysfunction may further impair drug metabolism and prolong opioid exposure.[8] Accordingly, minimizing opioid requirements while maintaining adequate analgesia is an important goal in this population. Consistent with this principle, enhanced recovery pathways and procedure-specific recommendations increasingly advocate multimodal analgesia, including regional and interfascial plane blocks, to reduce reliance on systemic opioids.[24–26] In the present study, the concordant improvements across opioid consumption, rescue analgesia, and PCIA-related outcomes indicate a broader reduction in postoperative analgesic requirements rather than an isolated difference in cumulative opioid dose. Such opioid-sparing effects may be clinically meaningful even when between-group differences in pain intensity are modest.[27] Collectively, these findings support the incorporation of either block into multimodal analgesic strategies for laparoscopic liver resection.

TAPB is one of the most widely used truncal blocks in abdominal surgery and is known to provide effective somatic analgesia to the anterior abdominal wall.[28] In the present study, TAPB improved early postoperative analgesia and reduced opioid consumption compared with the CON group, consistent with its established role in upper abdominal procedures. These effects may be attributable to blockade of the thoracoabdominal nerves supplying the upper abdominal wall, thereby reducing nociceptive input from the trocar sites and specimen-extraction incision.[29] Although ESPB and TAPB target different anatomical planes, their analgesic coverage may overlap, as both techniques can attenuate the somatic component of postoperative pain. This overlap, together with the standardized multimodal analgesic regimen used in all groups, may partly explain the absence of consistent differences between the two blocks across the overall postoperative pain trajectory.

ESPB involves the deposition of local anesthetic within the erector spinae fascial plane and has been applied at different thoracic and lumbar levels across a broad range of surgical procedures.[15] Nevertheless, its analgesic mechanisms remain incompletely defined. Proposed mechanisms include cranio–caudal spread within the erector spinae fascial plane and variable extension of local anesthetic toward the paravertebral, intercostal, and sympathetic pathways. However, anatomical and imaging studies have demonstrated considerable variability in the extent and pattern of local anesthetic spread, highlighting the importance of evaluating ESPB on the basis of reproducible clinical outcomes rather than presumed anatomical mechanisms alone.[30–33] In the present study, ESPB was associated with favorable postoperative analgesic outcomes compared with standard care, including a longer time to first rescue analgesia and lower cumulative opioid consumption, indicating benefits beyond reductions in early pain intensity. Pain during coughing represents dynamic, movement-evoked thoracoabdominal pain rather than a direct measure of cough-reflex function. Although coughing NRS scores were lower with ESPB than with subcostal TAPB at 12 hours, this isolated finding may have reflected broader segmental spread toward the intercostal or paravertebral pathways, thereby reducing movement-evoked thoracoabdominal nociception rather than directly affecting the cough reflex or phrenic nerve function. Because sensory distribution, cough strength, respiratory muscle function, and diaphragmatic motion were not assessed, the underlying mechanism remains uncertain, and this single-time-point difference should not be interpreted as evidence of an overall analgesic advantage of ESPB.

Consistent with previous studies in abdominal surgery, our findings support the clinical utility of ESPB as part of multimodal analgesia. Accumulating evidence suggests that the addition of ultrasound-guided erector spinae plane block to rectus sheath block is associated with reduced intraoperative opioid exposure and lower early postoperative analgesic requirements in laparoscopic cholecystectomy, supporting a broader analgesic role of ESPB.[19] In contrast, other studies have shown that although ESPB did not significantly reduce total opioid consumption within 24 hours after laparoscopic hepatectomy, it was associated with reduced rescue opioid use in the post-anesthesia care unit, indicating clinical value in acute postoperative pain management. These discrepancies may reflect differences in surgical techniques and patient populations.[34] Overall, reported effects of ESPB vary across procedures, underscoring the need for cautious interpretation and further high-quality studies to better define its role in laparoscopic liver resection.

Recent international efforts to evaluate the effectiveness of anesthesia interventions have increasingly prioritized patient-centered outcome measures.[35] While reducing pain scores remains a key objective, patients may not perceive their recovery as improved if accompanied by significant or debilitating side effects. This shift underscores the need for a holistic approach that balances effective pain management with minimizing adverse effects to enhance the overall recovery experience. The QoR-15 score is an internationally recognized and effective tool for assessing postoperative recovery quality, demonstrating strong validity, reliability, and clinical applicability.[36] In this study,

QoR-15 scores at 24 hours postoperatively were significantly higher in both the TAPB and ESPB groups than in the CON group, with between-group differences exceeding 8 points, suggesting a clinically meaningful improvement in early postoperative recovery. At 30 days postoperatively, the QoR-15 scores in all groups had returned to pre-operative levels, with no significant differences observed between groups. This suggests that the benefits of these blocks are most pronounced immediately following surgery. In this study, no significant differences were found in postoperative gastrointestinal recovery, time to mobilization, or length of stay between the three groups. These outcomes are likely influenced by a variety of factors, including patients' baseline health status, their psychological expectations regarding the surgery, preoperative and postoperative anxiety levels, and the quality of care delivered by the medical team.[37] The study also assessed several secondary outcomes, including the use of vasoactive medications, duration of surgery, length of hospital stays, time to first flatus and ambulation, PONV scores, pruritus, delirium, block-related complications, hypotension, and respiratory depression. No significant between-group differences were observed in the recorded adverse events, suggesting comparable short-term safety profiles among the three groups.

Several limitations should be acknowledged. First, although the trial registry specified Child–Pugh class A liver function as an eligibility criterion, five patients with Child–Pugh class B liver function were inadvertently enrolled because they were misclassified during eligibility screening. Sensitivity analyses excluding these patients yielded findings consistent with those of the full analysis population, suggesting that this protocol deviation did not materially affect the study conclusions. Second, sensory block onset, dermatomal distribution, and clinical block success were not systematically assessed before induction of general anesthesia, which limited confirmation of block effectiveness and mechanistic interpretation. Third, complete patient blinding was challenging because of the different positioning requirements for the two block techniques. Nevertheless, the surgeons and attending anesthesiologists responsible for intraoperative management, postoperative outcome assessors, postoperative care providers, and statistical analysts remained blinded to group allocation. Finally, the single-center design may limit the generalizability of the findings. Larger multicenter studies using standardized protocols and direct comparisons with other regional analgesic techniques are needed to validate these results, evaluate the consistency of analgesic effects, and further define the relative clinical roles of ESPB and TAPB in liver surgery.

Conclusion

In this single-center randomized trial, both subcostal TAPB and ESPB improved early postoperative analgesia, reduced opioid consumption and rescue analgesic requirements, and increased QoR-15 scores at 24 hours in patients undergoing LLR, without an observed increase in adverse events. Neither technique demonstrated consistent superiority over the postoperative period. With the increasing use of laparoscopic liver resection, these findings support the incorporation of either block into multimodal analgesia strategies. Given the single-center design, larger multicenter trials involving more diverse patient populations are needed to confirm these findings and further clarify optimal block selection and patient-tailored analgesic strategies.

Data Sharing Statement

The data underlying the findings of this study are available from the corresponding author upon reasonable request.

Ethics Approval and Consent to Participate

This study was approved by the Ethics Committee of the Second Affiliated Hospital of Anhui Medical University (approval no. YX2023-182(F1)) on December 4, 2023. This study was conducted in accordance with the Consolidated Standards of Reporting Trials criteria and in compliance with the Helsinki Declaration. Written informed consent was obtained from all patients.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors report no conflicts of interest in this work.

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