Systematic Review and Meta-Analysis of Application of Ultrasound-Guided Thoracic Paravertebral Block in Clinical Surgical Treatment

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AIM: There is a lack of consensus regarding the efficacy of thoracic paravertebral block (TPVB) and erector spinae plane block (ESPB) for postoperative pain in randomized controlled trials (RCTs). The comparison of TPVB and ESPB was explored through a systematic review and meta-analysis (MA) of relevant RCTs.

METHODS: A comprehensive search of relevant literature was conducted using databases such as PubMed, Embase, and MEDLINE, from 2019 to June 2024. The search utilized keywords such as "TPVB", "ESPB", and "postoperative analogy". Following the search, quality evaluation and extraction of outcome indicators were implemented. The software RevMan5.3 was employed for data analysis and evaluation.

RESULTS: The analysis included 18 articles. In patients at rest, a significant difference in pain scores was observed between the TPVB group and the ESPB group at 1 h postoperatively, with a standardized mean difference (SMD) of –0.52 [95% confidence interval (CI): –0.88 to –0.16, $p = 0.005$]. In non-resting patients, there were significant differences in pain scores between TPVB and ESPB at 24 and 48 h postoperatively. At 24 h postoperatively, the SMD was –0.37 (95% CI: –0.69 to –0.05, $p = 0.02$), and at 48 h postoperatively, in the visual analog scale (VAS) subgroup, the SMD was –0.38 (95% CI: –0.65 to –0.11, $p = 0.006$). Furthermore, notable statistical variations were identified in the frequency of rescue analgesia required following surgery between TPVB and ESPB.

CONCLUSIONS: The meta-analysis indicated that lower clinical pain scores in non-resting states at 24 and 48 h post-surgery were associated with TPVB rather than ESPB. This finding was accompanied by a more discernible and accurate analgesic effect, as well as a significant reduction in the need for rescue analgesia following surgical procedures.

Keywords: television-aided thoracic surgery; TPVB; ESPB; MA

Introduction

The transition from traditional thoracic surgery to video-assisted thoracic surgery (VATS) has been characterized by a progressive reduction in incision size, transitioning from large openings to minimally invasive techniques involving multiple ports, and ultimately to a single-port approach. This transformation has been propelled by recent advancements in surgical technology and equipment [1]. In addition, VATS encompasses a range of complex thoracic surgical operations [2, 3, 4]. The minimally invasive nature of VATS, as evidenced by the small incisions in the thoracic wall, leads to a faster recovery for patients post-operation. Compared to the more invasive thoracotomy, this method significantly reduces various postoperative pulmonary complications, facilitating an earlier resumption of physical activity for patients [5]. However, the recovery process is substantially impeded by current shortcomings in managing acute pain associated with early post-surgical incisions and areas surrounding closed thoracic drainage tubes. Additionally, the ineffectiveness of postoperative pain mitigation strategies and the absence of adequate measures to alleviate patient anxiety can lead to severe chronic pain. This scenario not only prolongs the duration and increases the cost of hospital visits but also heightens the pressures faced by both hospitals and patients [6, 7]. The increasing recognition among anesthesiologists of the need for effective analgesic management following VATS is noteworthy. Traditionally, thoracic epidural analgesia (TEA) has been considered the "gold standard" for postoperative pain relief following thoracic surgery. However, its intricate procedure, significant failure rates, and growing awareness of complications associated with TEA have resulted in a reduced application of this method in clinical practice [8]. Consequently, there is a pressing need for anesthesiologists to explore alternative analgesic strategies

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post-VATS. These strategies should be patient-friendly, deliver safe and effective pain mitigation, and significantly reduce dependence on opioid medications.

The increasing prevalence and innovation in ultrasound visualization have facilitated the accessibility of portable ultrasound devices, supporting the verification of the effectiveness and safety of peripheral nerve blocks in managing postoperative pain across various surgeries [9]. Thoracic paravertebral block (TPVB) technology involves the administration of a local anesthetic adjacent to the thoracic vertebra, which diffuses within the space to block spinal nerves as they pass, thereby providing pain relief [10, 11, 12]. The conventional TPVB technique relies exclusively on surface anatomical markers for site identification, which lacks precision and requires the operator to have a comprehensive understanding of the relevant anatomy involved and proficiency in executing the block. This approach is associated with a high occurrence of unsuccessful blocks and an increased risk of pneumothorax [13, 14]. Advances in ultrasound technology have enhanced imaging capabilities through improved ultrasonic scanning. The use of real-time ultrasound guidance in TPVB not only abbreviates the duration of the block procedure but also effectively minimizes the risk of complications inherent to the blind method.

The erector spinae plane block (ESPB) is a local anesthetic technique that involves the administration of medication into the fascial space between the deep aspect of the erector spinae muscle and the parapophysis. This allows the anesthetic to gradually diffuse, providing a blockade of the spinal nerves. ESPB has emerged in local anesthesia, employed for the alleviation of sharp postoperative discomfort and chronic pain [15]. Clinical study has demonstrated that ESPB significantly reduces the need for opioids within the first 24 h post-operation compared to patients who do not receive this block. Furthermore, patients who undergo ESPB report lower pain scores both at rest and during coughing. There is also a noted decrease in the frequency of postoperative nausea and vomiting (N&V) among these patients [16].

There is an ongoing divergence in findings from randomized controlled trials (RCTs) concerning the relative analgesic efficacy of TPVB compared to ESPB in postoperative clinical management. The controversy over their relative effectiveness in alleviating postoperative pain remains unresolved. This article presents a systematic review and meta-analysis (MA) of relevant RCTs, focusing on the evaluation of pain alleviation and safety of procedures using various postoperative metrics. These metrics include, but are not limited to, pain scores at different time intervals and opioid consumption. This analysis aims to provide a foundation for evidence-based medical practice in anesthesiology, facilitating the selection of appropriate analgesic regimens.

Materials and Methods

Inclusion and Exclusion Criteria

The design of the study, selection of research types, data sources and analysis methods can be found in the **Supplementary Material.**

The inclusion criteria were as follows: (i) RCTs focusing on TPVB and ESPB; (ii) adult participants aged 18 years old or older undergoing thoracoscopic surgery; (iii) studies comparing TPVB and ESPB for postoperative pain relief, without restrictions on the type, dosage, or timing of anesthetics; (iv) outcome measures encompassed pain scores at rest and during coughing at 1, 12, 24, and 48 h postoperatively, total morphine consumption (MC) within the first 24 h following operation, incidence of postoperative N&V, and frequency of postoperative rescue analgesic interventions.

The exclusion criteria were as follows: (i) non-RCT studies, including case reports, reviews, conference abstracts, and commentary articles; (ii) studies involving experimental procedures on animals; (iii) studies with incomplete data, rendering primary data inaccessible.

Retrieval

The databases, PubMed, Embase, MEDLINE, Science Direct, The Cochrane Library, Google Scholar, China National Knowledge Infrastructure, Wanfang Database, and Chinese Sci-tech Periodicals Database were systematically searched to retrieve papers from 2019 to 6 June 2024. These papers reported on RCTs exploring the use of TPVB and ESPB for pain relief following VATS. To complement this search and prevent the exclusion of pertinent articles, a manual search of selected professional journals was also conducted.

The retrieval strategies involved the use of English keywords such as “thoracic paravertebral block”, “TPVB”, “erector spinae plane block”, “ESPB”, “video-assisted thoracic surgery”, “VATS”, “thoracoscopic surgery”, and “postoperative analgesia” (POA). In Chinese, the keywords included “TPVB”, “ESPB”, “thoracoscopic surgery”, and “POA”.

A comprehensive search was conducted using various combinations of these terms to identify relevant articles. Following the initial search, search engines were employed to track down each article. The quality of the selected articles was subsequently assessed using RevMan5.3 (Cochrane Collaboration, London, UK).

Outcome Indexes

Assessing outcomes involved monitoring pain scores during both resting and coughing states at 1, 12, 24, and 48 h post-intervention. We also calculated the total MC within the first 24 h, documented the number of rescue analgesic interventions required, and recorded the occurrence of N&V as complications.

The opioid medications were converted into their intravenous morphine equivalents to facilitate analysis and com-

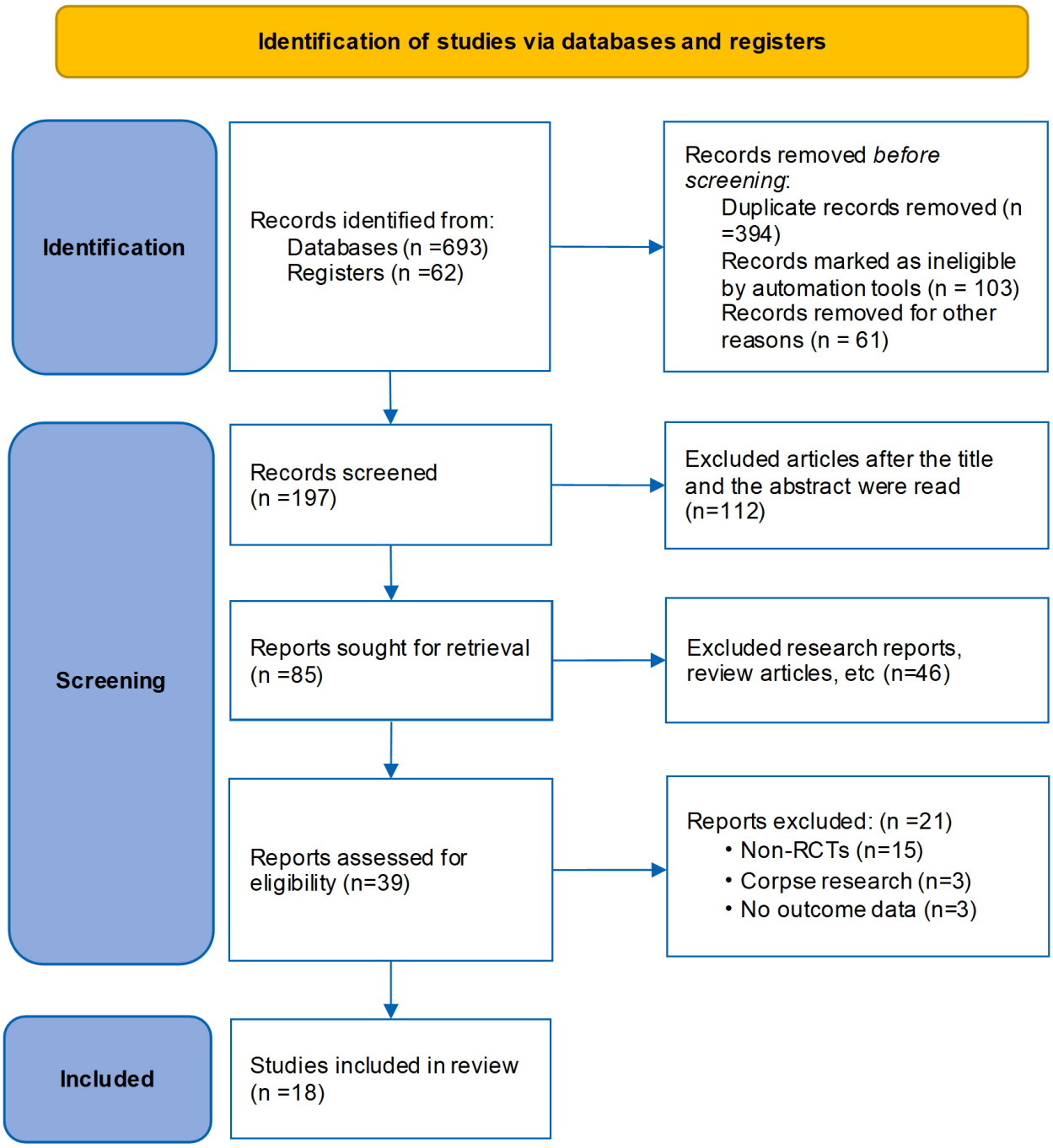

Fig. 1. Flow chart of article retrieval. RCTs, randomized controlled trials.

parative assessment. The conversion ratios used were as follows: 10 mg of intravenous morphine is equivalent to 30 mg of oral morphine, 100 mg of intravenous tramadol, 20 mg of oral oxycodone, 100 µg of intravenous fentanyl, and 10 µg of intravenous sufentanil [17]. The pain assessment scales include the visual analog scale (VAS), verbal rating scale (VRS), and numeric rating scale (NRS), all ranging from 0 to 10, where "0" indicates no pain and "10" represents the most severe pain. These scales are inherently consistent, allowing interchangeable use [18].

Data Extraction

Microsoft Excel 2019 (Microsoft Corporation, Redmond, WA, USA) was utilized by two experts for the independent screening of articles and data extraction. The outcome indices were systematically organized into tables. When discrepancies arose, they were resolved through discussion to

Table 1. Basic features of included articles.

The first author	Publication year	Number of cases		Surgical type	Intervention measures		Nerve block anesthetic and dosage		Outcome indexes
		TPVB	ESPB		TPVB	ESPB	TPVB	ESPB	
Chen [19]	2020	24	24	VATS	Multiple ultrasonic guidance (MUG) TPVB-T5+T6+T7	Single ultrasonic guidance (SUG) ESPB-T5	6.7 mL 0.375% ropivacaine (Rop) including T5, T6, and T7	20 mL 0.375% Rop	VAS, morphine dosage, N&V, and rescue analgesia times following surgical procedure
El Ghamry [20]	2019	35	35	Improved radical mammectomy	SUG TPVB-T5	SUG ESPB-T5	20 mL 0.25% bupivacaine (Bup)	20 mL 0.25% Bup	Morphine dosage 24 h following operation, first POA time, postoperative VAS, and N&V
Fang [21]	2019	47	47	Thoracotomy	SUG TPVB-T5	SUG ESPB-T5	20 mL 0.25% Bup	20 mL 0.25% Bup	VAS in resting status and during cough 1 h, 24 h, and 48 h following operation, patient-controlled intravenous analgesia effective press times 24 h following operation, and N&V
Gürkan [22]	2020	25	25	Breast cancer unilateral breast surgery	SUG TPVB-T4	SUG ESPB-T4	100 mg Tramadol	100 mg Tramadol	MC 24 h following operation, NRS, and N&V
Kukreja [23]	2021	34	20	Thoracoscopic pulmonary lobectomy	SUG TPVB-T5	SUG ESPB-T5	Oral morphine equivalent	Oral morphine equivalent	Postoperative VAS, and N&V
Moustafa [24]	2020	45	45	Improved radical mammectomy	SUG TPVB-T5	SUG ESPB-T5	20 mL 0.25% Bup	20 mL 0.25% Bup	MC 24 h following operation and NRS
Stewart [25]	2021	25	25	Total mastectomy	SUG TPVB-T5	SUG ESPB-T5	Intravenous injection of 0.2–0.5 mg hydromorphone every 4 h	Intravenous injection of 0.2–0.5 mg hydromorphone every 4 h	NRS in resting status and during cough and MC 24 h following operation
Taketa [26]	2019	41	40	Thoracoscopic lung cancer radical surgery	SUG TPVB-T5	SUG ESPB-T5	20 mL 0.2% Bup	20 mL 0.2% Bup	NRS in resting status and during cough, N&V, and rescue analgesia times following surgical procedure
Turhan [27]	2021	35	35	VATS	SUG TPVB-T5	SUG ESPB-T5	20 mL 0.5% Bup	20 mL 0.5% Bup	VAS, morphine dosage, N&V, and rescue analgesia times following surgical procedure
Zhao [28]	2020	33	33	VATS	MUG TPVB-T4+T6	MUG ESPB-T4+T6	30 mL 0.4% Rop	30 mL 0.4% Rop	NRS, morphine dosage, and rescue analgesia times following surgical procedure
Elewa [29]	2022	30	30	Improved radical mammectomy	SUG TPVB-T4	SUG ESPB-T4	30 mL 0.25% Bup	30 mL 0.25% Bup	Morphine dosage, VAS, N&V

Table 1. Continued.

The first author	Publication year	Number of cases		Surgical type	Intervention measures		Nerve block anesthetic and dosage		Outcome indexes
		TPVB	ESPB		TPVB	ESPB	TPVB	ESPB	
Moorthy [30]	2023	37	37	Unilateral minimally invasive thoracic surgery	MUG TPVB-T4+T5	SUG ESPB-T5	20 mL 0.375% levoBup	20 mL 0.375% levoBup	VRS and complications during rest and deep inhalation
Elawamy [31]	2022	30	30	Fracture and trauma management	-	-	25 mL 0.5% Rop + 8 mg dexamethasone	0.3 mL 0.5% regular Bup + 8 mg dexamethasone	Opioid dosage, VAS at 3, 6, 12, 18, and 24 h, adverse symptoms
Santonastaso [32]	2023	41	41	Radical mastectomy	MUG TPVBT2-T3 and T4-T5	MUG ESPB-T2+T5	8 mL 0.75% Rop	12 mL 0.5% Rop	Postoperative NRS at 2, 6, 12, 24, and 36 h, postoperative opioid dosage, N&V
Durey [33]	2023	53	54	Lobectomy	SUG TPVB-T6	SUG ESPB-T6	20 mL 0.2% Rop	0.2% 40 mL Rop	Postoperative NRS during 24-h rest and cough, MC within 24 h, and complications
Wittayapairoj [34]	2022	22	22	Breast resection surgery	SUG TPVB-T4	SUG ESPB-T4	20 mL 0.5% levoBup	20 mL 0.5% levoBup	Morphine demand within 24 h following operation, complications, NRS at 6, 12, 24, and 48 h
Sharma [35]	2023	33	33	Improved radical mammectomy	MUG TPVB-T3+T4	MUG ESPB-T3+T4	20 mL 0.5% Rop	20 mL 0.5% Rop	First rescue analgesia time, total consumption of rescue analgesics, occurrence of surgical related and postoperative complications, 24-h VAS
Duran [36]	2024	22	23	Selective posterior lateral thoracotomy surgery	SUG TPVB-T4	SUG ESPB-T4	20 mL 0.5% Bup	20 mL 0.5% Bup	Patient's resting and cough NRS score, MC, nausea, and vomiting

Abbreviations: TPVB, thoracic paravertebral block; ESPB, erector spinae plane block; VAS, visual analog scale; N&V, nausea and vomiting; POA, postoperative analgesia; MC, morphine consumption; NRS, numeric rating scale; VRS, verbal rating scale; VATS, video-assisted thoracic surgery.

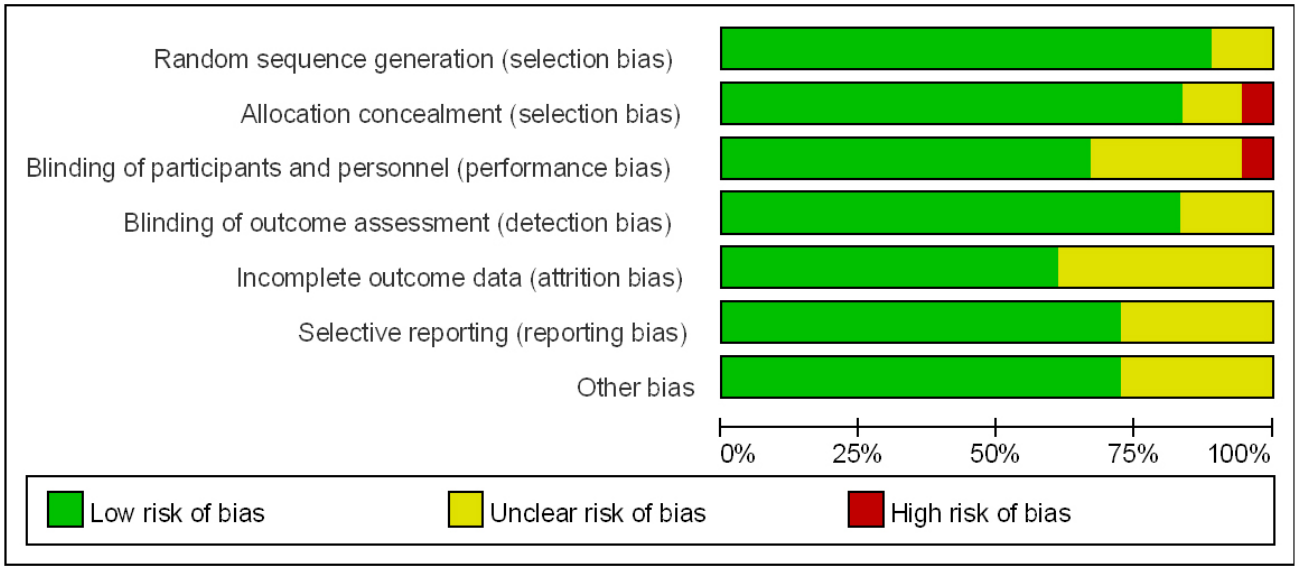

Fig. 2. Risk bias.

reach a consensus. The extracted data primarily included: (i) article source details; (ii) basic characteristics, including sample demographics, nerve block methodologies, thoracoscopic surgical procedures, puncture points, and specifics regarding the type and dosage of local anesthetics; and (iii) outcome metrics.

Quality Evaluation and Bias Risk Assessment

In adherence to the protocols outlined in the Cochrane 5.0 handbook, a thorough and independent evaluation of the included studies was performed by two experts. These assessments were conducted in duplicate to ensure reliability, with the outcomes being cross-examined for consistency. Differences were addressed through a process of discussion and negotiation between the two reviewers. Assessment parameters included: (i) the proper and standardized generation of random allocation sequences; (ii) the rigorous implementation of allocation concealment procedures; (iii) the application of blinding techniques for participants, interventionists, and outcome evaluators; (iv) the occurrence of dropouts or incomplete follow-up, as well as the integrity of the data integrity; (v) the comparability of participant numbers and age across groups, the evaluation of selection bias, and the identification and degree of performance bias. The quality of the included studies was categorized using ratings of "low risk", "high risk", or "unclear".

Statistical Methods

The risk of bias assessment was conducted using the RevMan 5.3 software (University of Oxford, Oxford, UK) to systematically evaluate potential biases. Data were organized, reviewed, and subsequently entered into the software to generate visual representations. Continuous outcomes measured in the same units were presented as mean difference (MD) with 95% confidence interval (CI). In contrast, outcomes measured in different units were expressed as standardized mean difference (SMD) with 95% CI. Categorical data were depicted using relative risk (RR) or risk difference (RD), each with 95% CI. Heterogeneity (Het) among studies was subjected to detection by I-squared (I^2). When $p < 0.1$ and $I^2 > 50\%$, it indicated significant Het, prompting the use of a random effects model (REM). When $p > 0.1$ and $I^2 < 50\%$, Het was considered insignificant, and fixed effects model (FEM) was employed to calculate combined statistics. Differences were considered statistically significant when the p-value was less than 0.05.

Sensitivity (Sen) Analysis

Funnel plots (FUPs) of various diagnostic indexes were drawn to assess potential publication bias (PB). The sensitivity (Sen) was analyzed by changing the model (REM/FEM) to evaluate the reliability of the conclusions.

Results

Retrieval Results and Article Basic Information

A total of 693 items were initially retrieved from the database. Additionally, 62 journals were manually sourced. Duplicate publications led to the disqualification of 394 papers. Subsequently, 103 articles were excluded for various reasons, and 61 articles were removed entirely. Following the title selection process, 197 articles remained. Following the review of abstracts and titles, 112 papers were further removed, leaving 85 articles intact. After the elimination of 46 research reports and summaries, 39 papers were retained. A full-text review led to the exclusion of 21 articles. A total of 15 studies were excluded for being non-RCTs, 3 studies were excluded as corpse research, and 3 studies were excluded due to no outcome data. Ultimately, the meta-analysis comprised 18 articles [19, 20, 21, 22, 23,

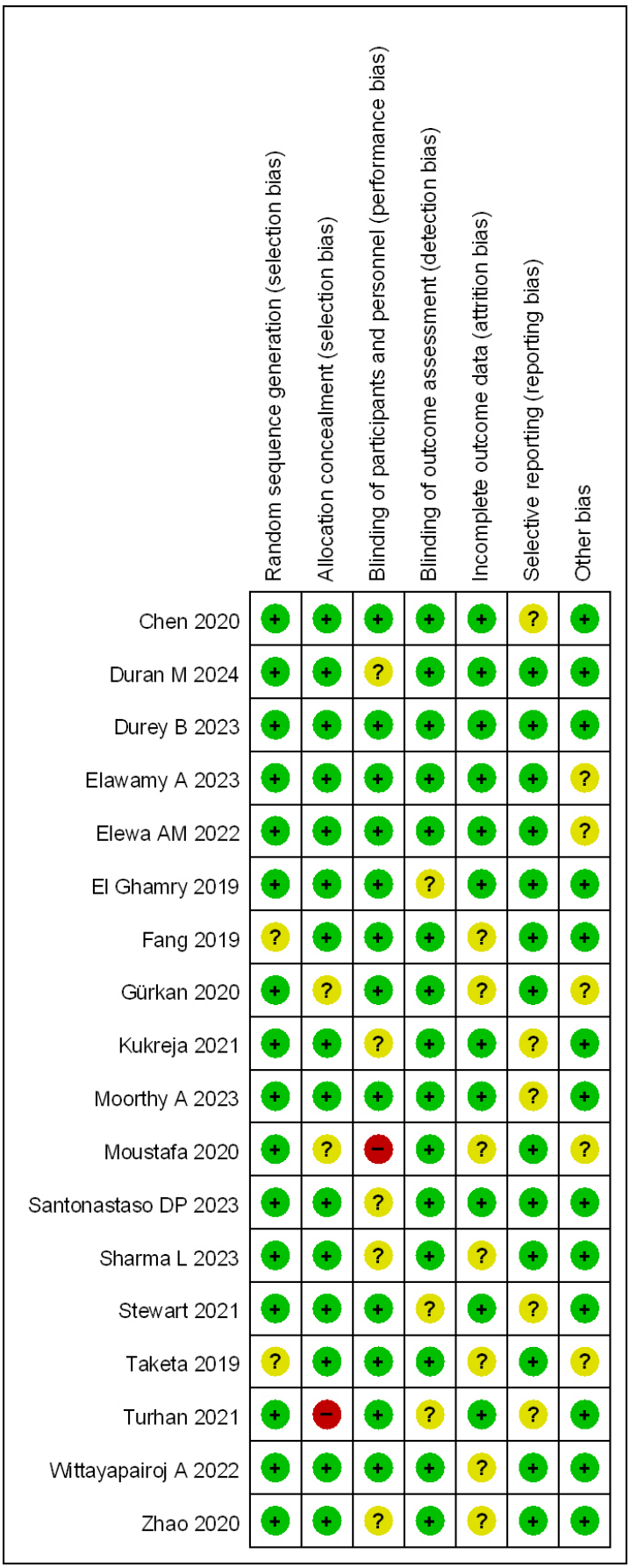

Fig. 3. Summary of risk bias. Note: "+" low risk, "-" high risk, and "?" "unclear".

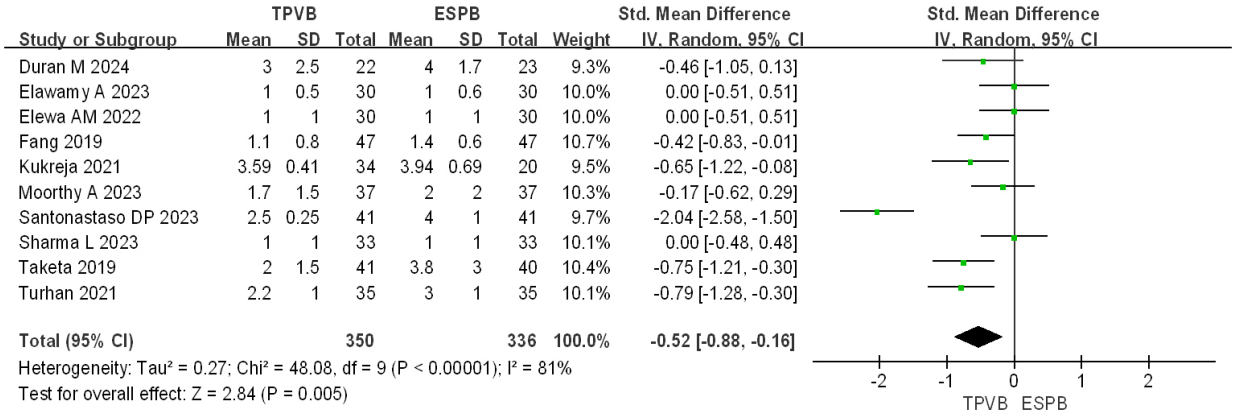

Fig. 4. Forest plot of pain scores in the resting state 1 h post-surgery.

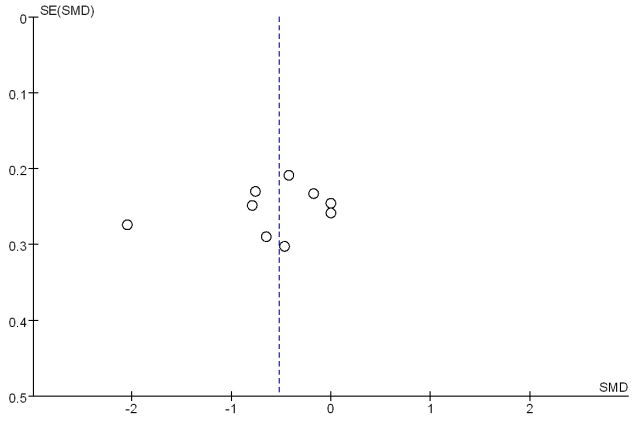

Fig. 5. Funnel plots of pain scores in the resting state 1 h post-surgery. SMD, standardized mean difference; SE, standard error.

24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36]. The article retrieval flow chart is displayed in Fig. 1.

The quality assessment outcomes indicated that 14 articles were rated as A (78%), while 2 articles received B (11%), and another 2 were classified as C (11%). Among the 18 articles that met the inclusion criteria, a total of 1211 patients were involved. The sample sizes of these articles ranged from a minimum of 44 to a maximum of 107 participants (Table 1).

Ten articles provided detailed pain scores at rest and during movement, coughing, or deep breathing at different postoperative time points. This study primarily focused on pain scores at 1, 12, 24, and 48 h postoperatively, as well as the total MC at 24 h postoperatively, the occurrence of postoperative N&V, and the number of rescue analgesic doses administered postoperatively. Among the 10 studies, the quality assessment results showed that there were 6 articles (60%) with an evaluation grade of A, 2 articles (20%) with a grade of B, and 2 articles (20%) with a grade of C. A total of 673 patients were included, with sample sizes ranging from 48 to 94 patients across the 10 articles (Table 1).

Evaluation Results of Risk Bias

In the analysis of 18 RCTs, 16 articles employed a random number table for randomization. One paper described allocation concealment; one article did not use the blind approach; and all trial outcome indices were comprehensive. A detailed evaluation of the quality of these items is illustrated in Figs. 2,3.

MA of Pain Scores in Resting States at 1 h Postoperatively between TPVB and ESPB

The analysis of 10 studies focused on postoperative pain scores during resting states at 1 h after surgery for both TPVB and ESPB (Fig. 4). Each study contributed more than 10% to the overall weight of the analysis. The total sample included 686 patients, with 350 receiving TPVB and 336 receiving ESPB. There was significant Het in pain scores between the two groups at 1 h ($Chi^2 = 48.08$, $I^2 = 81\%$, $p < 0.00001$). The overall effect size, represented by the diamond in the forest plot, was positioned to the left of the null line (SMD: –0.52, 95% CI = [–0.88, –0.16]), indicating the use of a REM for the MA. These findings suggest that pain scores during resting states at 1 h postoperatively were significantly lower in the TPVB group compared to the ESPB group ($Z = 2.84$, $p = 0.005$).

The FUP of pain scores during resting states at 1 h postoperatively showed that the data points, represented as circles for the included studies, were primarily clustered around the central line. This clustering indicates the absence of PB and suggests high reliability of the results (Fig. 5).

Due to Het among the included studies when comparing patients' pain scores during resting states at 1 h, potentially related to the methods used for pain assessment, the data were divided into two subgroups based on different pain scoring methods: VAS and NRS. The results (Fig. 6) showed that within the VAS subgroup, there was no significant Het between the two anesthesia methods ($p = 0.12$, $I^2 = 42\%$). The diamond representing the overall effect was positioned to the left of the null line (SMD: –0.33, 95% CI = [–0.53, –0.14]). A FEM was used for the MA. The pain scores dur-

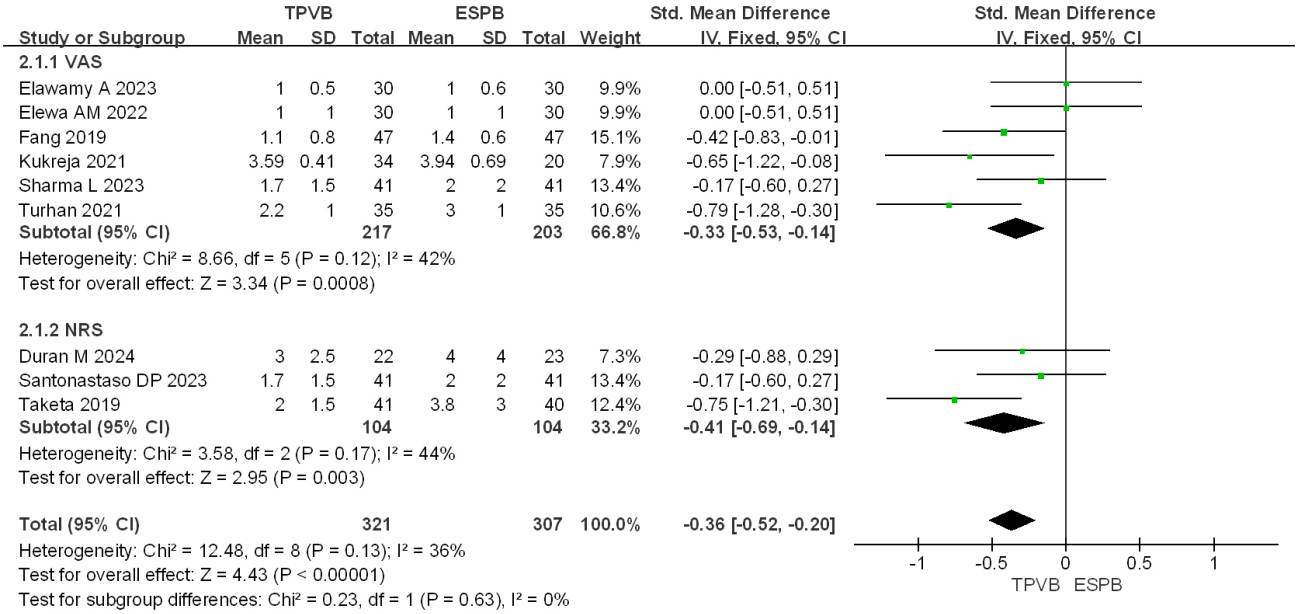

Fig. 6. Forest plot of subgroup analysis of pain scores in the resting state 1 h post-surgery. CI, confidence interval.

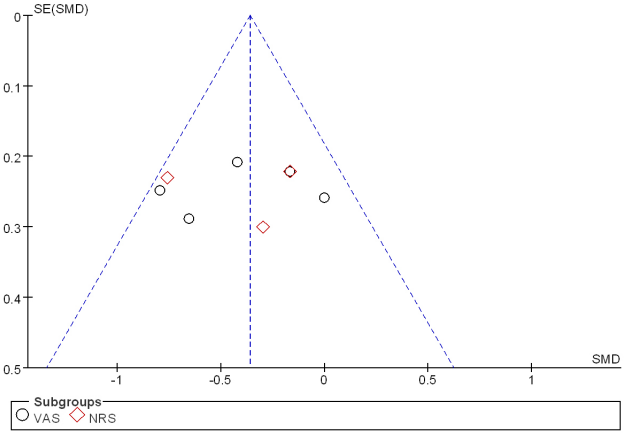

Fig. 7. Funnel plot (FUP) of subgroup analysis of pain scores in the resting state 1 h post-surgery.

ing resting states at 1 h postoperatively were significantly lower in the TPVB group compared to the ESPB group (Z = 3.34, $p = 0.0008$). Within the NRS subgroup, there was no significant Het between the two anesthesia methods ($p = 0.17$, $I^2 = 44\%$). The diamond representing the overall effect was positioned to the left of the null line (SMD: –0.41, 95% CI = [–0.69, –0.14]). The FEM analysis results were consistent with those of the REM MA, showing that the pain scores during resting states at 1 h postoperatively were significantly lower in TPVB group compared to ESPB group (Z = 2.95, $p = 0.003$).

The FUP analysis of pain scores during resting states at 1 h postoperatively revealed that the data points were predominantly clustered near the central line. This distribution further suggests the absence of PB and indicates high reliability (Fig. 7).

MA of Pain Scores in Resting States at 12 h Postoperatively between TPVB and ESPB

The analysis of 11 studies focusing on pain scores during resting states at 12 h postoperatively for both TPVB and ESPB included a total of 682 patients, with 348 in the TPVB group and 334 in the ESPB group (Fig. 8). The Het in pain scores between the two groups was significant ($Chi^2 = 88.85$, $I^2 = 89\%$, $p < 0.00001$). The overall effect size, represented by the diamond in the forest plot, was positioned to the left of the null line (SMD: –0.31, 95% CI= [–0.78, –0.16]). This suggests that a REM was used for the MA. Despite this, the comparison of pain scores during resting states at 12 h postoperatively showed no statistically significant difference between the TPVB and ESPB groups (Z = 1.29, $p = 0.20$).

The presence of Het among the studies included in the analysis of patients' pain scores during resting states at 12 h required the division of data into two subgroups based on different pain scoring methods: the VAS and the NRS. Subsequent analysis (Fig. 9) showed that the Het test for the NRS subgroup ($Chi^2 = 50.96$, $I^2 = 92\%$, $p < 0.00001$) indicated a higher level of Het compared to the overall analysis. This suggests that the observed Het may be attributed to the measurement tools used in the studies. The REM analysis (SMD: –0.29, 95% CI = [–1.15, –0.58]) revealed no significant difference in pain scores during resting states at 12 h postoperatively between the TPVB and ESPB groups (Z = 0.65, $p = 0.52$), consistent with the overall findings before subgroup analysis. In the VAS subgroup, the Het test ($Chi^2 = 34.76$, $I^2 = 86\%$, $p < 0.00001$) demonstrated increased Het. The REM analysis (SMD: –0.34, 95% CI = [–0.89, –0.22]) for this subgroup also showed no significant differ-

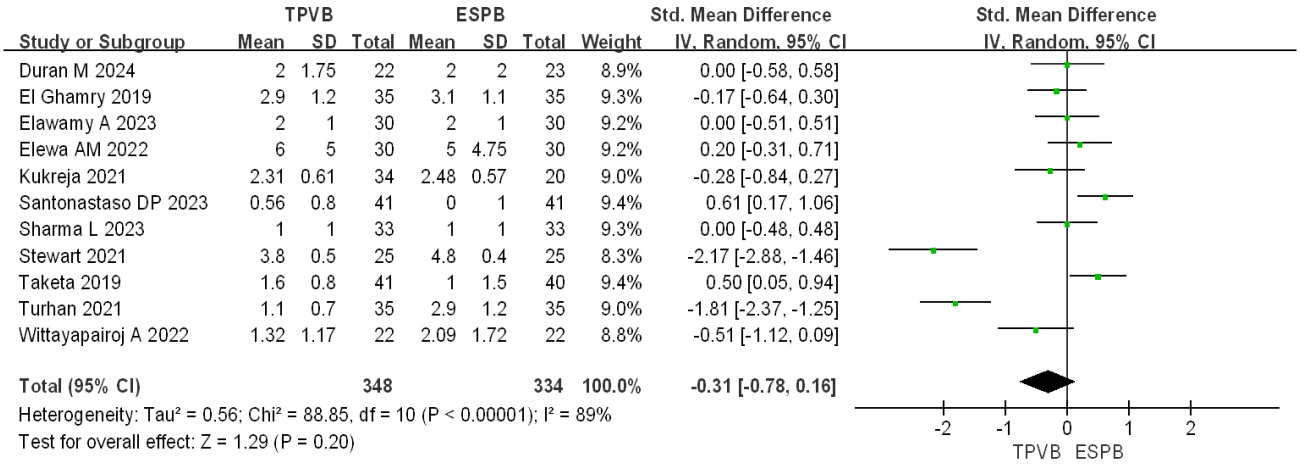

Fig. 8. Forest plot of pain scores in the resting state 12 h after operation.

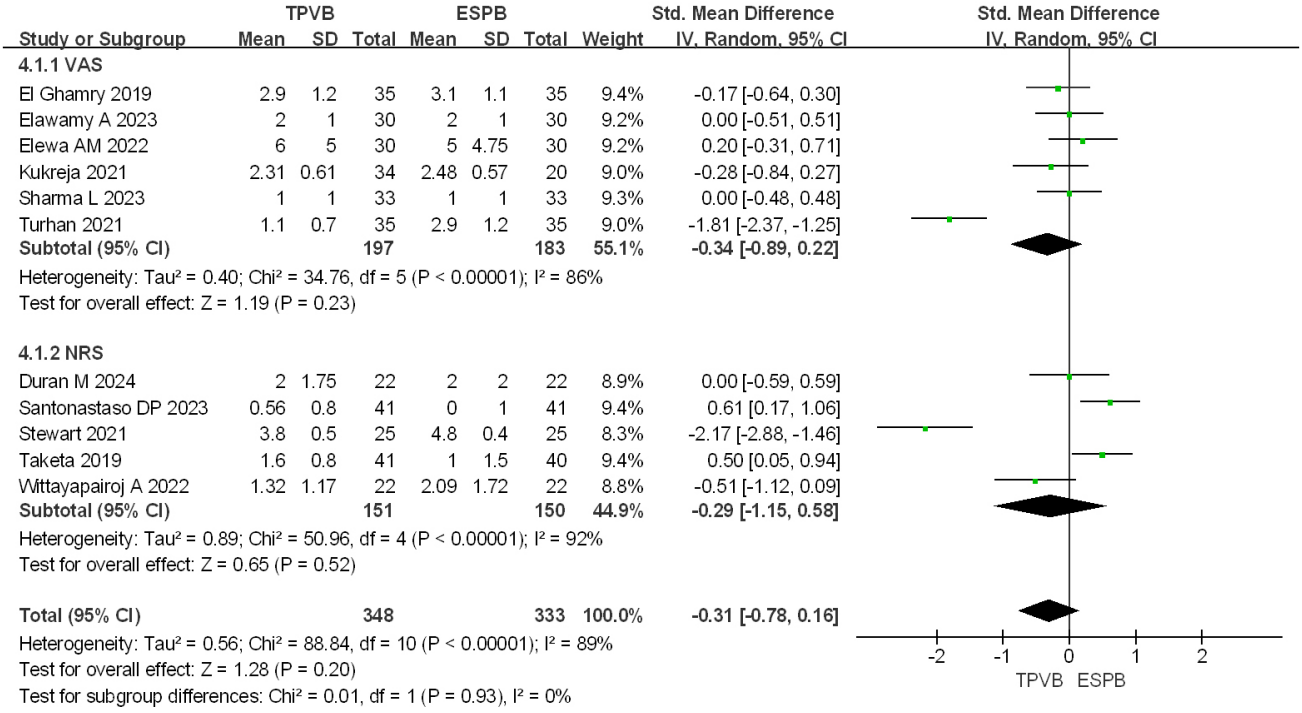

Fig. 9. Forest plot of subgroup analysis of pain scores in the resting state 12 h after operation.

ence in pain scores at 12 h postoperatively between TPVB and ESPB (Z = 1.19, $p = 0.23$), consistent with the overall findings before subgrouping.

MA of Pain Scores in Resting States at 24 h Postoperatively between TPVB and ESPB

A total of 14 studies assessed pain scores during resting states 24 h postoperatively for both TPVB and ESPB (Fig. 10). The analysis included 931 patients, with 472 in the TPVB group and 459 in the ESPB group. There was significant Het in pain scores at rest between the two groups at 24 h postoperatively ($Chi^2 = 79.22$, $I^2 = 84\%$, $p < 0.00001$). The overall effect size, represented by the diamond, was positioned to the left of the null line (SMD: –0.24, 95% CI = [–0.57, 0.09]), indicating the use of a REM for the MA. The comparison of pain scores during resting states at 24 h postoperatively showed no significant difference between the TPVB and ESPB groups (Z = 1.42, $p = 0.16$).

The FUP analysis of pain scores during resting states at 24 h postoperatively showed that the data points representing the included studies were primarily clustered around the central line. This distribution indicates an absence of PB and suggests high reliability (Fig. 11).

Due to Het among the included studies when comparing patients' pain scores during resting states at 24 h, the data were divided into two subgroups based on different pain scoring methods: VAS and NRS, for further analysis. The results (Fig. 12) revealed that the Het test for the NRS subgroup

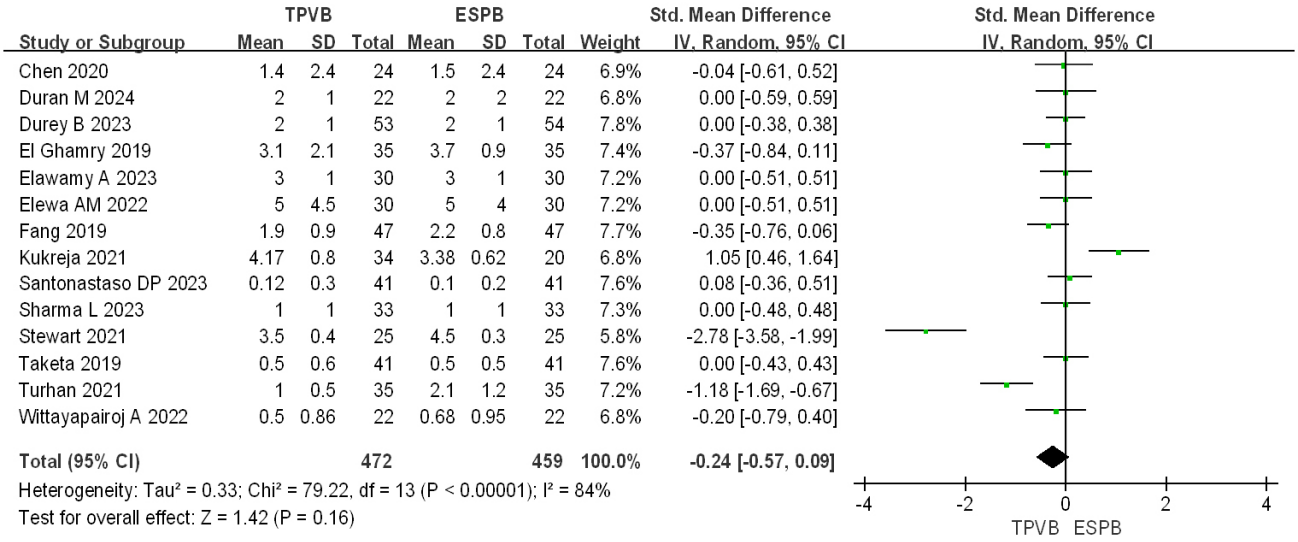

Fig. 10. Forest plot of pain scores in the resting state 24 h following operation.

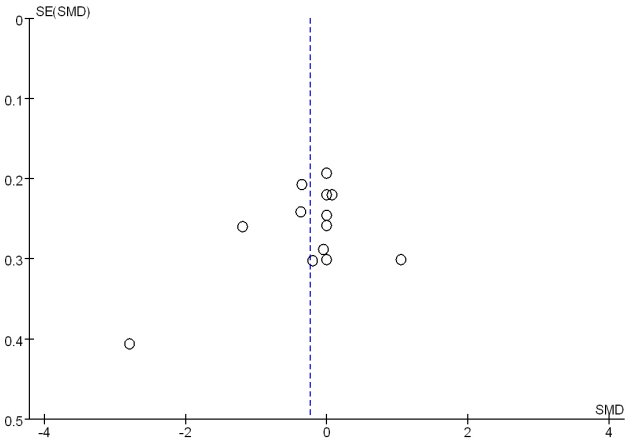

Fig. 11. FUP of pain scores in the resting state 24 h following operation. SE, standard error; SMD, standardized mean difference.

($Chi^2 = 44.55$, $I^2 = 89\%$, $p < 0.00001$) indicated increased Het compared to the overall analysis, suggesting that the Het may stem from the measurement tools used in the studies. The REM analysis (SMD: –0.42, 95% CI = [–1.04, 0.19]) indicated no significant difference in pain scores during resting states 24 h postoperatively between the TPVB and ESPB groups ($Z = 1.34$, $p = 0.18$). The results align with the overall findings before subgrouping. In the VAS subgroup, the Het test ($Chi^2 = 34.54$, $I^2 = 80\%$, $p < 0.0001$) indicated increased Het. The REM analysis for this subgroup (SMD: –0.13, 95% CI = [–0.52, 0.26]) also revealed no significant difference in pain scores during resting states 24 h postoperatively between TPVB and ESPB ($Z = 0.64$, $p = 0.52$), consistent with the overall findings before subgrouping.

After subgrouping, FUP for pain scores during resting states at 24 h revealed that the distribution of the data points was predominantly found near the central line, providing further evidence for the non-existence of PB and underscoring the elevated reliability (Fig. 13).

MA of Pain Scores in Resting States at 48 h Postoperatively between TPVB and ESPB

Seven studies evaluated pain scores during resting states at 48 h postoperatively for both TPVB and ESPB (Fig. 14). The analysis indicated that each of the seven included studies contributed more than 10% to the overall weight. The total sample comprised 527 patients, with 264 in the TPVB group and 263 in the ESPB group. There was significant Het in pain scores between the two groups at 48 h postoperatively ($Chi^2 = 45.45$, $I^2 = 87\%$, $p < 0.00001$). The overall effect size, represented by the diamond, was positioned to the left of the null line (SMD: –0.39, 95% CI = [–0.92, 0.15]), indicating the use of a REM for the MA. The comparison of pain scores during resting states at 48 h postoperatively showed no significant difference between the TPVB and ESPB groups ($Z = 1.42$, $p = 0.15$).

Due to Het among the included studies when comparing patients' pain scores during resting states at 48 h, the data were divided into two subgroups based on different pain scoring methods: VAS and NRS for further analysis. The results (Fig. 15) showed that the Het test for the NRS subgroup ($Chi^2 = 44.40$, $I^2 = 93\%$, $p < 0.00001$) indicated increased Het compared to the overall analysis, suggesting that the Het may originate from the measurement tools employed in the studies. The REM analysis (SMD: –0.61, 95% CI = [–1.67, 0.45]) revealed no significant difference in pain scores during resting states at 48 h postoperatively between the TPVB group and the ESPB group ($Z = 1.13$, $p = 0.26$). This finding is consistent with the overall results observed before subgrouping. In the VAS subgroup, the Het test ($Chi^2 = 0.68$, $I^2 = 0\%$, $p = 0.71$) indicated no significant Het, justifying the use of a FEM analysis (SMD: –0.18, 95% CI

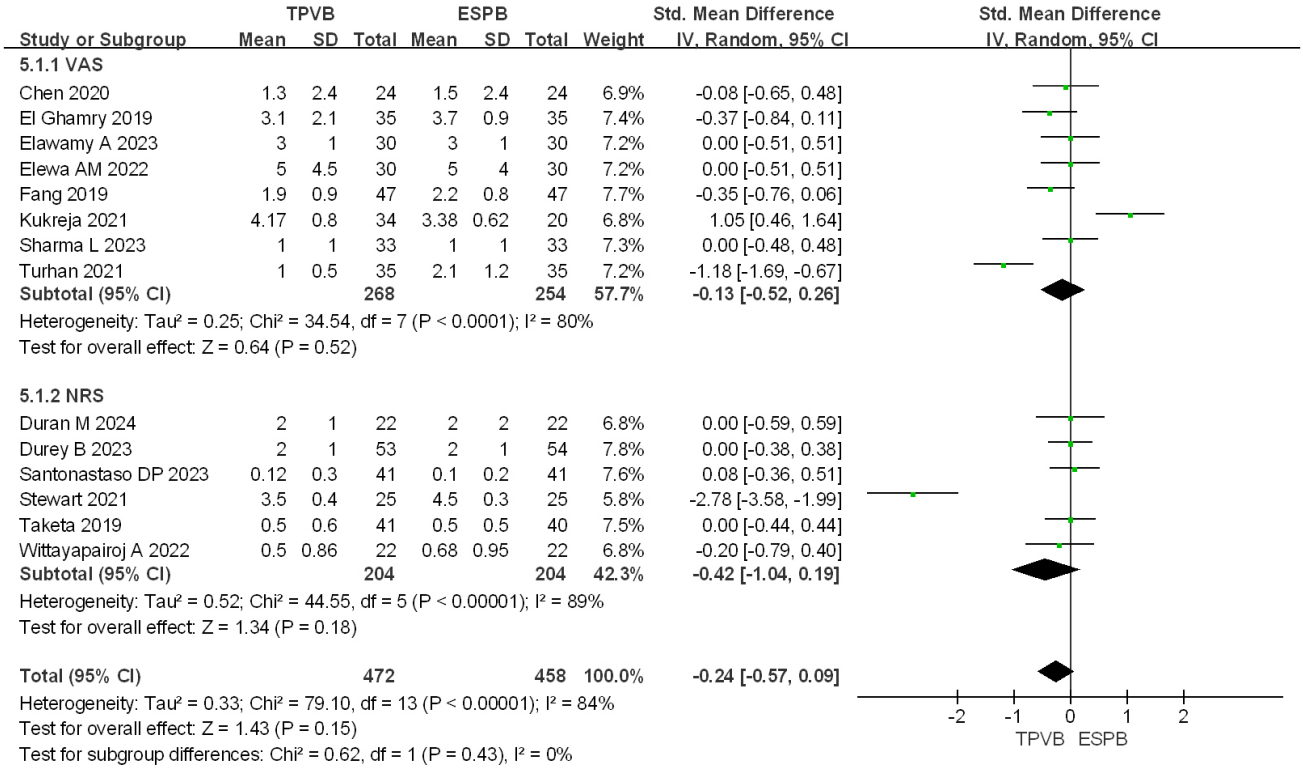

Fig. 12. Forest plot of subgroup analysis of pain scores in the resting state 24 h following operation.

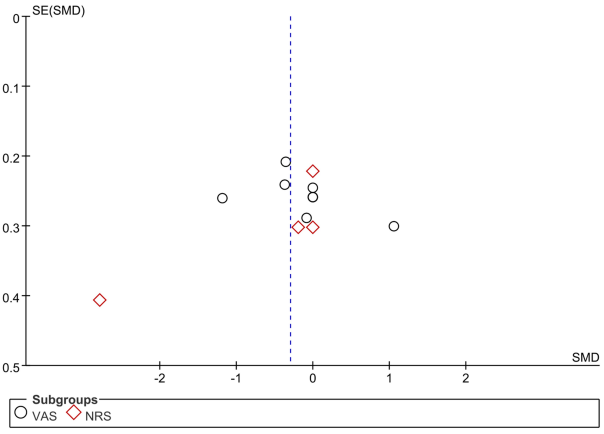

Fig. 13. FUP of subgroup analysis of pain scores in the resting state 24 h following operation.

= [–0.45, 0.09]). Similarly, no significant difference was found in pain scores during resting states at 24 h postoperatively between TPVB and ESPB (Z = 1.32, p = 0.19), which is consistent with the overall findings before subgrouping.

MA of Pain Scores in Non-Resting States at 1 h Postoperatively between TPVB and ESPB

Six studies evaluated pain scores during non-resting states at 1 h postoperatively for both TPVB and ESPB (Fig. 16). Each study contributed approximately 20% to the overall analysis weight. The analysis included 445 patients, with 223 in the TPVB group and 222 in the ESPB group. There was significant Het in pain scores during non-resting states at 1 h between the two groups (Chi^2 = 15.76, I^2 = 68%, p = 0.008). The overall effect size, represented by the diamond, was positioned to the left of the null line (SMD: –0.19, 95% CI = [–0.53, 0.14]), indicating the use of a REM for the MA. The comparison of pain scores during non-resting states at 1 h postoperatively showed no noticeable disparity between the TPVB and ESPB groups (Z = 1.14, p = 0.26).

Based on the different pain scoring methods used between the two groups, the data were divided into two subgroups: VAS and NRS, for further analysis. The results (Fig. 17) showed that the Het test for the VAS subgroup (Chi^2 = 9.90, I^2 = 70%, p = 0.02) demonstrated increased Het compared to the overall analysis, suggesting that the Het may stem from the measurement tools used in the studies. The REM analysis (SMD: –0.06, 95% CI= [–0.48, 0.37]) revealed no significant difference in non-resting pain scores at 48 h postoperatively between TPVB and ESPB (Z = 0.26, p = 0.79), consistent with the overall findings before subgrouping. It is noteworthy that only one study was included in the VAS subgroup.

MA of Pain Scores in Non-Resting States at 12 h Postoperatively between TPVB and ESPB

The analysis included six studies that assessed pain scores during non-resting states at 12 h postoperatively for both TPVB and ESPB (Fig. 18). Each study contributed more than 10% of the overall weight of the analysis. A total of

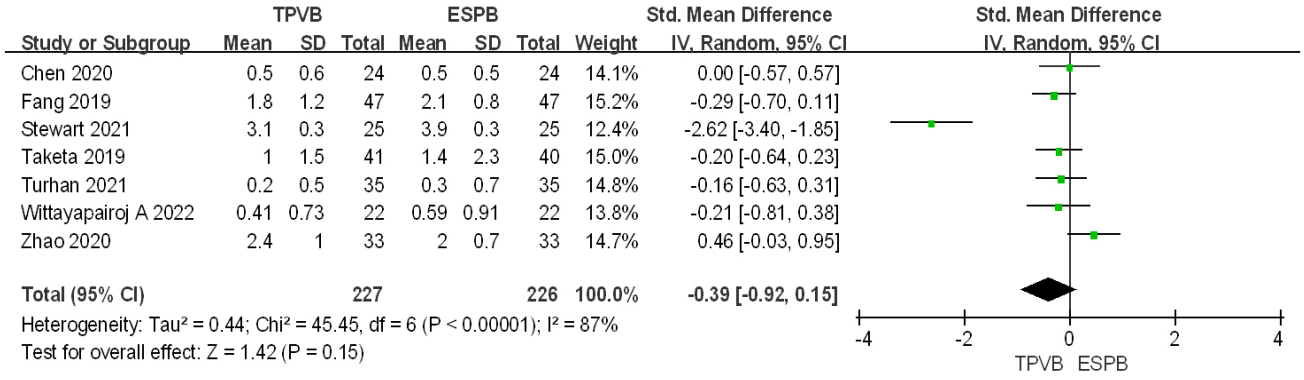

Fig. 14. Forest plot of pain scores in the resting state 48 h following operation.

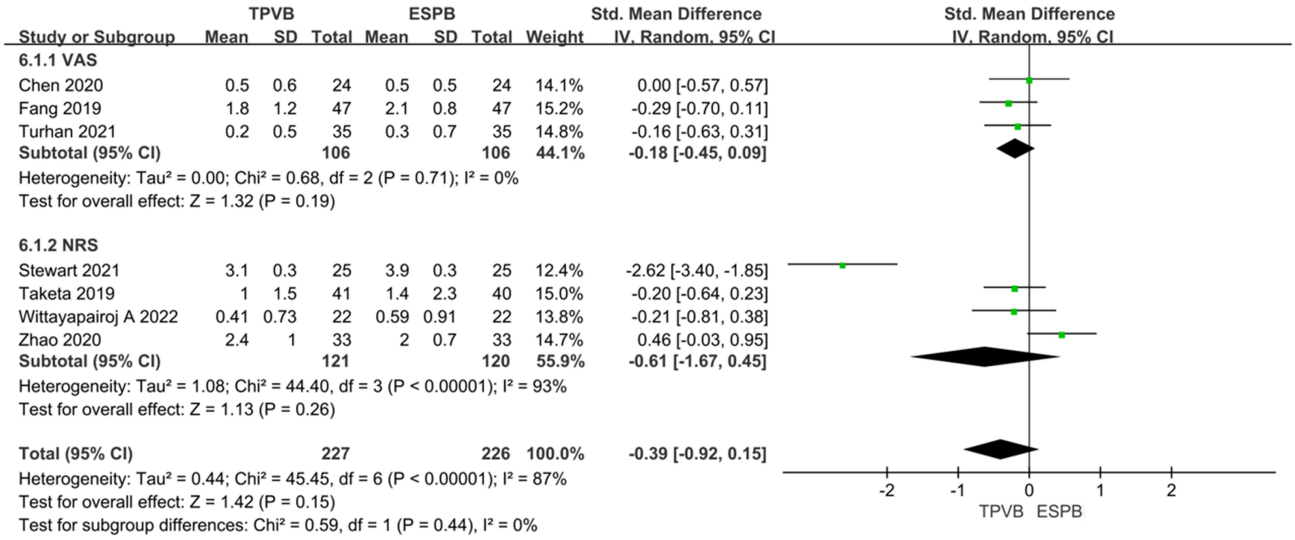

Fig. 15. Forest plot of subgroup analysis of pain scores in the resting state 48 h following operation.

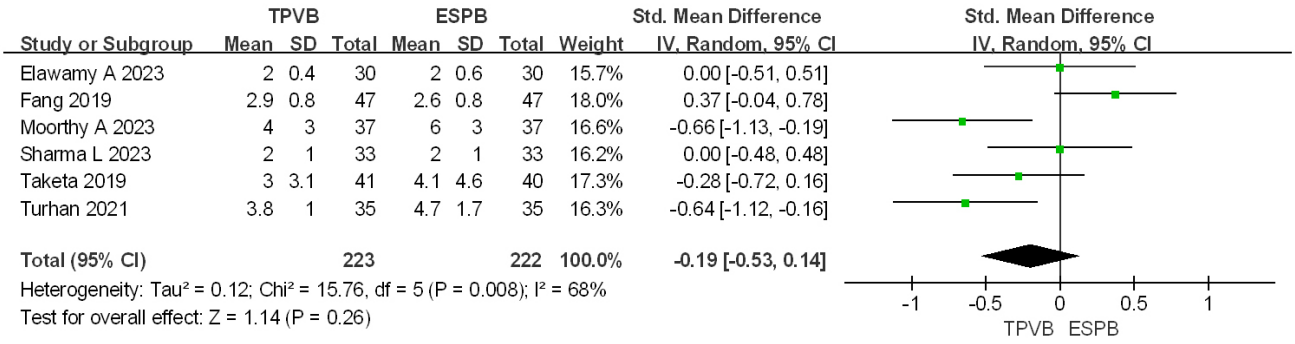

Fig. 16. Forest plot of pain score in the non-resting state 1 h following operation.

371 patients were included, with 186 in the TPVB group and 185 in the ESPB group. There was significant Het in pain scores between the two groups during non-resting states at 12 h postoperatively ($Chi^2 = 9.03$, $I^2 = 45\%$, $p = 0.11$). The overall effect size, represented by the diamond on the forest plot, was positioned to the left of the null line (MD: –0.49, 95% CI = [–0.67 –0.31]), indicating the use of a FEM for the MA. The comparison of pain scores during non-resting states at 12 h postoperatively suggested significant difference between the TPVB and ESPB groups ($Z = 5.28$, $p < 0.00001$).

Based on the different pain scoring methods used between the two groups, the data were divided into two subgroups: VAS and NRS for further analysis. In the NRS subgroup, the Het test results ($Chi^2 = 11.33$, $I^2 = 82\%$, $p = 0.003$) indicated a higher degree of Het compared to the over-

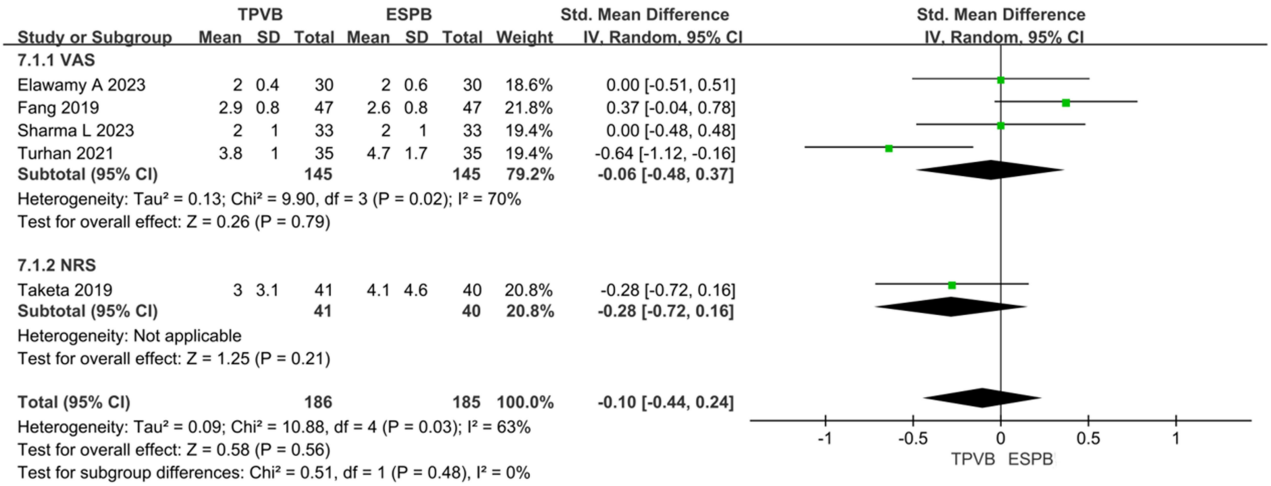

Fig. 17. Forest plot of subgroup analysis of pain scores in the non-resting state 1 h following operation.

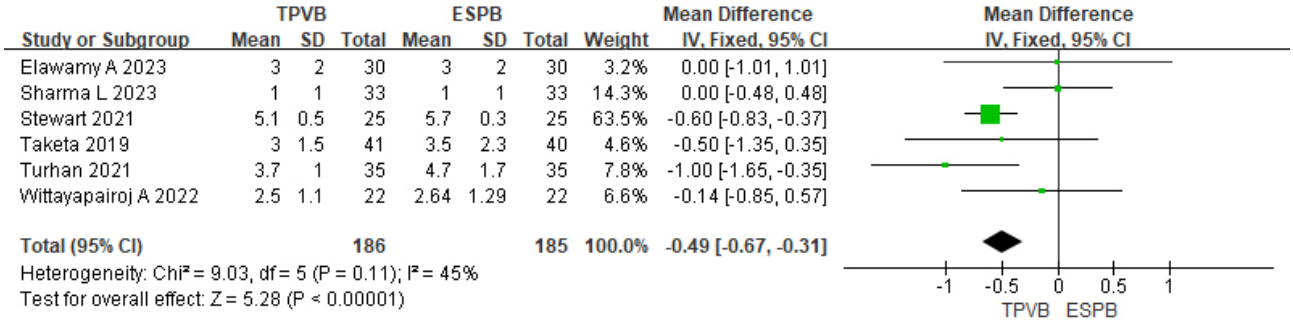

Fig. 18. Forest plot of pain score in the non-resting state 12 h following operation.

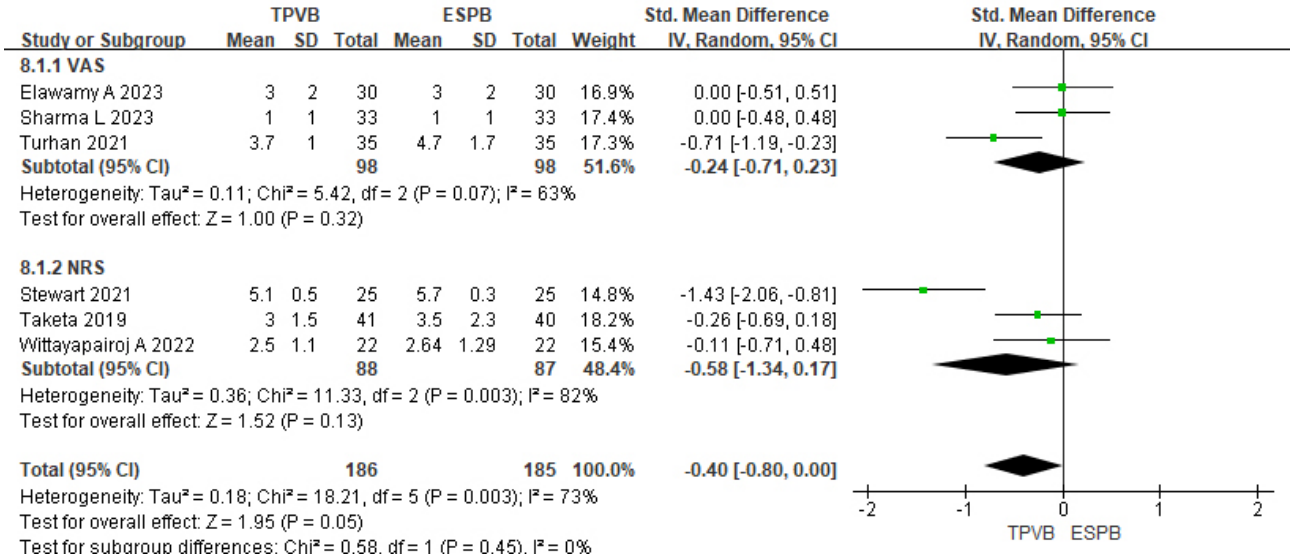

Fig. 19. Forest plot of subgroup analysis of pain scores in the non-resting state 12 h following operation.

all analysis, suggesting that the Het may be attributed to the measurement tools used in the studies (Fig. 19). The REM analysis for this subgroup (SMD: –0.58, 95% CI = [–1.34, 0.17]) did not demonstrate a significant difference in non-resting pain scores at 12 h postoperatively between the TPVB group and the ESPB group ($Z = 1.52$, $p = 0.13$). In contrast, the VAS subgroup exhibited moderate Het as indicated by the Het test ($Chi^2 = 5.42$, $I^2 = 63\%$, $p = 0.07$). The REM analysis (SMD: –0.24, 95% CI = [–0.71, 0.23]) also revealed no significant difference in non-resting pain

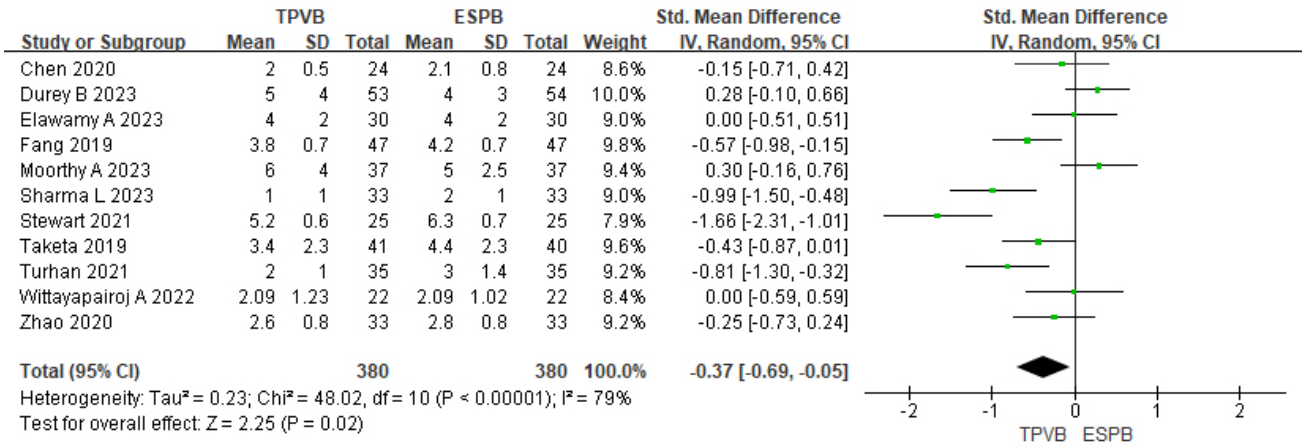

Fig. 20. Forest plot of pain scores in the non-resting state 24 h following operation.

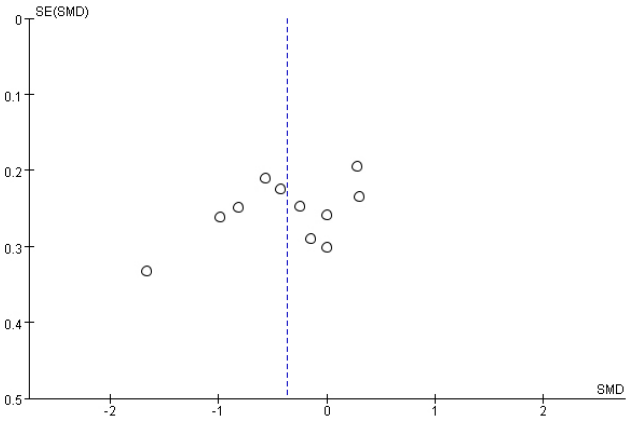

Fig. 21. FUP of pain scores in the non-resting state 24 h following operation.

scores at 12 h postoperatively between TPVB and ESPB (Z = 1.00, $p = 0.32$). These findings are consistent with the overall results obtained before subgrouping.

MA of Pain Scores in Non-Resting States at 24 h Postoperatively between TPVB and ESPB

11 studies reported pain scores during non-resting states at 24 h postoperatively for both TPVB and ESPB (Fig. 20). The study by Durey *et al*. (2023) [33] contributed the most weight to the analysis, accounting for 10%. The total sample size comprised 760 patients, with 380 in the TPVB and 380 in the ESPB. There was significant Het in pain scores during non-resting states at 24 h between the two groups ($Chi^2 = 48.02$, $I^2 = 79\%$, $p < 0.00001$). The overall effect size, represented by the diamond in the analysis, was positioned to the left of the null line (SMD: –0.37, 95% CI = [–0.69, –0.05]), indicating the use of a REM for the MA. The comparison of pain scores during non-resting states at 24 h postoperatively revealed a statistically significant difference between the TPVB and ESPB groups (Z = 2.25, $p = 0.02$).

The FUP analysis of pain scores during non-resting states at 24 h postoperatively suggested that the data points representing the included studies were primarily clustered around the central line. This clustering suggests the absence of PB and indicates high reliability (Fig. 21).

Regarding different pain scoring methods between the two groups, data were divided into two subgroups for further analysis: VAS and NRS. The results (Fig. 22) suggested that the Het test for the NRS subgroup ($Chi^2 = 26.90$, $I^2 = 85\%$, $p < 0.0001$) indicated increased Het compared to the overall analysis, suggesting that the Het may stem from the measurement tools used in the studies. The REM analysis (SMD: –0.38, 95% CI = [–0.96, 0.19]) revealed no significant difference in non-resting pain scores at 24 h postoperatively between the TPVB group and the ESPB group (Z = 1.31, $p = 0.19$), consistent with the overall results before subgrouping. For the VAS subgroup, the Het test ($Chi^2 = 5.64$, $I^2 = 29\%$, $p = 0.23$) indicated no significant Het, allowing for FEM analysis (SMD: –0.68, 95% CI = [–0.94, –0.42]). A significant difference was observed in non-resting pain scores at 24 h postoperatively between TPVB and ESPB, favoring the TPVB (Z = 5.11, $p < 0.00001$).

The FUP for subgroup analysis of pain scores during non-resting states at 24 h postoperatively also suggested that the data points were predominantly located near the central line. This observation suggests an absence of PB and high reliability (Fig. 23).

MA of the Pain Scores in the Non-Resting State at 48 h Postoperatively between TPVB and ESPB

Eight studies evaluated pain scores during non-resting states at 48 h postoperatively for both TPVB and ESPB (Fig. 24). The analysis indicated that six of these studies each contributed more than 10% of the overall weight in the MA. Collectively, the studies included 461 patients, with 231 in the TPVB group and 230 in the ESPB group. There was significant Het in pain scores during non-resting states at 48 h between the two groups ($Chi^2 = 56.68$, $I^2 = 88\%$, $p < 0.00001$). The diamond representing the overall effect was

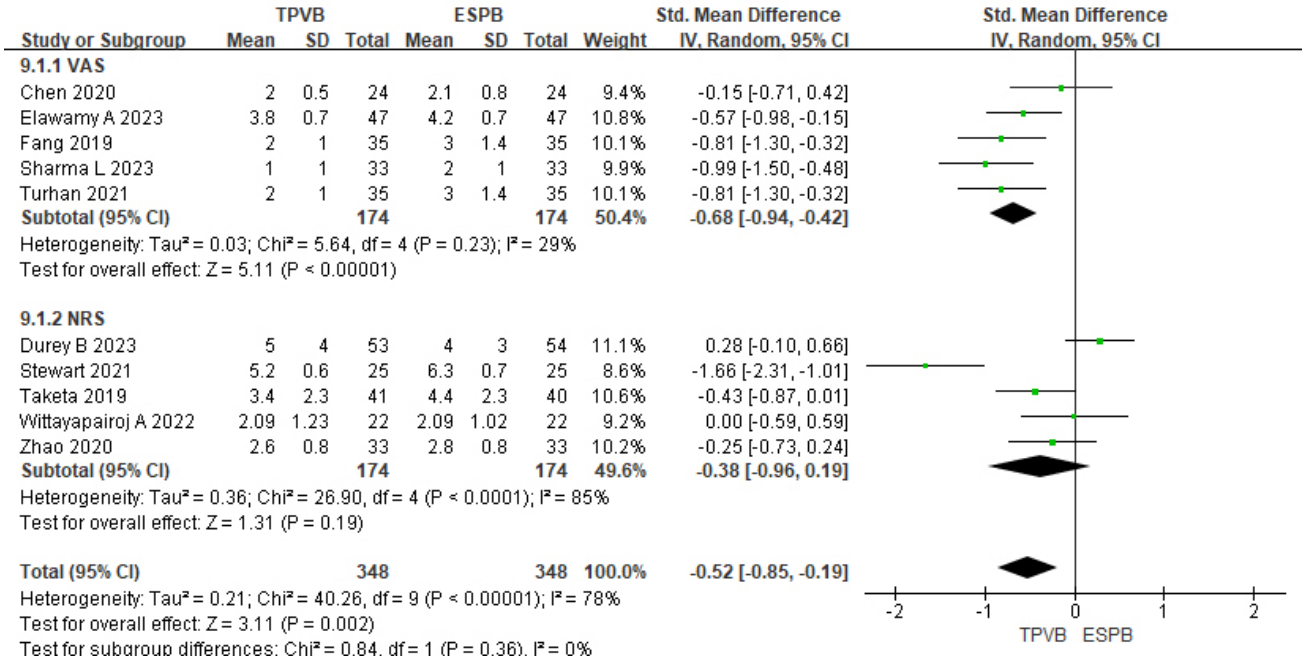

Fig. 22. Forest plot of subgroup analysis of pain scores in the non-resting state 24 h following operation.

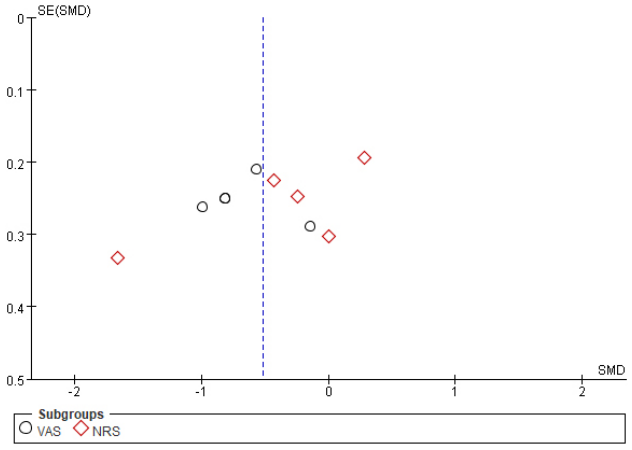

Fig. 23. FUP of subgroup analysis of pain scores in the non-resting state 24 h following operation.

positioned to the left of the null line (SMD: –0.12, 95% CI = [–0.63, 0.38]), indicating the use of a REM for the MA. The comparison of pain scores during non-resting states at 48 h postoperatively suggested a discernible difference between the TPVB and ESPB groups (Z = 0.48, $p = 0.63$).

Based on the different methods of pain scoring between the two groups, the data were divided into two subgroups: VAS and NRS, for further analysis. The results (Fig. 25) suggested that the Het test for the NRS subgroup ($Chi^2 = 30.48$, $I^2 = 90\%$, $p < 0.00001$) showed an increase in Het compared to the undivided analysis, suggesting that the Het may originate from the measurement tools used in the studies. The REM analysis (SMD: –0.23, 95% CI = [–1.08, 0.62]) revealed no significant difference in non-resting pain scores at 48 h postoperatively between TPVB and ESPB (Z = 0.53, $p = 0.60$), consistent with the overall results before subgrouping. For the VAS subgroup, the Het test ($Chi^2 = 1.30$, $I^2 = 0\%$, $p = 0.52$) indicated no significant Het, allowing for FEM analysis (SMD: –0.38, 95% CI = [–0.65, –0.11]). A significant difference was observed in non-resting pain scores at 48 h postoperatively between TPVB and ESPB, favoring TPVB (Z = 2.74, $p = 0.006$).

MA Results of Equivalent MC 24 h Post-Surgery

In a total of 12 articles, the total consumption of equivalent morphine at 24 h was reported. The Het among each article was significant ($Chi^2 = 72.77$, $I^2 = 85\%$, $p < 0.00001$). Consequently, REM was used to calculate the combined effect size (ES). Moreover, there was no statistically significant difference in the 24-hour consumption of morphine equivalents between the ESPB and TPVB groups (SMD: –0.13, 95% CI = [–0.50, 0.23], and $p = 0.48$) (Fig. 26).

Due to the Het between the two groups, they were divided into two subgroups for analysis based on the number of blocks performed, resulting in a single-block group and a multiple-block group. The results (Fig. 27) indicated Het within the single-block subgroup ($Chi^2 = 45.53$, $I^2 = 87\%$, $p < 0.00001$), showing increased Het compared to the pre-subgrouping state, suggesting that the Het may originate from the experimental detection tools. A REM analysis (SMD: –0.23, 95% CI = [–0.74, 0.29]) indicated no significant difference in total MC at 24 h postoperatively between the TPVB group and the ESPB group (Z = 0.86, $p = 0.39$), consistent with the results before subgrouping. Het testing within the multiple-block subgroup ($Chi^2 = 43.32$, I-squared (I^2) = 91%, $p < 0.00001$) also revealed significant

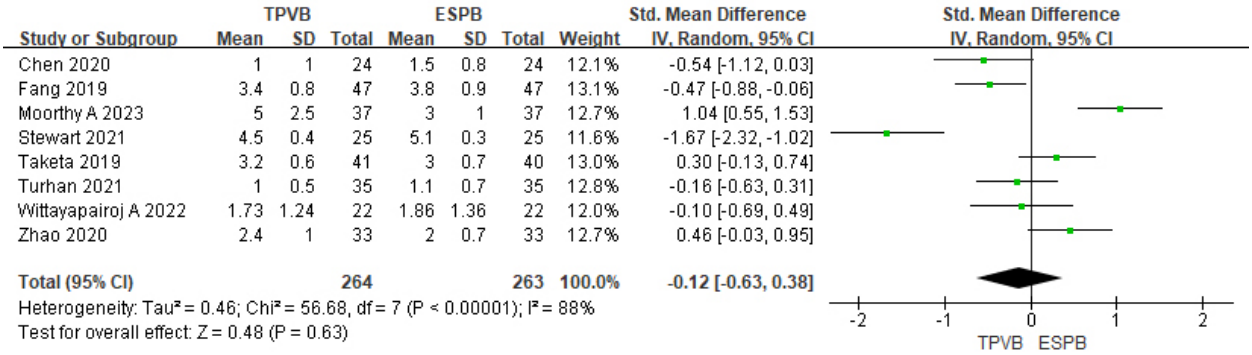

Fig. 24. Forest plot of pain score in the non-resting state 48 h following operation.

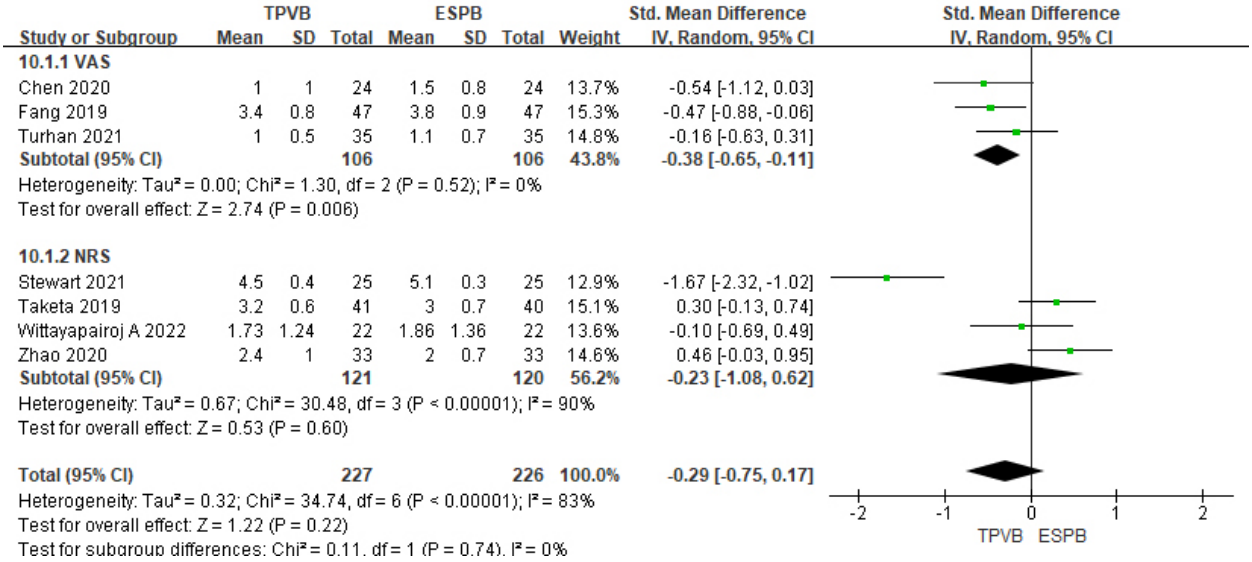

Fig. 25. Forest plot of subgroup analysis of pain score in the non-resting state 48 h following operation.

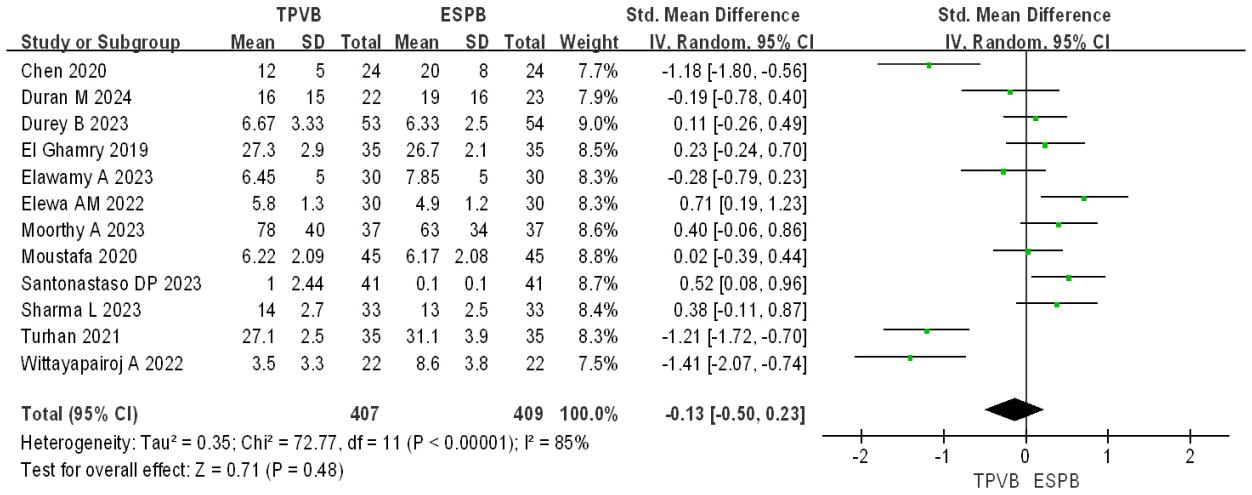

Fig. 26. Forest plot of morphine consumption (MC) equivalents 24 h following operation.

Het. The REM analysis (SMD: –0.21, 95% CI = [–0.62, 0.19]) similarly suggested no significant difference in total MC at 24 h postoperatively between TPVB and ESPB ($Z = 1.03$, $p = 0.30$).

MA Results of Occurrence of Postoperative N&V

The occurrence of postoperative N&V was evaluated across 14 studies. Het among these studies was not significant ($Chi^2 = 23.88$, $I^2 = 46\%$, $p = 0.03$). Consequently, a FEM

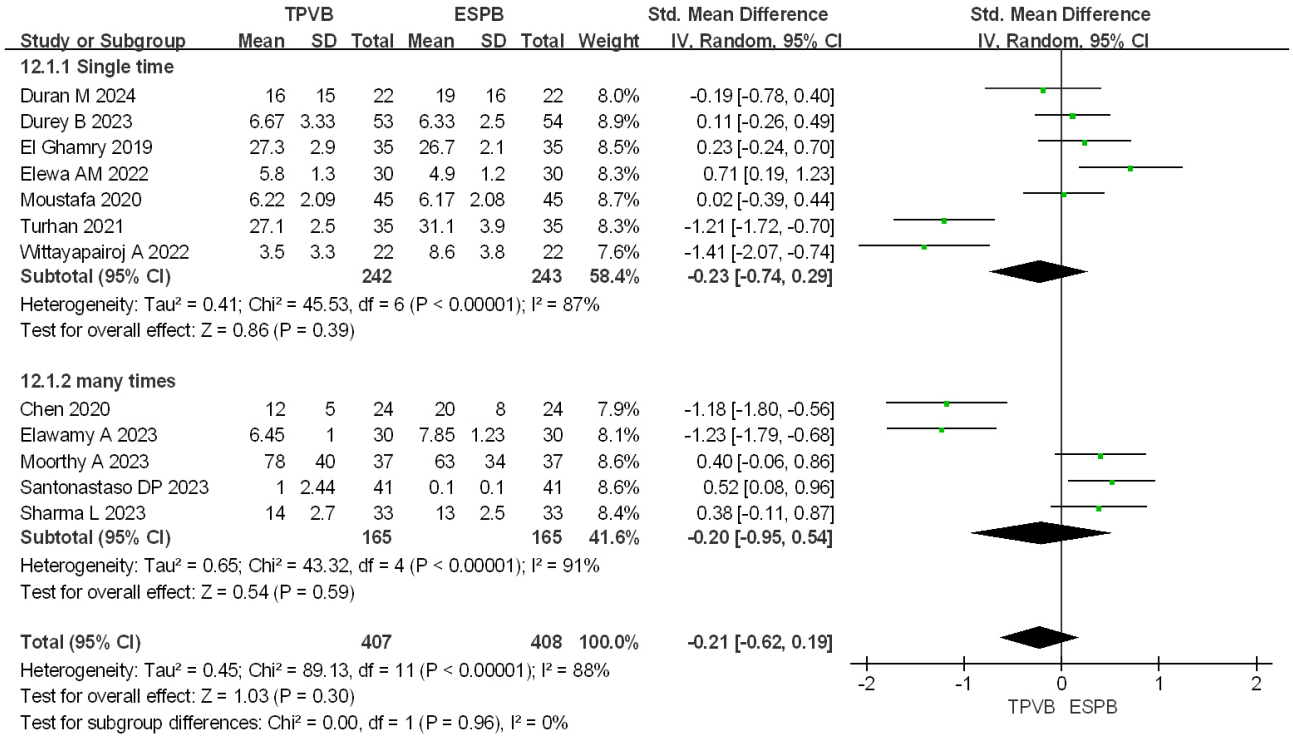

Fig. 27. Forest plot of subgroup analysis of total MC 24 h following operation.

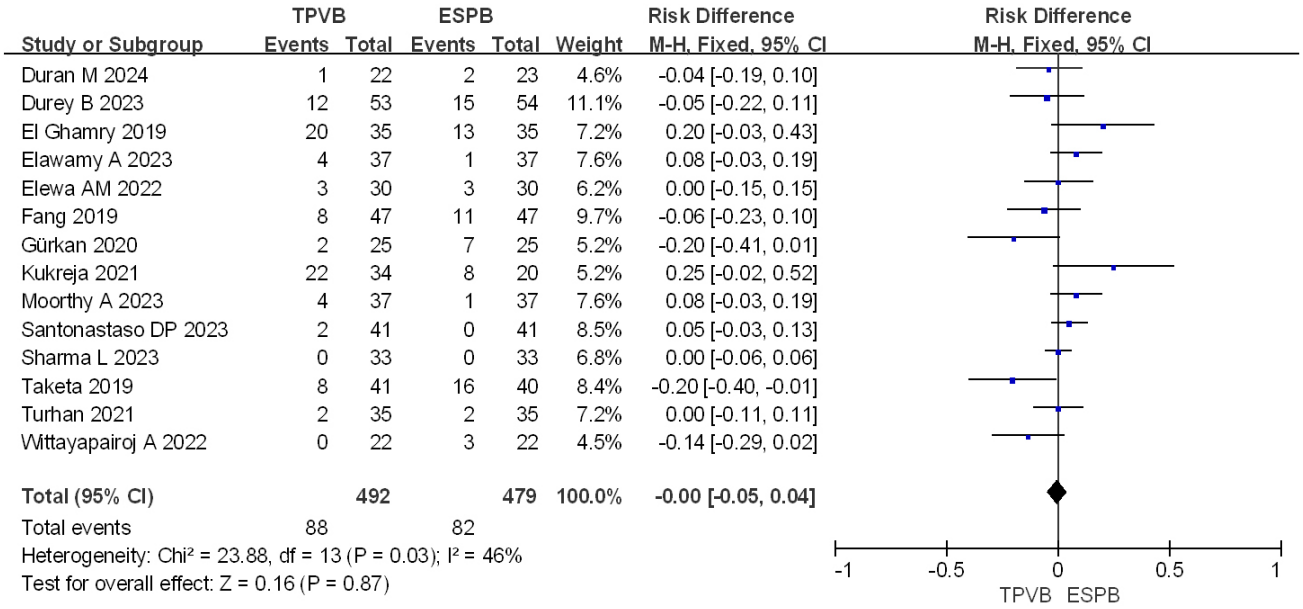

Fig. 28. Forest plot of occurrence of postoperative nausea and vomiting (N&V).

was employed to determine the pooled ES. The analysis revealed no statistically significant difference in the occurrence of postoperative N&V between the TPVB and the ESPB groups (RD = –0.00, 95% CI = [–0.05, 0.04], and $p = 0.87$) (Fig. 28).

The FUP analysis of the occurrence of postoperative N&V revealed that the data points were frequently clustered near the center line, suggesting the absence of PB and demonstrating high reliability (Fig. 29).

MA Results of Rescue Analgesia Times Following Surgical Procedure

The study examined three articles (items 19, 26, and 28) focusing on the timing of rescue analgesia following surgical procedures. Het among these articles was low ($I^2 < 50\%$). Therefore, a FEM was employed to calculate the combined ES. The analysis revealed significant statistical differences in rescue analgesia time between the TPVB group and ESPB group (RR = 0.46, 95% CI = [0.30, 0.71],

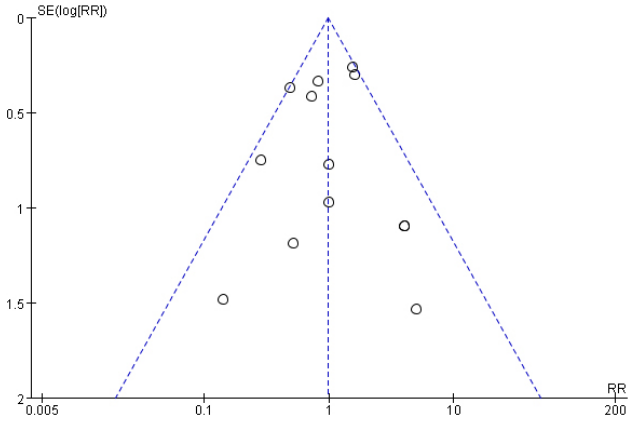

Fig. 29. FUP of occurrence of postoperative N&V.

and $p = 0.0004$) (Fig. 30). This indicates that rescue analgesia time was notably longer in the ESPB compared to the TPVB.

Discussion

Individuals undergoing thoracic surgery often experience excruciating discomfort. Effective management of postoperative pain is crucial for promoting early rehabilitation and recovery. The TPVB procedure involves the direct injection of anesthetic into the paravertebral interval, guided by ultrasonography. This technique allows for precise modulation of pain-induced hemodynamic changes. Consequently, study has characterized ultrasound-guided TPVB as a highly safe and efficient anesthetic method [37]. The ESPB is a contemporary trunk nerve block technique that has been increasingly utilized in clinical settings since the early 21st century. This procedure involves the injection of local anesthetic into the fascial plane located between the deep aspect of the erector spinae muscle and the parapophysis. The anesthetic subsequently diffuses into the paravertebral space, where it exerts its effect by blocking the dorsal, ventral, and communicating branches of the spinal nerves [38].

At 1 h postoperatively, patients who underwent thoracic paravertebral nerve block in a resting state exhibited significantly lower pain scores compared to those who underwent ESPB. Although both groups showed reduced pain scores after 12 h postoperatively, no significant difference was observed between them. In a non-resting state, at 24 and 48 h, the thoracic paravertebral nerve block demonstrated superior analgesic efficacy over the ESPB. Postoperative incisional pain was more severe in patients in a non-resting state compared to those at rest. There was no significant difference in total opioid consumption at 24 h between the two groups. However, the thoracic paravertebral nerve block group required significantly fewer rescue analgesia interventions compared to the ESPB group. The analgesic outcomes of TPVB on pain during cough at 12 h and 24 h postoperation were superior to those of the ESPB, consistent with the findings of Leong *et al*. (2021) [39]. Similarly, the study by Li *et al*. (2023) [40] indicated that both TPVB and ESPB were highly effective in alleviating postoperative pain. However, there was no significant difference between the two techniques regarding overall adverse reactions, such as postoperative vomiting and nausea, which aligns with our findings [40].

The TPVB method involves the direct administration of pharmaceuticals into the paravertebral spaces to effectively and precisely inhibit spinal nerve conduction [21]. The procedure of TPVB is technically challenging. In the meta-analysis of 18 RCTs, there were no reports of severe complications, such as pneumothorax or hematoma at the puncture site. The precision of real-time ultrasound-assisted TPVB is dependent on the clear visualization of anatomical layers and the precise identification of cardinal structures. Complications of a grave nature were prevalent in TPVB operations conducted under blind conditions using body surface markers. A comparison of N&V rates between TPVB and ESPB indicated no significant differences, underscoring that the utilization of localized nerve blockade diminishes postoperative opioid consumption and the risk of postoperative respiratory depression. This finding is consistent with the outcomes of Frauenknecht *et al*. (2019) [41]. Furthermore, clinical study has shown that the combination of ESPB with serratus anterior plane block is comparable to TPVB in terms of POA, consumption of intravenous morphine, VAS scores, pulmonary function parameters, frequency of rescue analgesia, duration of chest tube drainage, length of hospital stay, and the occurrence of other adverse events [42].

The analysis of sensitivity revealed that modifications to the cough-induced pain scores and the combined effects model did not alter the outcomes, suggesting that the MA results are stable and reliable. Nonetheless, the MA had certain limitations. First, some articles included in the analysis presented result indicators as line charts, which may lead to discrepancies between the extracted data and the original data. Second, there was a lack of standardization in the surgical methods, anesthesia regimens, and dosages, which could result in variations in evaluation results and introduce bias. Therefore, future meta-analyses should incorporate more multicenter, large-sample RCTs to address these issues.

Conclusions

The meta-analysis results indicated that the pain scores associated with TPVB during non-resting states at 24 h and 48 h postoperatively were significantly lower compared to those with ESPB. In resting states, the pain scores of thoracic paravertebral nerve block were lower than those of ESPB at 1 h postoperatively in clinical analgesia. Furthermore, TPVB markedly reduced the need for postoperative rescue analgesic interventions and provided more precise analgesic outcomes. Overall, it is expected that subsequent

Fig. 30. Rescue analgesia time following surgical procedure.

MA will encompass a greater number of RCTs and offer a more detailed classification of local anesthetic agents and their concentrations.

Availability of Data and Materials

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

Author Contributions

YCF, HYL, JXY, HLH, and SHR designed the research study. YCF and HYL performed the research. JXY and HLH wrote the manuscript. SHR analyzed the data. All authors contributed to important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.62713/aic.3495.

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