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Is robotic thoracic surgery associated with lower postoperative pain after lung cancer resection? A systematic review and meta-analysis of pain trajectories and recovery

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Abstract

Background This study aimed to evaluate postoperative pain evolution and perioperative rehabilitation in patients undergoing multiportal robotic-assisted thoracic surgery (RATS) versus video-assisted thoracic surgery (VATS) for lung cancer. The primary focus was to delineate the impact of these two surgical modalities on recovery trajectories.

Main body of the abstract We systematically queried PubMed, Embase, Web of Science, and the Cochrane Library through January 2026. Adhering to PRISMA 2020 criteria, 18 studies ($N=2,940$) comparing multiportal RATS versus VATS were identified. The primary endpoint was acute pain intensity on postoperative day (POD) 1. Secondary metrics encompassed extended pain evolution (from POD 3 to discharge), drainage duration, postoperative morbidity, and length of stay. Data synthesis was performed using a random-effects model. Evidence certainty was assessed via the GRADE framework. No significant difference was observed in the primary pooled analysis of POD 1 pain (mean difference [MD]: 0.09; 95% CI: -0.62 to 0.79; $P=0.81$), which remained non-significant after sensitivity adjustment (MD: 0.00; 95% CI: -0.34 to 0.35; $P=0.98$). RATS also demonstrated comparable extended pain intensity from POD 3 onwards (MD: -0.11; 95% CI: -0.47 to 0.25; $P=0.54$). RATS exhibited a non-significant trend toward shorter drainage periods initially (MD: -0.29 days; 95% CI: -0.59 to 0.02; $P=0.06$), which became statistically significant after sensitivity adjustment for outlier exclusion (MD: -0.41 days; 95% CI: -0.63 to -0.18; $P=0.0005$). Furthermore, RATS significantly reduced length of stay (MD: -0.84 days; 95% CI: -1.06 to -0.63; $P<0.00001$). The incidence of overall morbidity was statistically comparable between both cohorts (risk ratio [RR]: 0.88; 95% CI: 0.74 to 1.04; $P=0.13$).

Short conclusion Multiportal RATS achieved equivalent postoperative pain control at POD 1 compared to multiportal VATS, though clinical recovery efficiency proved superior. These advantages likely stem from technical

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precision and earlier tube removal. However, due to the predominance of retrospective data, these findings are underpinned by very low evidence certainty.

Keywords Lung cancer, Robotic-assisted thoracic surgery, Video-assisted thoracic surgery, Postoperative pain, Analgesic consumption, Meta-analysis

Background

Lung cancer remains the primary cause of malignancy-related mortality worldwide [1, 2], and surgical resection is the cornerstone of curative intent for early-stage disease [3]. Over recent decades, multiportal video-assisted thoracic surgery (VATS) has emerged as the definitive surgical standard [4, 5]. By significantly minimizing operative trauma and streamlining patient rehabilitation compared to open thoracotomy, it has redefined perioperative care in thoracic surgery [6].

The emergence of robot-assisted thoracic surgery (RATS) marks a significant progression in minimally invasive techniques [7, 8]. By offering high-definition three-dimensional imaging, tremor suppression, and increased degrees of freedom for instrument manipulation, it addresses several limitations of conventional video-assisted approaches. Theoretically, these technological advancements are hypothesized to permit precise anatomical dissection and limit mechanical stress on the chest wall. However, despite the rapid global adoption of RATS, its comparative advantage in alleviating postoperative pain remains a subject of intense debate. Existing literature reveals notable discrepancies regarding pain outcomes. While randomized controlled trials (RCTs) like Catelli et al. reported significantly reduced pain intensity for RATS [9], other robust data, such as the findings by Duclos et al., indicated no such advantage at rest. Furthermore, subjective pain assessments often diverge from objective analgesic consumption. For example, despite Duclos et al. noting higher 48-hour morphine requirements in RATS cases [10], recent evidence from Wang et al. in ambulatory settings demonstrated a significant decrease in total analgesic intake compared to VATS [11].

Such contradictory findings regarding both subjective pain trajectories and objective analgesic consumption highlight the need for a comprehensive meta-analysis to clarify these discrepancies. To address this, we conducted a systematic review and meta-analysis aimed at rigorously evaluating the clinical efficacy and safety profiles of multiportal RATS versus multiportal VATS for lung cancer patients. By gathering the best evidence available, this research seeks to assess if RATS technological advancements lead to better clinical recovery and improved postoperative medication management, to inform clinical decision-making.

Methods

Search strategy

This meta-analysis was executed in accordance with the preferred reporting items for systematic reviews and meta-analyses (PRISMA) 2020 reporting standards [12]. We prospectively documented the research protocol in the PROSPERO registry (ID: CRD420251250780) to ensure methodological transparency.

A systematic query was performed across the Cochrane Library, Web of Science, Embase, and PubMed, encompassing all literature from their respective commencement dates through January 2026. Two reviewers amongst the authors (DW and AP) independently evaluated the initially identified publications. The retrieval strategy integrated MeSH descriptors with unrestricted text strings centered on the following clinical themes: (1) Target Disease and Procedures: "lung neoplasms", "pneumonectomy", "pulmonary surgical procedures", "lobectomy", "segmentectomy", "wedge resection", and "pulmonary resection"; (2) Surgical Approaches: "robotic surgical procedures", "RATS", "thoracic surgery, video-assisted", and "VATS"; (3) Outcomes and Recovery: "postoperative pain", "analgesia", "analgesics", "opioid consumption", "pain measurement", "visual analog scale (VAS)", and "recovery of function".

Complete search algorithms for all utilized databases are documented in Supplementary Material 1. To ensure thoroughness, we also hand-searched the bibliographies of identified reviews and original studies for further pertinent records.

Selection criteria

Criteria for inclusion were defined as follows: (1) Participants: individuals treated for lung cancer via surgical resection; (2) Intervention: Multiportal RATS; (3) Comparison: Multiportal VATS (operationally defined as ≥2 ports, with uniportal VATS strictly excluded); (4) Endpoints: acute pain on postoperative day (POD) 1 served as the primary measure. Secondary metrics included extended pain evolution (from POD 3 until discharge), analgesic intake, drainage duration, overall morbidity (standardized across cohorts as any documented surgical or medical complication occurring within 30 days or during the index hospitalization), and length of hospital stay (LOS). (5) Study Design: RCTs or comparative observational studies.

Data extraction and quality assessment

Data extraction was performed independently by two researchers (DW and AP) utilizing a pre-formatted collection template. Recorded variables encompassed: (1) Study identifiers: primary author, year of publication, geographic origin, and design; (2) Participant and operative profiles: cohort size, age, surgical techniques, and port layout; (3) Clinical endpoints: acute pain on POD 1, longitudinal pain evolution (POD 3 through discharge), analgesic utilization (encompassing drug class, dosage, and duration), drainage time, overall morbidity, and LOS. To facilitate meta-analysis, results originally presented as medians with interquartile ranges (IQR) or ranges were transformed into means and standard deviations (SD) via validated, sample-size-dependent statistical estimation formulas. Regarding pain outcomes, scores reported via different scales were linearly standardized to a uniform 0–10 point system prior to pooling. To minimize clinical heterogeneity, pain intensities measured under resting conditions (at rest) were preferentially extracted and utilized for the final quantitative synthesis.

The quality of the methods used in the included studies was independently evaluated by the same two reviewers. The Cochrane Risk of Bias tool was used to assess RCTs. Methodological quality of observational studies was appraised via the Newcastle-Ottawa Scale (NOS), wherein a threshold of 7 or higher signified superior quality. Additionally, we utilized the GRADE system (via the GRADEpro GDT online tool) to determine the certainty of evidence for each endpoint. To detect potential publication bias, funnel plot asymmetry was visually inspected and statistically corroborated through Egger's linear regression test. Any discrepancies between the primary reviewers were resolved by consensus or through referral to a third senior arbiter (EP).

Statistical analysis

Data processing and synthesis were executed via Stata (version 17.0) and Review Manager (version 5.4). Continuous parameters, including pain intensity, drainage time, and LOS, were expressed as mean differences (MDs) alongside 95% confidence intervals (CIs). Mean differences were preferentially selected over standardized mean differences for pain outcomes because all metrics were mathematically harmonized to a uniform 0–10 baseline, thereby preserving direct clinical interpretability. For dichotomous variables, including overall morbidity, the risk ratio (RR) with 95% CIs was determined.

Inter-study variability was evaluated via the I^2 index and Cochran's Q-test. Evidence of substantial heterogeneity was defined as an I^2 value exceeding 50% or a P-value below 0.10. Consequently, a random-effects model was employed for all quantitative syntheses, regardless of the observed heterogeneity. Specifically, the classical DerSimonian-Laird (DL) random-effects estimator was utilized without the Hartung-Knapp adjustment. Additionally, to address potential selection bias inherent in observational designs, a protocol-pre-specified methodological subgroup analysis was performed for pain outcomes by stratifying the evidence into high-quality cohorts (RCTs and PSM studies) versus unadjusted observational studies.

To ensure the reliability of our findings, sensitivity analyses were executed through systematic, one-by-one study exclusion. Additionally, an alternative sensitivity analysis was implemented by systematically omitting all cohorts relying on transformed data to ensure that mathematical estimations did not distort the primary findings. Due to diverse reporting metrics (e.g., Morphine Milligram Equivalents [MME], rescue frequency), analgesic consumption was synthesized qualitatively rather than quantitatively pooled.

Evidence certainty was appraised across the five standard GRADE dimensions: risk of bias, inconsistency, indirectness, imprecision, and publication bias using GRADEpro GDT online tool. To detect potential reporting bias, we combined visual funnel plot inspection with Egger's linear regression analysis in Stata 17, thereby ensuring a more robust quantitative evaluation.

Results

Study selection

Our systematic search identified 536 citations across EMBASE ($n = 373$), Web of Science ($n = 121$), PubMed ($n = 37$), and the Cochrane Library ($n = 5$). Following the removal of 128 duplicates, 408 unique records underwent title and abstract evaluation. At this stage, 358 were excluded for the following reasons: (1) non-original research, including reviews, meta-analyses, letters, case reports, or meeting abstracts ($n = 183$); (2) studies not involving target surgical procedures (lobectomy, segmentectomy, or wedge resection) ($n = 169$); and (3) non-English publications ($n = 6$).

Fifty papers were prioritized for comprehensive full-text review. Upon thorough appraisal, 32 reports were discarded for the following reasons: (1) ongoing research lacking available data ($n = 1$); (2) non-target demographics, specifically pediatric cases ($n = 1$); (3) absence of relevant clinical endpoints ($n = 24$); (4) uncontrolled, single-arm investigations ($n = 3$); and (5) lack of comparative control groups ($n = 3$). Consequently, 18 studies fulfilled all eligibility requirements and were synthesized in this meta-analysis. The selection trajectory is detailed in the PRISMA flow diagram (Fig. 1A).

Study characteristics and quality assessment

Table 1 provides a comprehensive overview of the clinical features across the 18 enrolled cohorts. A total of 2,940

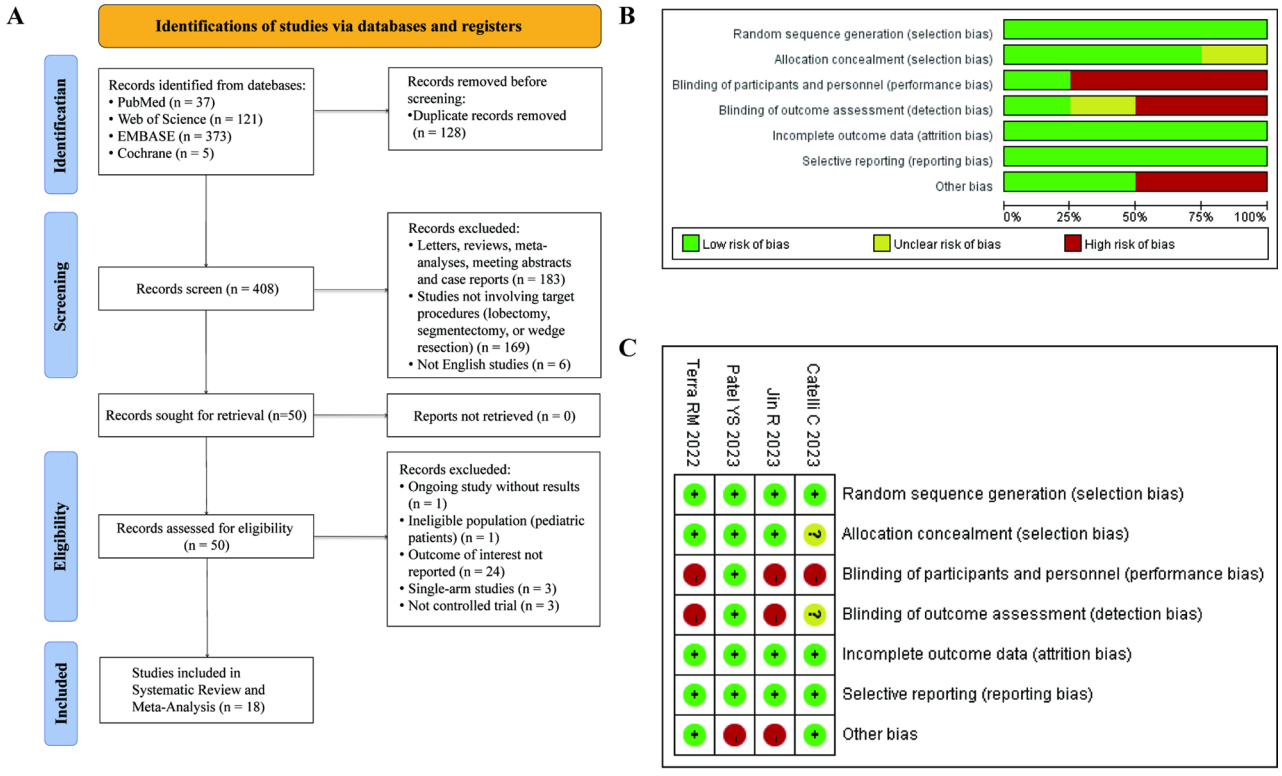

Fig. 1 Selection and quality assessment. (**A**) PRISMA flow diagram. (**B**) Risk of bias graph. (**C**) Risk of bias summary

Table 1 Foundational profiles of 18 eligible studies evaluating RATS versus VATS

Author (Year)	Country	Design	*N*(*R*/V)	Procedures	Ports (*R*/V)	Age (Year)		Pain Scale
						R	V	
Catelli C (2023) [9]	Italy	RCT	25/50	Lob	4/2	67.00 ± 10.00	68.00 ± 10.00	VAS
Jin R (2023) [14]	China	RCT	157/163	Lob	4/2	61.00 ± 8.89	62.00 ± 11.11	NRS
Patel YS (2023) [15]	Canada, etc.	RCT	81/83	Lob	4/3	67.26 ± 11.11	66.52 ± 10.37	EQ-VAS
Terra RM (2022) [16]	Brazil	RCT	37/39	Lob	4/3	68.40 ± 9.78	65.70 ± 12.27	NR
Zhang Y (2025) [17]	China	Pro	106/92	Lob/Seg	4/3	51.25 ± 14.75	51.25 ± 12.25	NR
Novellis P (2021) [18]	Italy	Pro-PSM	45/45	Lob	4/2	NR	NR	NRS
Duclos G (2018) [10]	France	Pro-PSM	75/75	Lob/Seg	4/3	NR	NR	VAS
Deeb AL (2024) [19]	USA	Ret-PSM	71/142	Lob/Seg	4/3	68.25 ± 11.26	68.10 ± 9.63	NRS
Lan Z (2024) [20]	China	Ret-PSM	42/84	Lob	4/2	58.10 ± 9.40	58.10 ± 11.50	NR
Qu C (2022) [21]	China	Ret-PSM	316/316	Lob/Seg	4/2	58.48 ± 9.60	57.93 ± 11.02	NRS
Zheng L (2022) [13]	China	Ret-PSM	55/55	Lob/Seg	3/3	61.24 ± 8.56	62.15 ± 9.12	NRS
Catelli C (2025) [22]	Italy	Ret	39/58	Seg	4/3	70.10 ± 8.30	68.70 ± 8.80	VAS
Tao H (2025) [23]	Japan	Ret	43/46	Lob/Seg	5/3	73.13 ± 5.56	71.00 ± 7.41	NRS
Wang Y (2024) [11]	China	Ret	102/102	Lob	3/2	56.95 ± 10.73	54.07 ± 12.52	VAS
Asemota N (2023) [24]	UK	Ret	47/79	Lob/Seg	4/3	69.80 ± 9.10	75.60 ± 9.60	NR
Testori A (2022) [25]	Italy	Ret	22/17	Lob	4/2	67.10 (SD NR)	69.10 (SD NR)	NRS
Gullo R (2021) [26]	Italy	Ret	35/96	Lob/Seg	4/2	69.30 ± 12.75	65.50 ± 10.25	NRS
van der Ploeg APT (2020) [27]	Netherlands	Ret	50/50	Lob	5/3	65.70 ± 10.37	68.00 ± 6.67	NRS

Notes: R, robot-assisted thoracic surgery; V, video-assisted thoracic surgery; RCT, randomized controlled trial; Pro, prospective study; Ret, retrospective study; PSM, propensity-score matched; Lob, lobectomy; Seg, segmentectomy; NR, not reported; N (R/V), sample size in RATS and VATS groups; Ports (R/V), number of surgical incisions in RATS and VATS groups; SD, standard deviations; Data are reported as mean ± SD except where indicated otherwise; VAS, visual analog scale; NRS, numerical rating scale; EQ-VAS, EuroQol Visual Analogue Scale

patients participated in these studies, which were published from 2018 to 2025, with 1,348 in the RATS group and 1,592 in the VATS group. The number of patients in each study varied from 39 to 632. Regarding the regional distribution of the analyzed literature, a significant proportion of the research originated from Europe (n = 8) and Asia (n = 7). The remaining cohorts were identified in North America (n = 2) and South America (n = 1), representing a diverse global perspective on the subject. Regarding the surgical configuration, 14 studies utilized a four-port RATS technique (three operative ports and one assistant port), while 2 studies (Zheng et al. [13] and Wang et al. [11]) employed a three-port robotic approach. In the VATS group, 10 studies followed a triportal approach, whereas biportal techniques were reported in 8 studies. All robotic procedures were performed using the da Vinci Surgical System (Si, Xi, or X). Regarding postoperative management, a standardized single chest tube protocol was utilized across all studies. Additionally, 11 studies reported data on postoperative analgesic consumption. Quantitative pooling was not performed because reporting metrics, such as MME and cumulative doses, were too heterogeneous. Specifically, key barriers to a standardized subset analysis (e.g., 0–48 h in MME) included the mixing of acute perioperative data with total length-of-stay totals, the omission of standard deviations in primary reports, and the aggregate reporting of non-opioid co-analgesics, which mathematically precluded reliable quantitative pooling. Regarding chest tube placement, the RATS cohort predominantly used posterior or lateral port sites (typically in the 7th–9th intercostal spaces). Conversely, the VATS cohort more frequently placed the tube through the anterior utility incision or anterior axillary line ports. All 18 publications compared multiportal RATS versus VATS for pulmonary resection, including lobectomy and segmentectomy.

Table 2 Evaluation of the quality of included observational studies using the Newcastle-Ottawa Scale (NOS)

Author (Year)	Selection (up to 4 stars)	Comparability (up to 2 stars)	Outcome (up to 3 stars)	Total Score	Quality
Zhang Y (2025) [17]	★★★★	★★	★★★	9	High
Novellis P (2021) [18]	★★★★	★★	★★★	9	High
Duclos G (2018) [10]	★★★★	★★	★★★	9	High
Deeb AL (2024) [19]	★★★★	★★	★★★	9	High
Qu C (2022) [21]	★★★★	★★	★★★	9	High
Zheng L (2022) [13]	★★★★	★★	★★★	9	High
Catelli C (2025) [22]	★★★★	★☆	★★★	8	High
Tao H (2025) [23]	★★★★	★☆	★★★	8	High
Lan Z (2024) [20]	★★★★	★★	★★★	9	High
Wang Y (2024) [11]	★★★★	★☆	★★★	8	High
Asemota N (2023) [24]	★★★☆	☆☆	★★★	6	Moderate
Testori A (2022) [25]	★★★★	★☆	★★★	8	High
Gullo R (2021) [26]	★★★★	★★	★★★	9	High
van der Ploeg APT (2020) [27]	★★★★	★☆	★★★	8	High

Note: Quality was evaluated using the Newcastle-Ottawa Scale (NOS), with scoring criteria as follows: Selection (up to 4 stars), Comparability (up to 2 stars), and Outcome (up to 3 stars). Adjustment: Studies rated 2 stars for comparability employed methods such as propensity score matching (PSM), multivariable regression, or generalized estimation equations (GEE) models to adjust for confounders. Grading: Scores ranging from 7 to 9 are considered High quality, while scores from 4 to 6 are deemed Moderate quality. Symbols: '★' signifies one star given; '☆' signifies no star given

The methodological rigor of the 4 RCTs was appraised through the Cochrane Risk of Bias tool (Fig. 1B and C), whereas the 14 observational studies were evaluated using the NOS (Table 2). RCTs primarily exhibited low risk of bias, though blinding was achieved only by Patel et al. [15]. Among observational cohorts, 92.9% (n = 13) were rated high-quality (scores 7 to 9), with Asemota et al. [24] as the sole moderate-quality study. To ensure comparability, 6 observational studies employed propensity-score matched (PSM), while others utilized multivariable regression or generalized estimation equations (GEE). Evidence certainty for each endpoint was appraised via the GRADE methodology. Overall, the robust methodology across studies provides a reliable foundation for this meta-synthesis.

Short-term postoperative pain at POD 1

A total of 8 primary studies (including the cohorts by Wang et al. [11], Qu et al. [21], and others [9, 10, 14, 16, 18, 19]) contributed baseline data to the postoperative pain analysis at POD 1. Preliminary synthesis of 8 investigations identified equivalent POD 1 pain levels between RATS and VATS cohorts (MD: 0.09; 95% CI: -0.62 to 0.79; P = 0.81; Cochran's Q = 359.79, τ^2 = 0.94, I^2 = 98%; 95% prediction interval [PI]: -2.44 to 2.62; Fig. 2A). To investigate the origin of statistical inconsistency, we performed a sensitivity analysis by removing two methodological outliers (Qu et al. [21] and Wang et al. [11]). This adjustment diminished the I^2 to 62%, while the overall estimate persisted as non-significant (MD: 0.00; 95% CI: -0.34 to 0.35; P = 0.98; Cochran's Q = 13.24, τ^2 = 0.10, I^2 = 62%; 95% PI: -1.00 to 1.00; Fig. 2B). These results reinforce the primary outcome's reliability, demonstrating that the robotic system achieves clinical parity with VATS in early pain management. Methodological subgroup analysis confirmed that the equivalence in POD 1 pain remained highly robust, with no significant differences observed in either the high-quality cluster (RCT + PSM: P = 0.76; I^2 =

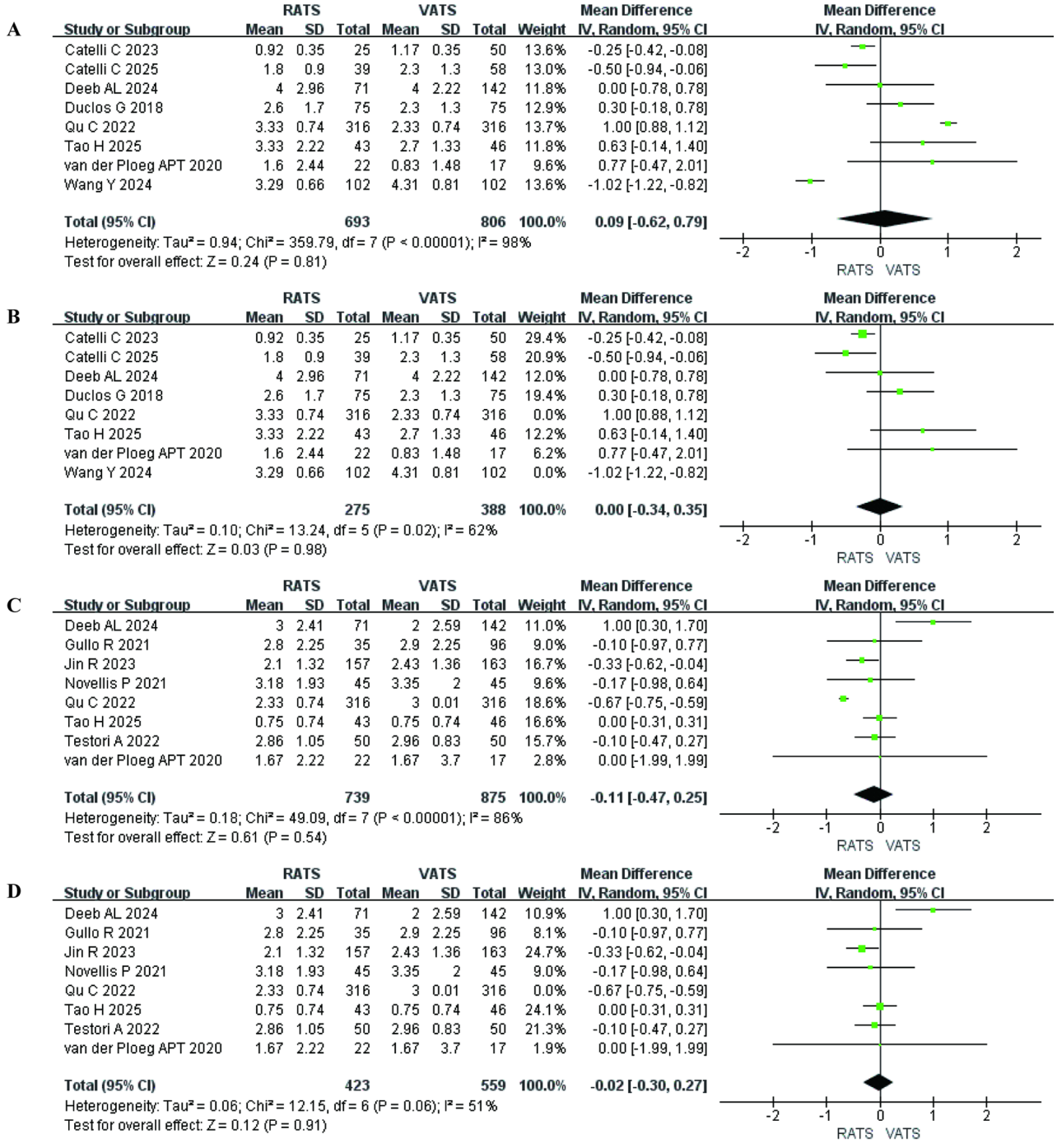

Fig. 2 Forest plots for pain intensity at POD 1 and long-term. (**A**) POD1 initial analysis of 8 studies (I^2 = 98%); (**B**) Sensitivity analysis for POD1, excluding the studies by Qu et al. and Wang et al. (I^2 = 62%); (**C**) Long-term initial analysis of 8 studies (I^2 = 86%); (**D**) Long-term sensitivity analysis excluding Qu et al. (I^2 = 51%). RATS, robotic-assisted thoracic surgery; VATS, video-assisted thoracic surgery; CI, confidence interval

66%, Fig. 3A) or the unadjusted observational cohort (P = 0.67; I^2 = 77%, Fig. 3B).

Long-term pain (POD 3 to discharge or later)

A total of 8 primary studies (including the cohorts by Jin et al. [28], Novellis et al. [29], and others [14, 16, 19, 21, 30, 31]) were pooled for the evaluation of long-term postoperative pain. Synthesis of 8 trials identified statistically equivalent long-term pain severity across the RATS and VATS cohorts (MD: -0.11; 95% CI: -0.47 to 0.25; P = 0.54; Cochran's Q = 49.09, tau² = 0.18, I^2 = 86%; 95% PI: -1.24 to 1.02; Fig. 2C). Subsequent sensitivity assessment, omitting Qu et al. [21], reduced the I^2 to 51% without substantially altering the pooled estimate (MD: -0.02;

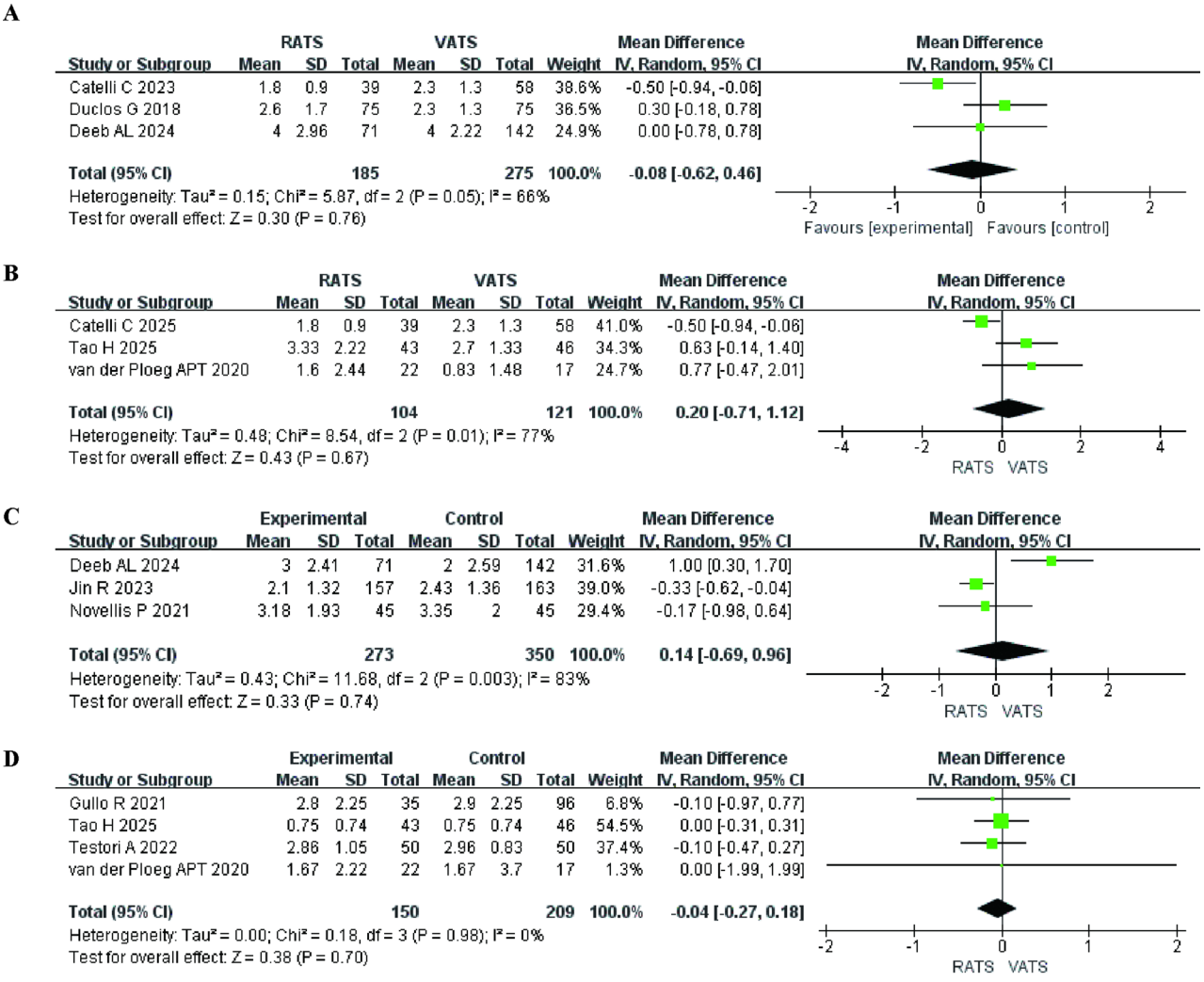

Fig. 3 Methodological subgroup analyses by study design for postoperative pain outcomes. (**A**) Subgroup forest plot for pain intensity on postoperative day (POD) 1 within the high-quality cohort (RCT + PSM: I^2 = 66%, P = 0.76); (**B**) Subgroup forest plot for pain intensity on POD 1 within the unadjusted observational cohort (I^2 = 77%, P = 0.67); (**C**) Subgroup forest plot for long-term pain outcomes within the high-quality cohort (RCT + PSM: I^2 = 83%, P = 0.74); (**D**) Subgroup forest plot for long-term pain outcomes within the unadjusted observational cohort (I^2 = 0%, P = 0.70). RATS, robotic-assisted thoracic surgery; VATS, video-assisted thoracic surgery; CI, confidence interval; POD, postoperative day; RCT, randomized controlled trial; PSM, propensity score matching

95% CI: -0.30 to 0.27; P = 0.91; Cochran's Q = 12.15, tau² = 0.06, I^2 = 51%; 95% PI: -0.75 to 0.71; Fig. 2D). These data indicate that RATS and VATS provide comparable pain control from POD 3 through the later postoperative follow-up periods. Similarly, stratified analysis for long-term pain revealed identical non-significant trends across both the high-quality (P = 0.74; I^2= 83%, Fig. 3C) and unadjusted subgroups (P = 0.70; I^2 = 0%, Fig. 3D), reinforcing the stability of our pooled estimates.

Postoperative analgesic consumption (qualitative synthesis)

Eleven studies reported data on postoperative analgesic requirements (Table 3). Quantitative synthesis was not performed because reporting metrics, such as MME and cumulative drug doses, were too heterogeneous. Comparable opioid intake between groups was supported by four high-quality RCTs (Patel et al. [15], P = 0.89; Jin et al. [28], P > 0.05; Terra et al. [32], P = 0.61; Catelli et al. [9], NR [not reported]) and several observational studies (Asemota et al. [24], P = 0.81; Novellis et al. [29], P = 0.77; Zheng et al. [13], NR). Nevertheless, findings remain divergent: two reports (Duclos et al. [10], P = 0.04; Deeb et al. [14], P = 0.01) indicated elevated RATS requirements, whereas Wang et al. [11] (P < 0.001) and Qu et al. [21] (P < 0.05) identified significantly lower consumption for the robotic platform.

Table 3 Qualitative synthesis of postoperative analgesic consumption

Author (Year)	Metrics	Main Findings	*P*	Direction
Patel YS (2023) [15]	PCA usage and duration	No significant differences in PCA requirements	0.89	Equivalent
Jin R (2023) [14]	Rescue analgesia	Comparable analgesic management and doses	> 0.05	Equivalent
Catelli C (2023) [9]	Narcotic requirements	Similar initial requirements between groups	NR	Equivalent
Terra RM (2022) [16]	Opioid needs (POD 30)	No significant difference at follow-up	0.61	Equivalent
Duclos G (2018) [10]	Cumulative morphine (mg)	Significantly higher consumption in RATS	0.04	RATS > VATS
Deeb AL (2024) [19]	48 h MME	Median consumption higher in RATS	0.01	RATS > VATS
Wang Y (2024) [11]	Total analgesics (mg)	Significantly lower doses in RATS	< 0.001	RATS < VATS
Asemota N (2023) [24]	Opioid prescription rates	No significant differences during follow-up	0.81	Equivalent
Novellis P (2021) [18]	Analgesic use (%)	Utilization rates were largely consistent	0.77	Equivalent
Zheng L (2022) [13]	Clinical management	Comparable perioperative analgesic demand	NR	Equivalent
Qu C (2022) [21]	Adjuvant analgesia	Trend toward lower usage in RATS group	< 0.05	RATS < VATS

Notes: MME, morphine milligram equivalents; NR, not reported; P, P-value; PCA, patient-controlled analgesia; POD, postoperative day; RATS, robotic-assisted thoracic surgery; VATS, video-assisted thoracic surgery

Chest tube duration

A total of 13 primary studies (including the cohorts by Wang et al. [11], Lan et al. [33], and others [5, 9, 10, 13, 15, 16, 18, 19, 21, 32, 34]) provided relevant data for the quantitative evaluation of postoperative chest tube duration. Preliminary pooling of 13 studies revealed comparable chest tube drainage periods for RATS and VATS (MD: -0.29; 95% CI: -0.59 to 0.02; P = 0.06; Cochran's Q = 55.37, tau² = 0.20, I^2 = 78%; 95% PI: -1.33 to 0.75; Fig. 4A). To investigate the high heterogeneity, we conducted a sensitivity analysis by omitting Duclos et al. [10], which subsequently lowered the I^2 to 55% (Fig. 4B). This refined synthesis demonstrated a significantly shorter drainage time in the RATS cohort compared to the VATS group (MD: -0.41; 95% CI: -0.63 to -0.18; P = 0.0005; Cochran's Q = 24.40, tau² = 0.07, I^2 = 55%; 95% PI: -1.05 to 0.23).

Overall morbidity

A total of 16 primary studies (including the cohorts by Wang et al. [11], Jin et al. [28], and others [9, 10, 13, 15, 16, 18, 19, 21, 24, 29, 31–34]) reported baseline clinical records regarding overall postoperative morbidity. Aggregated data from 16 trials indicated comparable overall morbidity between the RATS and VATS cohorts (RR: 0.88; 95% CI: 0.74 to 1.04; P = 0.13; Cochran's Q = 23.63, tau² = 0.04, I^2 = 37%; 95% PI: 0.55 to 1.40; Fig. 5A). Complication events were documented in 296 of 1276 patients within the RATS group, relative to 410 of 1525 individuals in the VATS group. These data indicate comparable postoperative safety profiles between the two surgical platforms. Regarding the severity of postprocedural adverse events, the majority of documented complications across the aggregated cohorts were classified as minor variants (Clavien-Dindo Grade I–II) requiring conservative management. Available data from the constituent studies indicated that major, life-threatening complications (Clavien-Dindo Grade ≥ III) were rare and statistically balanced between the multiportal RATS and VATS groups, suggesting a comparable safety profile regarding severe complication burden.

Length of hospital stay (LOS)

A total of 15 primary studies (including the cohorts by Lan et al. [33], Qu et al. [21], and others [9–11, 13, 15, 16, 18, 19, 28, 29, 31, 32, 34]) were pooled for the evaluation of postoperative length of hospital stay. Aggregated data from 15 investigations highlighted that RATS correlated with a significantly reduced LOS (MD: -0.84; 95% CI: -1.06 to -0.63) relative to the VATS approach (P < 0.00001; Cochran's Q = 27.89, tau² = 0.07, I^2 = 50%; 95% PI: -1.46 to -0.22; Fig. 5B). This data indicates a reduction in postoperative hospitalization for patients in the RATS group.

Certainty of evidence and publication bias

Evidence certainty for all endpoints was appraised via the GRADEpro GDT platform (Table 4). Given the predominance of retrospective study designs, the initial certainty was established as low. Due to significant statistical heterogeneity (inconsistency) and 95% CIs crossing the null effect line (imprecision) in specific outcomes, the certainty for all clinical metrics—including pain intensity, drainage duration, morbidity, and LOS—was ultimately downgraded to very low. Regarding publication bias assessments, metrics with fewer than 10 constituent cohorts (POD 1 pain, k = 8; long-term pain, k = 8) were excluded from formal linear regression due to restricted statistical power. No evidence of reporting bias was

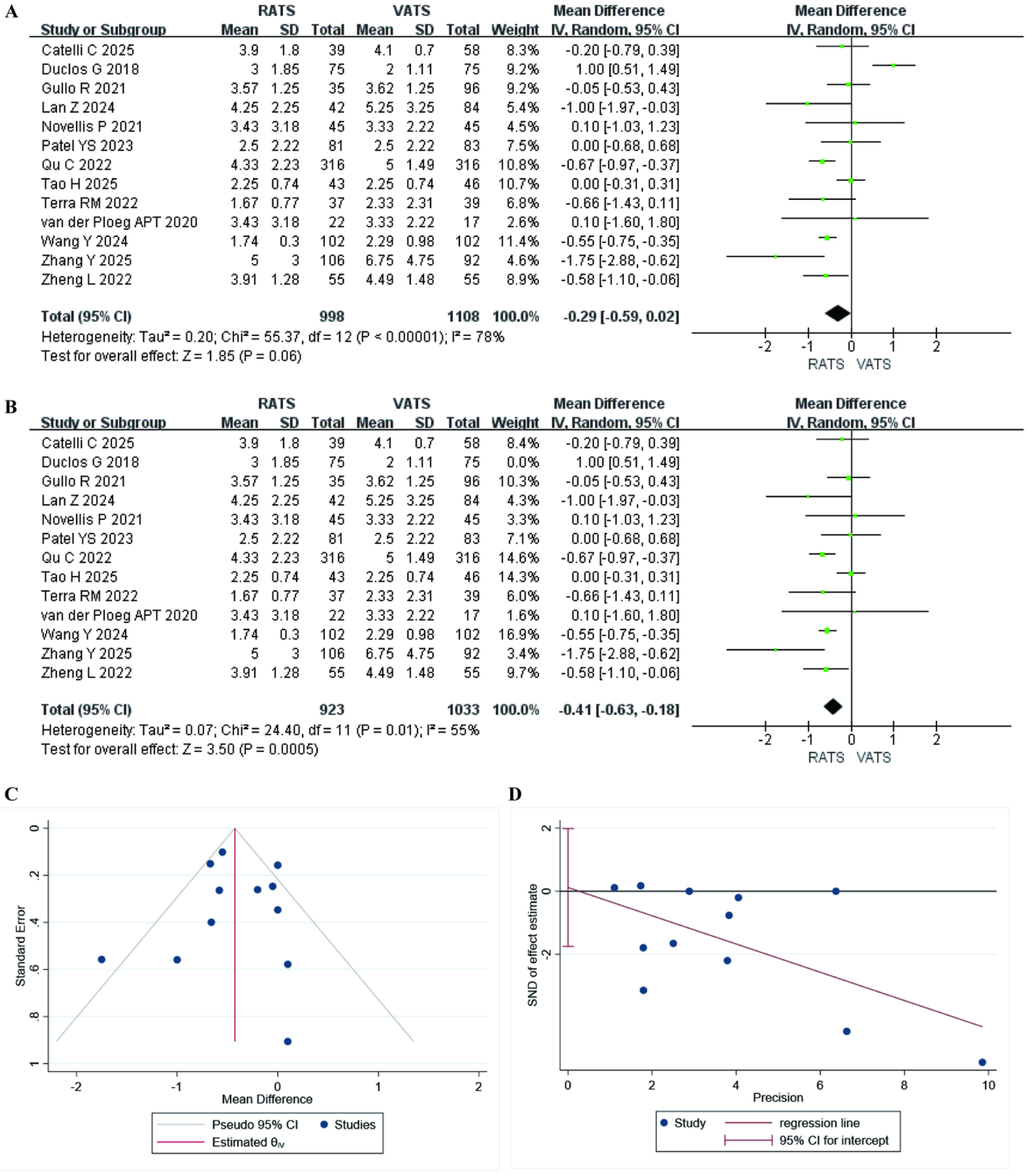

Fig. 4 Statistical evaluation of chest tube duration. (**A**) Initial forest plot of 13 studies (I^2 = 78%); (**B**) Forest plot sensitivity analysis excluding Duclos et al. (I^2 = 55%); (**C**) Funnel plot illustrating the appraisal of potential publication bias (P = 0.652); (**D**) Egger's regression plot for the objective quantification of funnel plot asymmetry. RATS, robotic-assisted thoracic surgery; VATS, video-assisted thoracic surgery; CI, confidence interval; SND, standard normal deviate

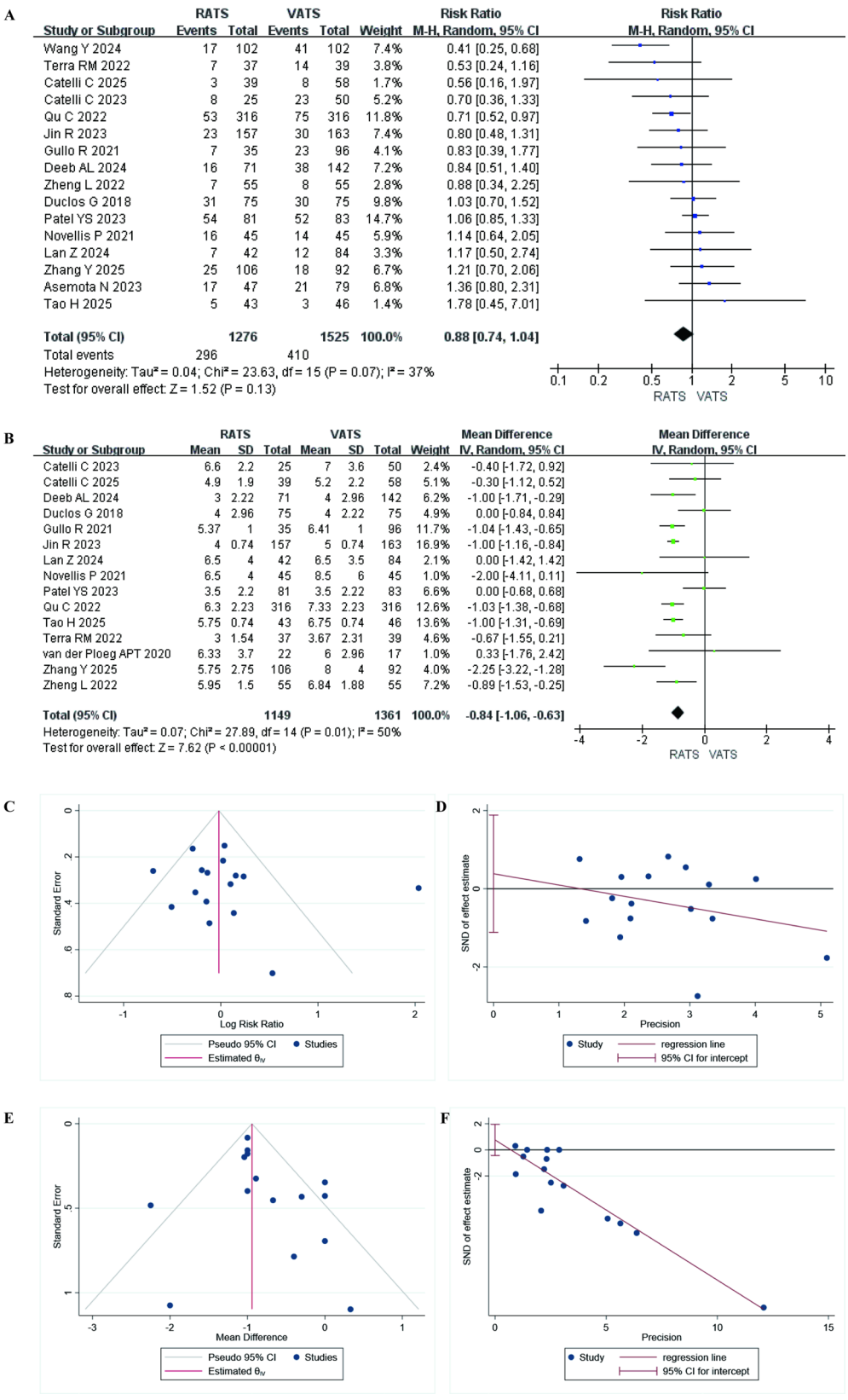

Fig. 5 (See legend on next page.)

(See figure on previous page.)

Fig. 5 Statistical evaluations of overall morbidity and LOS. (**A**) Forest plot for overall morbidity (I^2 = 37%); (**B**) Forest plot for LOS (I^2 = 50%); (**C**) Funnel plot of overall morbidity for the assessment of potential publication bias (P = 0.601); (**D**) Egger's regression plot of overall morbidity for the statistical quantification of funnel plot asymmetry; (**E**) Funnel plot of LOS for the assessment of potential publication bias (P = 0.227); (**F**) Egger's regression plot of LOS for the statistical quantification of funnel plot asymmetry. RATS, robotic-assisted thoracic surgery; VATS, video-assisted thoracic surgery; CI, confidence interval; SND, standard normal deviate; LOS, length of stay

detected for drainage duration (P = 0.652), overall morbidity (P = 0.601), or LOS (P = 0.227) via visual funnel plot inspection and Egger's regression (Figs. 4C–D and 5C–F).

Discussion

The current investigation provides a multidimensional appraisal of perioperative metrics comparing multiportal RATS and VATS. To our knowledge, it constitutes the inaugural meta-analysis to prioritize acute postoperative pain as the primary endpoint. Compared with recent meta-analyses, it incorporates a significantly larger sample size (18 studies, N = 2,940) [23, 35]. By integrating the latest clinical evidence from 2024 to 2025, this analysis ensures greater timelines and statistical power than earlier reports [26, 36].

Our findings indicate equivalent postoperative analgesic outcomes across both operative modalities, with no notable disparities identified on POD 1 (P = 0.81) or during the subacute period from POD 3 onwards (P = 0.54). Crucially, this parity in pain trajectories across multiple time points is further corroborated by our qualitative synthesis of 11 studies regarding postoperative analgesic consumption. High-quality evidence from RCTs indicated equivalent narcotic requirements between groups, suggesting that these identical pain profiles are not confounded by variations in pharmacological intervention. This structural parity is further validated by our methodological subgroup analysis. The persistent non-significant differences observed in both the high-quality (RCT + PSM) and unadjusted subgroups demonstrate that our primary pain findings are highly robust and not skewed by selection bias across different study designs. Despite these similar analgesic outcomes, RATS showed higher clinical efficiency in recovery metrics.

RATS was characterized by a notably shorter drainage duration (MD = -0.41 days), which likely facilitated the observed reduction in LOS (MD = -0.84 days). This suggests that the early removal of chest tubes is a primary driver for the accelerated discharge seen in the robotic cohort.

In terms of surgical safety, total morbidity was statistically comparable between modalities (P = 0.13), despite a marginal numeric inclination toward the robotic platform. Overall, these findings suggest that while RATS and VATS share a similar level of surgical invasiveness regarding the number of ports and postoperative analgesia, the technical precision of the robotic platform facilitates more meticulous dissection and a faster transition to discharge.

Even with the very low certainty of evidence, our analysis did not find a significant difference in pain intensity between RATS and VATS on POD 1. This parity suggests a complex trade-off between technical precision and access trauma. Specifically, while RATS involves more ports (4 to 5 vs. 2 to 3 in VATS), the robotic system utilizes a fixed 'remote center' for instrumentation. Although this design is hypothesized to minimize the 'lever-like' fulcrum effect inherent to manual VATS, its definitive nerve-sparing superiority remains unproven. In fact, the lower port placement typical of RATS (frequently involving the 8th or 9th intercostal spaces) carries an inherent risk of injuring the lower intercostal nerves. Such trauma can clinically manifest as abdominal wall weakness or muscle atrophy, directly challenging the assumption of inherent nerve preservation. Furthermore, this potential risk is initially compounded by the additional assistant port and the posterior-lateral placement of RATS drainage tubes (e.g., 8th or 9th intercostal space). Unlike anterior VATS tubes, these posterior locations trigger localized positional pain during supine recumbency due to direct mechanical compression and constant stimulation of the indwelling catheter against the intercostal nerves under body-weight pressure [17]. Importantly, the shortened drainage duration observed in the RATS cohort (MD = -0.41 days) likely accelerates the alleviation of tube-associated irritation. This expedited removal may minimize the inflammatory response and mechanical stimulation caused by the indwelling catheter. In summary, the robotic platform's nerve-sparing precision and earlier tube removal effectively neutralize the impact of its multiportal configuration and posterior tube placement during the acute phase. Additionally, the unstandardized application of perioperative regional anesthesia across historical cohorts represents a major confounding factor. Institutional variations in preemptive nerve blocks may partially obscure the intrinsic differences in access trauma between the two surgical platforms.

The current meta-analysis identified comparable long-term pain outcomes between RATS and VATS, with no statistically significant disparity observed. Qu et al. was identified as the primary source of heterogeneity because its large sample size (n = 632) exerted disproportionate statistical weight and its specific focus on diverse BMI ranges introduced clinical variance [21]. Excluding

Table 4 GRADE evidence certainty and quality assessment for clinical and rehabilitation outcomes comparing multiportal RATS versus VATS

Certainty assessment							No. of patients		Effect		Certainty	Importance
No. of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	multiportal RATS	multiportal VATS	Relative (95% CI)	Absolute (95% CI)		
POD 1 Pain												
8	non-randomised studies	serious[a]	serious[b]	not serious	not serious	none	693	806	-	MD **0.09 higher** (0.62 lower to 0.79 higher)	⨁◯◯◯ Very low[a, b]	NOT IMPORTANT
Long-term Pain												
8	non-randomised studies	serious[a]	serious[b]	not serious	not serious	none	739	875	-	MD **0.11 lower** (0.47 lower to 0.25 higher)	⨁◯◯◯ Very low[a, b]	NOT IMPORTANT
Chest Tube Duration												
13	non-randomised studies	serious[a]	serious[b]	not serious	not serious	none	998	1108	-	MD **0.29 lower** (0.59 lower to 0.02 higher)	⨁◯◯◯ Very low[a, b]	IMPORTANT
Length of Stay												
15	non-randomised studies	serious[a]	serious[b]	not serious	not serious	none	1149	1361	-	MD **0.84 lower** (1.06 lower to 0.63 lower)	⨁◯◯◯ Very low[a, b]	IMPORTANT
Overall Morbidity												
16	non-randomised studies	serious[a]	not serious	not serious	serious[c]	none	296/1276 (23.2%)	410/1525 (26.9%)	**RR 0.88** (0.74 to 1.04)	**32 fewer per 1,000** (from 70 fewer to 11 more)	⨁◯◯◯ Very low[a, c]	NOT IMPORTANT

CI: confidence interval; **MD**: mean difference; **RR**: risk ratio; **POD**: postoperative day; **RATS**: robotic-assisted thoracic surgery; **VATS**: video-assisted thoracic surgery

Explanations

a. Downgraded one level due to the predominance of retrospective observational studies in the evidence body

b. Downgraded one level due to high statistical heterogeneity among the pooled studies

c. Downgraded one level as the 95% CI crosses the null effect (RR = 1.0)

this study significantly improved consistency, reducing I^2 from 86% to 51%. Despite this adjustment, the overall non-significant trend remained stable. This stability suggests that neither surgical interface offers a distinct advantage in preventing Chronic Postoperative Pain (CPSP), which reportedly affects 25% to 60% of patients after thoracic surgery [20]. Although RATS facilitates meticulous hilar dissection, the cumulative mechanical trauma to the intercostal nerves appears similar to that of the triportal-biportal VATS approaches. Consequently, both minimally invasive platforms yield comparable long-term patient-reported pain outcomes.

Postoperative analgesic consumption serves as an objective surrogate for pain intensity. Our qualitative synthesis of 11 studies consistently showed that narcotic requirements were equivalent between RATS and VATS in high-quality randomized trials. This alignment suggests that the comparable pain scores observed at POD 1 and POD 3 were not confounded by differences in pharmacological intervention. These findings indicate that the robotic platform achieves a level of surgical invasiveness similar to VATS during the acute and subacute phases. The conflicting results reported in several observational cohorts likely reflect institutional variance in clinical pathways and nursing protocols. For instance, the higher consumption observed by Duclos et al. [10] and Deeb et al. [14] may be attributed to differences in early postoperative management or the learning curve of the robotic program. Alternatively, the marked attenuation in analgesic requirements documented by Wang et al. [11] and Qu et al. [21] underscores the clinical utility of RATS within accelerated recovery protocols or ambulatory surgical frameworks. Overall, these discrepancies suggest that while the surgical interface provides technical precision, postoperative analgesic demand is heavily influenced by the maturity of the institutional clinical pathway.

RATS significantly reduced the duration of chest tube drainage compared to VATS (MD = -0.41 days). Such a decline is fundamentally driven by the enhanced technical accuracy of the robotic system. The integration of high-fidelity three-dimensional imaging and articulated instrumentation facilitates refined dissection of hilar structures and mediastinal lymph nodes. This superior dexterity mitigates mechanical trauma to the pulmonary tissue, thereby lowering the frequency of postoperative air leaks, intraoperative hemorrhage, and accidental hilar vascular compromise [22]. Supporting this, Wang et al. reported significantly lower total drainage volumes (185.44 mL vs. 268.70 mL) and shorter drainage times in the RATS cohort [11]. The robustness of the chest tube duration analysis was confirmed through sensitivity analysis. Excluding the study by Duclos et al. resolved significant statistical heterogeneity. While their numerical drainage threshold (< 200 mL/day) was consistent with other cohorts, the reported median duration was notably longer at 3.0 days. This discrepancy likely reflects a more cautious clinical management strategy during the early implementation of their RATS program in 2016 [10]. This conservative approach contrasts with contemporary aggressive fast-track protocols, such as the day-surgery model reported by Wang et al., where drainage assessment begins as early as 12 h postoperatively [11]. Consequently, the exclusion of this outlier ensures that the pooled results more accurately represent current surgical practices and accelerated recovery pathways.

Our synthesis indicates that RATS is associated with a significantly abbreviated LOS relative to VATS (MD = -0.84 days). Notably, this finding is supported by very low-certainty evidence according to the GRADE framework. This advantage is primarily driven by the accelerated removal of chest tubes, which serves as the final prerequisite for discharge in most lung resection protocols. This accelerated recovery aligns with the ERAS Society guidelines, which emphasize that standardized chest tube management and early mobilization are critical for reducing hospital stay [25]. However, the heterogeneity in LOS data across studies is influenced by the diverse observation periods required for tube removal. While the volume threshold remained consistent (< 200 mL), management strategies varied from conservative protocols requiring 3 consecutive days of stability (Qu et al.) to aggressive day-surgery models initiating assessment at 12 h postoperatively (Wang et al.) [11, 21]. This discrepancy in clinical pathways, rather than surgical technique alone, represents a major source of variance in reported recovery times. Beyond management protocols, the predictability of the robotic platform enhances discharge efficiency. Qu et al. reported that RATS significantly lowered the rate of "delayed recovery" (19.3% vs. 26.6%), presumably due to more precise hilar dissection that reduces minor air leaks and blood loss. Notably, this efficiency is maintained even in challenging patient populations [21]. Tao et al. confirms that RATS preserves short LOS and low conversion rates in obese patients (BMI ≥ 30 kg/m2), where the robotic system's maneuverability overcomes the mechanical resistance of a thick chest wall [16]. From a value-based perspective, RATS optimizes resource utilization, narrowing the consumable-driven cost gap (€13,321 vs. €11,567) [27] through an 0.84-day reduction in LOS. By maximizing throughput and minimizing bed-day charges, RATS demonstrates competitive cost-effectiveness within a total-care-cycle framework.

Regarding overall morbidity, RATS and VATS demonstrated comparable perioperative safety profiles. Postoperative morbidity rates remained statistically comparable between the two surgical cohorts. The robotic system provides high-definition 3D visualization and tremor suppression [30]. These technical features ensure high

surgical precision. They maintain clinical safety at a level equal to the established VATS approach. The data show that the complexity of robotic instruments does not increase operative risk. Therefore, RATS proves a reliable and safe alternative in modern thoracic oncology.

These findings reflect a shift toward value-based thoracic surgery. Although RATS incurs higher intraoperative costs, its ability to reduce drainage duration and LOS optimizes resource utilization. Furthermore, robotic precision maintains safety and efficiency in challenging scenarios like obesity. Ultimately, establishing an international consensus on robotic-specific clinical pathways is essential to fully capitalize on these technical advantages. On the other hand, the emergence of day-surgery models underscores the potential of both RATS and VATS to streamline care via standardized fast-track protocols [8, 11, 16].

This study has several limitations, leading to a very low certainty of evidence under the GRADE framework. The classification of 'very low certainty' primarily reflects the strict application of GRADE criteria to a body of evidence dominated by retrospective designs and high statistical heterogeneity; however, these results still represent the most comprehensive synthesis of available clinical data to date. First, most included studies are retrospective, with 4 RCTs, potentially introducing selection bias (Risk of Bias). Second, significant heterogeneity exists in institutional postoperative management, particularly regarding drainage and discharge criteria, contributing to inconsistency in recovery metrics. For instance, the conservative chest tube management in Qu et al. (requiring 3 days of stability) contrasts with the aggressive day-surgery protocols in Wang et al. (assessment at 12 h), which directly confound recovery metric evaluations such as LOS [11, 21]. Third, the diverse reporting metrics for medication consumption precluded a formal quantitative meta-analysis for analgesic requirements (Imprecision). Furthermore, variations in perioperative regional anesthetic protocols (including thoracic epidural analgesia, paravertebral blocks, and erector spinae plane blocks) were poorly or inconsistently documented in the primary retrospective literature, introducing an inherent source of clinical heterogeneity that could confound early pain trajectories. Additionally, none of the enrolled primary studies documented pre-existing chronic pain conditions or baseline analgesic requirements; the lack of such data prevents us from controlling for these potential confounders, which might heavily influence postoperative pain tolerance and narcotic consumption. Fourth, significant variations in procedural design and technical execution remained across the included literature. Specifically, the lack of stratified analyses between lobectomy and segmentectomy limited our ability to isolate procedural-specific variances in operative time or recovery pathways. In addition to the surgical extent, substantial variations in port configurations existed within both cohorts (such as two- versus three-port VATS, and three- versus four-port RATS), these unaligned technical parameters inevitably acted as critical confounding factors that contributed to the elevated statistical heterogeneity (I^2) observed across several pain metrics. Fifth, variability in surgeon experience and institutional learning curves may affect outcomes during the early adoption phase [30]. Lastly, the absence of extended longitudinal surveillance hinders a thorough appraisal of persistent pain evolution, sustained quality-of-life scores, and definitive oncological milestones, including five-year survival rates.

Conclusions

The current evidence synthesis indicates that RATS and VATS provide equivalent postoperative analgesic profiles, encompassing both pain alleviation and medication utility, though these conclusions are underpinned by very low-certainty evidence. However, RATS offers significant efficiency advantages in reducing drainage duration and LOS. Although overall morbidity showed a non-significant trend favoring RATS, the robotic platform may offer potential technical advantages in managing complex anatomical structures. Ultimately, RATS represents a safe alternative for pulmonary resection associated with shorter drainage duration and length of stay, which could potentially contribute to more efficient hospital resource utilization; however, these findings must be viewed through the lens of very low evidence certainty. Future large-scale, multicenter RCTs with standardized perioperative pathways are required to substantiate long-term oncological durability and holistic cost-benefit profiles.

Abbreviations

BMI	Body mass index
CI	Confidence interval
CPSP	Chronic postoperative pain
ERAS	Enhanced Recovery After Surgery
GEE	Generalized estimation equations
GRADE	Grading of Recommendations, Assessment, Development, and Evaluations
IQR	Interquartile range
LOS	Length of stay
MD	Mean difference
MeSH	Medical Subject Headings
MME	Morphine milligram equivalents
NOS	Newcastle-Ottawa Scale
POD	Postoperative day
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PROSPERO	Prospective Register of Systematic Reviews
PSM	Propensity-score matching
RATS	Robotic-assisted thoracic surgery
RCTs	Randomized controlled trials
RR	Risk ratio
SD	Standard deviation
VATS	Video-assisted thoracic surgery
VAS	Visual Analog Scale

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Author contributions
All authors contributed to the study's conception and design. Data collection and analysis were performed by Drs. Alexandro Patirelis, Vincenzo Ambrogi, Stefano Elia, Sebastiano Angelo Bastone, Yixing Chen, and Eugenio Pompeo. The first draft of the manuscript was written by Dr. Dong Wang, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability
Attached as electronic supplementary table. And data supporting the findings of this investigation are accessible from the corresponding author upon justified inquiry.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
All authors read and approved the final manuscript.

Competing interests
Drs. Dong Wang, Alexandro Patirelis, Vincenzo Ambrogi, Stefano Elia, Sebastiano Angelo Bastone, Yixing Chen, and Eugenio Pompeo have no conflicts of interest or financial ties to disclose.

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