Effect of Preoperative Respiratory Training on Perioperative Outcomes in Thoracic Surgery: A Systematic Review and Meta-Analysis

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AIM: Postoperative pulmonary complications (PPCs) commonly ensue after thoracic surgery and can impair patients' recovery. This study aimed to evaluate the effectiveness of preoperative respiratory training (PRT) in various perioperative outcomes in patients undergoing thoracic surgery, including pulmonary function, exercise capacity, incidence of postoperative complications, and length of hospital stay.

METHODS: Randomized controlled trials (RCTs) comparing PRT with routine care, that were published in the period of 1 January 2000 to 30 June 2025, were identified through PubMed, Embase, Web of Science, and Cochrane Library. Pooled analyses were performed using RevMan 5.4.1 to calculate odds ratio (OR) or mean difference (MD) with 95% CI.

RESULTS: Nine studies were included in the meta-analysis. The results revealed that PRT significantly reduces PPCs (OR = 0.31, 95% CI: 0.21 to 0.46) and improved the change in six-minute walking distance (6MWD) (MD = 20.50, 95% CI: 11.72 to 29.28). No significant effects were observed on absolute 6MWD, forced expiratory volume in one second (FEV_1), peak expiratory flow, or length of hospital stay. Sensitivity analysis confirmed result stability, and no substantial publication bias was found.

CONCLUSIONS: PRT reduces PPCs and improves postoperative functional recovery in patients undergoing thoracic surgery. Its impact on spirometry-based pulmonary function and length of hospital stay remains uncertain. Further large-scale trials are needed to investigate the effect of integrating perioperative care into routine healthcare, especially for high-risk patients.

Keywords: preoperative respiratory training; thoracic surgery; postoperative pulmonary complications; six-minute walking distance; meta-analysis

Introduction

Postoperative pulmonary complications (PPCs) are among the most common and severe adverse events following thoracic surgery, with reported incidence rates ranging from 15% to 40%, depending on patient characteristics and surgical complexity [1,2]. Although complications such as atelectasis, pneumonia, and respiratory failure can significantly impair postoperative recovery and increase mortality risk [3,4], recent attention has shifted toward preventive strategies aimed at reducing these risks. Among them, preoperative respiratory training (PRT) has emerged as a promising approach in perioperative care for thoracic surgery. One promising strategy is PRT, which is used to optimize respiratory function and enhance recovery capacity before surgical insult. By strengthening respiratory muscles, improving alveolar ventilation, and facilitating airway clearance, PRT may mitigate the risk of PPCs and improve postoperative functional outcomes. The pathogenesis of PPCs is multifactorial, involving anesthesia-induced diaphragmatic dysfunction, postoperative pain that limits deep breathing, impaired mucociliary clearance, and prolonged immobilization [5,6]. With the global volume of thoracic surgical procedures continuing to rise, the development of effective strategies to reduce PPCs has become an important focus in perioperative care.

PRT encompasses structured interventions such as inspiratory muscle training, breathing exercises, and incentive spirometry that aim to optimize pulmonary function before surgery [7,8]. The underlying rationale is that PRT can enhance alveolar recruitment, strengthen respiratory muscles, and promote airway clearance, thereby mitigating the likelihood of PPCs and facilitating postoperative re-

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covery [9]. Over the past decade, randomized controlled trials (RCTs) have reported mixed findings in this field—some demonstrating reduced morbidity and improved functional capacity [10,11], while others observed limited benefits. Moreover, prior meta-analyses often included heterogeneous surgical populations or focused mainly on cardiac surgery [12,13], leaving a gap in evidence specific to thoracic surgery. Addressing this gap forms the basis and clinical significance of the present study.

To address the current evidence gaps, this systematic review and meta-analysis was conducted to synthesize and critically appraise the best available evidence from RCTs on the effectiveness of PRT in adult patients undergoing thoracic surgery. The primary objective was to evaluate its impact on the incidence of PPCs, while the secondary objectives included assessing its effects on functional recovery—measured by the change in six-minute walking distance—as well as on spirometry-based pulmonary function parameters (forced expiratory volume in one second (FEV_1), peak expiratory flow (PEF)) and length of hospital stay. We hypothesized that PRT would reduce postoperative complications, improve functional capacity, and potentially contribute to optimized perioperative care strategies for patients undergoing thoracic surgery.

Materials and Methods

Literature Search

A comprehensive search of several authoritative medical and biomedical literature databases, including PubMed, Embase, Web of Science, and the Cochrane Library, was conducted. This systematic review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines, and the completed PRISMA 2020 Checklist is provided in the **Supplementary Material**. The search was limited to studies in English published in the period of 1 January 2000 to 30 June 2025. In PubMed and Embase, both subject terms (e.g., Medical Subject Headings (MeSH) or Emtree) and free-text terms were used in combination, as shown in **Supplementary Table 1**. Searches in Web of Science and the Cochrane Library were conducted using free-text terms only. The search terms included: "thoracic surgery", "cardiothoracic surgery", "perioperative period", "preoperative respiratory training", "pulmonary function rehabilitation", and "pulmonary rehabilitation training" (**Supplementary Table 1**).

Inclusion and Exclusion Criteria

Identified studies that fulfill the following criteria were included:

(1) Participants: Adult patients (aged ≥18 years) undergoing thoracic surgery.

(2) Interventions: Interventions: The intervention arm involved structured pulmonary rehabilitation, including inspiratory muscle training, breathing exercises, or incentive spirometry, delivered by trained nursing staff. Details of the equipment and procedures are shown in **Supplementary Fig. 1**.

(3) Control: Patients receiving standard perioperative management without specialized pulmonary rehabilitation.

(4) Outcomes: Eligible studies had to report at least one of the following:

① Pulmonary function indicators, such as PaO_2, $PaCO_2$, and FEV_1;

② Duration of hospitalization;

③ Postoperative pulmonary or systemic complication rates.

(5) Study design: RCTs were included, with clearly defined intervention and control groups.

(6) Language: Publications available in English only.

Exclusion criteria of this meta-analysis are as follows:

(1) Non-original studies such as reviews, conference abstracts, and case reports.

(2) Studies in which the intervention was not focused on pulmonary rehabilitation (e.g., psychological care, nutritional support).

(3) Studies lacking a clearly defined control group or with unclear descriptions of the intervention.

(4) Studies with incomplete data or outcomes.

Study Selection and Data Extraction

The initial screening was performed independently by two reviewers based on the titles and abstracts, with irrelevant studies or those not meeting the inclusion criteria excluded. The subsequent screening involved a full-text review to ensure that all included articles fully met the eligibility criteria. Any disagreements were resolved through discussion or consultation with a third reviewer. For each included study, two reviewers independently extracted data, including basic study information, participant characteristics, and outcome measures. All extracted data were cross-checked to ensure accuracy and consistency, and discrepancies were resolved through discussion or expert consultation.

Quality Assessment

The risk of bias of the included studies was assessed independently by two reviewers using the Cochrane Risk of Bias tool (RoB 1.0; Cochrane Collaboration, London, UK) for randomized trials, following the Cochrane Handbook for Systematic Reviews of Interventions, version 5.1.0. This tool evaluates seven domains: (1) random sequence generation (selection bias), (2) allocation concealment (selection bias), (3) blinding of participants and personnel (performance bias), (4) blinding of outcome assessment (detection bias), (5) incomplete outcome data (attrition bias), (6) selective reporting (reporting bias), and (7) other sources of bias. Each domain was judged as "low risk of bias", "unclear risk of bias", or "high risk of bias" according to the criteria specified in the Cochrane Handbook. Any dis-

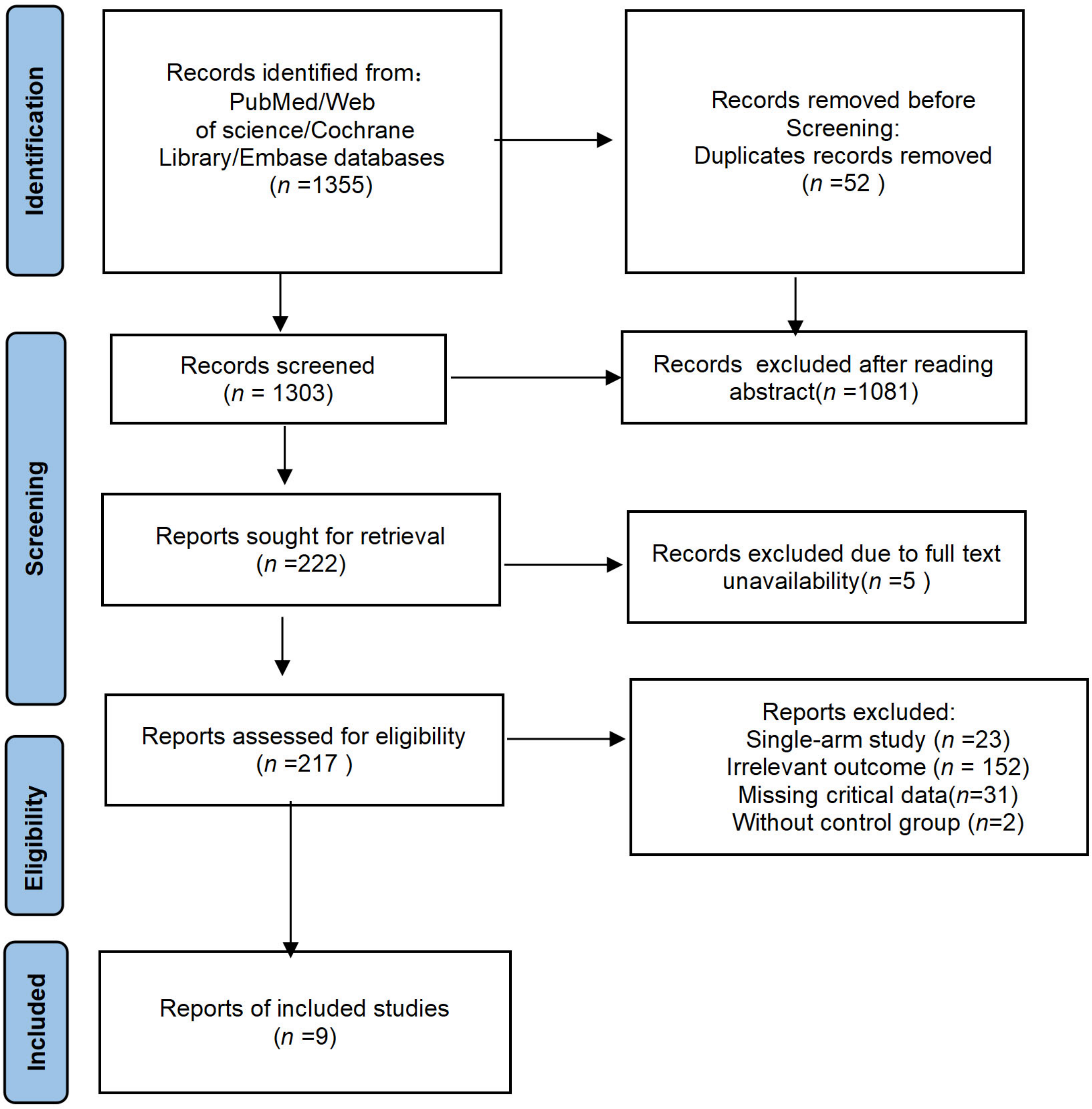

Fig. 1. Schematic diagram depicting literature screening and inclusion.

agreements between the two reviewers' assessments were resolved through discussion or by consulting a third reviewer.

Statistical Analysis

NoteExpress 3.2 software (Aegean Software Company, Beijing, China) was used for literature management, and Excel 2003 (Microsoft Corporation, Redmond, WA, USA) was used for data extraction. Meta-analysis was performed using RevMan version 5.4.1 (The Cochrane Collaboration, London, UK). Between-study heterogeneity was examined using the Chi-square (Q) test, and its magnitude was described with the I^2 statistic. If I^2 was $\leq$50% or the Q test yielded $p > 0.10$, a fixed-effects approach was chosen; otherwise, a random-effects model was applied. Effect sizes were summarized as odds ratio (OR) or mean difference (MD) with 95% CI, and forest plots were generated accordingly. Sensitivity tests were carried out to evaluate the stability of results, while funnel plots were used to explore potential publication bias. p-value < 0.05 was considered statistically significant.

Results

Literature Search Results

A total of 1355 relevant studies were initially retrieved from the selected databases. Fifty-two duplicates were removed using literature management software, leaving behind 1303 studies. A preliminary screening excluded 1081 articles that were clearly unrelated to the topic of this study, leaving 222 articles for further evaluation. Five articles without accessible full text were excluded, and the remaining studies underwent full-text review and detailed assessment, which led to the exclusion of an additional 208 studies. Ultimately, nine studies (corresponding to 10 data entries, as one study included two intervention subgroups analyzed separately for risk of bias assessment) met the inclusion cri-

Table 1. Basic characteristics of included literature.

Study	Year	Study design	Country	Sample size		Age (year)		Sex (M/F)		Outcomes
				Experimental	Control	Experimental	Control	Experimental	Control	
Chen *et al.* [14]	2023	RCT	China	40	40	39.33 ± 12.81	42.94 ± 9.57	19/21	17/23	FEV_1, 6MWD
Lai *et al.* [15]	2019	RCT	China	34	34	64.2 ± 6.8	63.4 ± 8.2	18/16	17/17	6MWD creased
Wang *et al.* [16]	2020	RCT	China	31	34	59 (52–62)	55.5 (46.75–63.25)	11/20	11/23	6MWD increased
Karenovics *et al.* [17]	2017	RCT (PROBE)	Switzerland	74	77	64 ± 10	64 ± 13	50/24	55/22	FEV_1
Lai *et al.* [18]	2017	RCT	China	51	50	63.8 ± 8.2	64.6 ± 6.6	28/23	28/22	Pulmonary complications, PEF, 6MWD
Huang *et al.* [19]	2017	RCT	China	30/30	30	63.0 ± 8.7 64.1 ± 5.3	63.6 ± 6.5	20/10 21/9	21/9	Pulmonary complications, PEF, 6MWD, length of hospital stay
Licker *et al.* [20]	2017	RCT	Switzerland	74	77	64 ± 13	64 ± 10	33/41	27/50	Pulmonary complications, length of hospital stay
Zhou *et al.* [21]	2025	RCT	China	51	50	57 (47–62)	56 (52–61)	19/32	21/29	Pulmonary complications, length of hospital stay
Laurent *et al.* [22]	2020	RCT	France	14	12	64 ± 7	62 ± 9	9/5	9/3	Pulmonary complications, FEV_1, length of hospital stay

Note: In Huang *et al.*'s study [19], the experimental group consisted of two subgroups: respiratory training alone (n = 30) and respiratory training combined with other interventions (n = 30). Age data are presented as reported in the original publications (mean ± SD, median [range], or subgroup-specific means).

Abbreviations: FEV_1, forced expiratory volume in one second; PEF, peak expiratory flow; RCT, randomized controlled trial; 6MWD, six-minute walking distance; M, male; F, female.

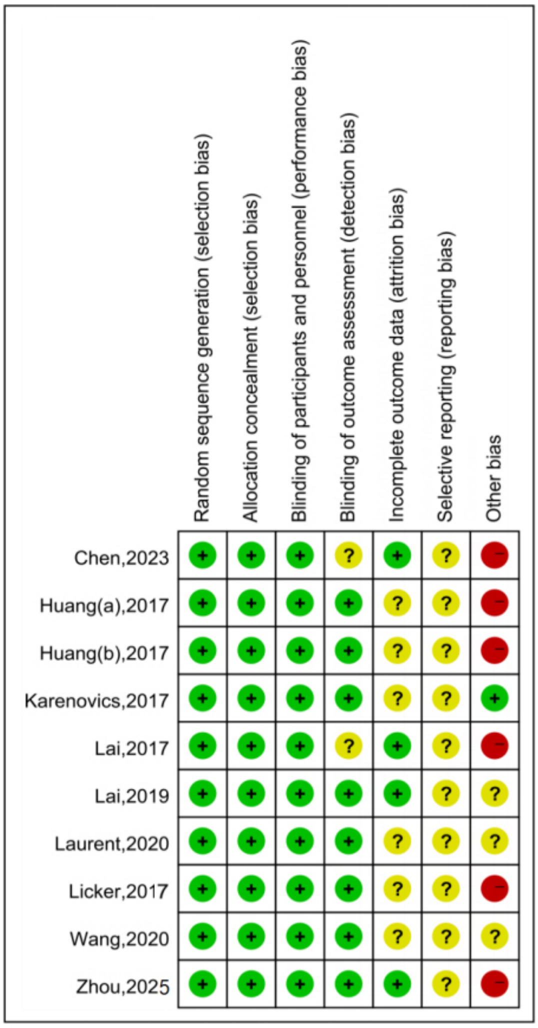

Fig. 2. The evaluation results of literature quality.

teria and were included in the meta-analysis (Fig. 1). The general characteristics of the included studies are summarized in Table 1 (Ref. [14–22]).

Quality Assessment of Included Studies

Quality assessment showed that all included studies were randomized controlled trials. [14–22]. The methods of random sequence generation and allocation concealment were clearly described in the majority of these studies, ensuring baseline comparability between groups. A substantial proportion of the studies exhibited unclear risk of bias in blinding of outcome assessment and incomplete outcome data, while several studies also showed either unclear or high risk in selective reporting. Moreover, many of these studies demonstrated high risk in the domain of other bias, which may involve unreported methodological limitations. Despite these concerns, the overall methodological quality of the included studies was acceptable and met the requirements for this meta-analysis (Figs. 2,3).

Meta-Analysis Results

Length of Hospital Stay

Four studies reported the total length of hospital stay for both the experimental and control groups [19–22]. In the study by Huang *et al*. (2017) [19], data were available for both a combined intervention group versus control and a single intervention group versus control; these comparisons were analyzed separately. In total, 199 patients were included in each group. Heterogeneity analysis showed I^2 = 66% with p = 0.02, indicating significant statistical heterogeneity among the included studies; therefore, a random-effects model was applied. The meta-analysis demonstrated a borderline significant reduction in hospital stay in patients receiving preoperative respiratory training compared with the control group (MD = –1.13, 95% CI: –2.25 to –0.01, p = 0.05) (Fig. 4).

Peak Expiratory Flow

Two studies reported the PEF outcomes for both the experimental and control groups [18,19]. In the study by Huang *et al*. (2017) [19], data were available for both a combined intervention group versus control and a single intervention group versus control; these comparisons were analyzed separately, resulting in three data entries overall. A total of 111 patients were included in the experimental group and 110 in the control group. Heterogeneity analysis showed I^2 = 0% with p = 0.49, indicating no significant statistical heterogeneity among the included studies; therefore, a fixed-effects model was applied. The meta-analysis revealed no statistically significant difference in PEF levels between the experimental and control groups (MD = 13.68, 95% CI: –13.92 to 41.29, p = 0.33) (Fig. 5).

Forced Expiratory Volume in One Second

Four studies reported FEV_1 levels for both the experimental and control groups [14,17,19,22]. In the study by Huang *et al*. (2017) [19], data were available for both a combined intervention group versus control and a single intervention group versus control; these comparisons were analyzed separately. In total, 188 patients were included in the experimental group and 189 in the control group. Considerable heterogeneity was detected across studies (I^2 = 89% with $p < 0.00001$), so a random-effects model was used. The pooled analysis suggested that FEV_1 did not differ meaningfully between intervention and control groups (MD = 0.10, 95% CI: –0.21 to 0.40, p = 0.54) (Fig. 6).

Increase in Six-Minute Walking Distance (6MWD)

To distinguish between postoperative functional status and the extent of functional improvement, two separate outcomes related to the 6MWD were analyzed: the absolute postoperative 6MWD and the change in 6MWD from baseline. Two studies reported the change in 6MWD between the experimental and control groups [15,16]. A total of 65 patients were included in the experimental group and

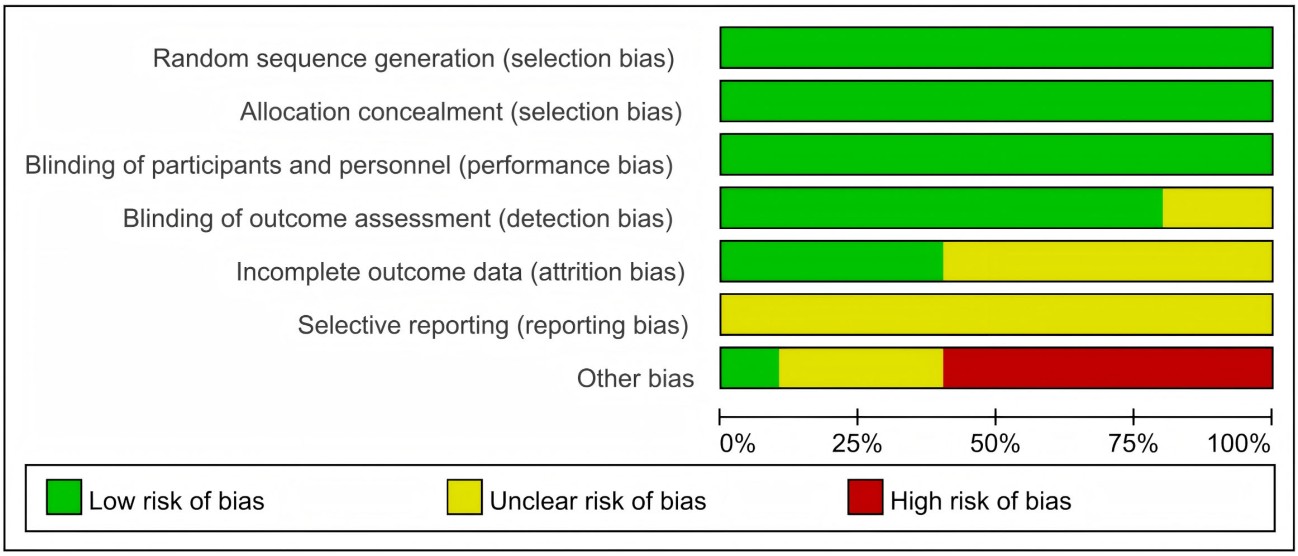

Fig. 3. Risk of bias summary for included randomized controlled trials, showing judgments for each risk domain across all studies.

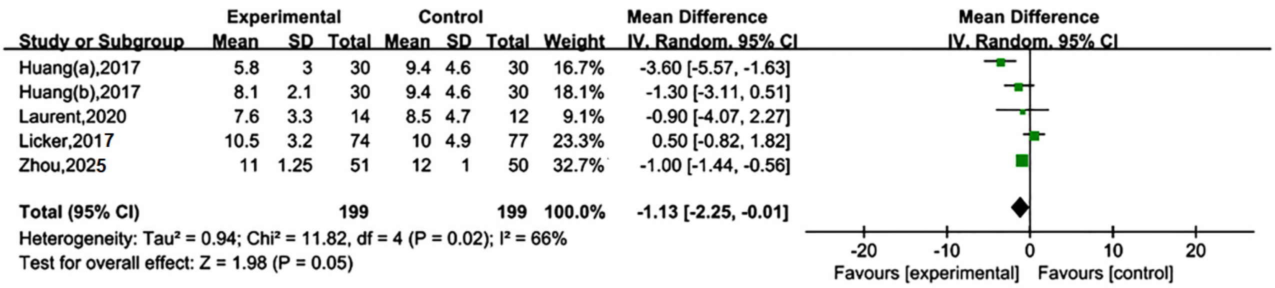

Fig. 4. Forest plot comparing length of hospital stay between the experimental and control groups.

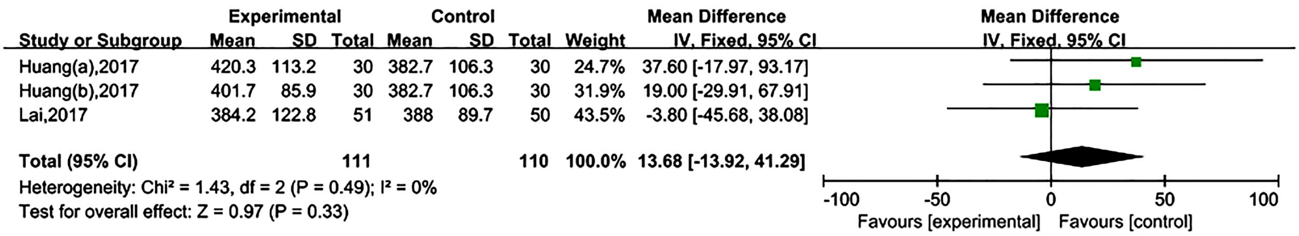

Fig. 5. Forest plot comparing PEF between the experimental and control groups.

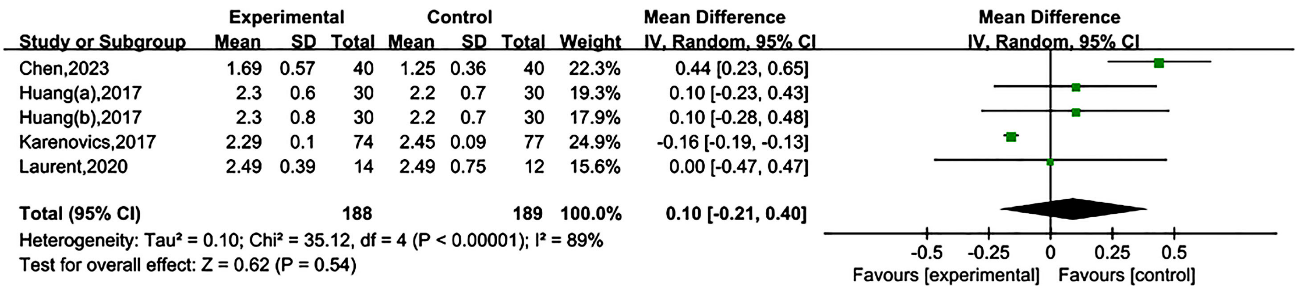

Fig. 6. Forest plot comparing FEV_1 between the experimental and control groups.

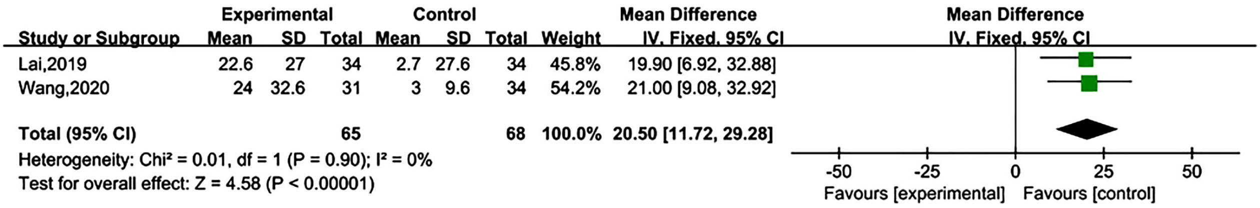

Fig. 7. Forest plot comparing the increase in 6MWD between the experimental and control groups.

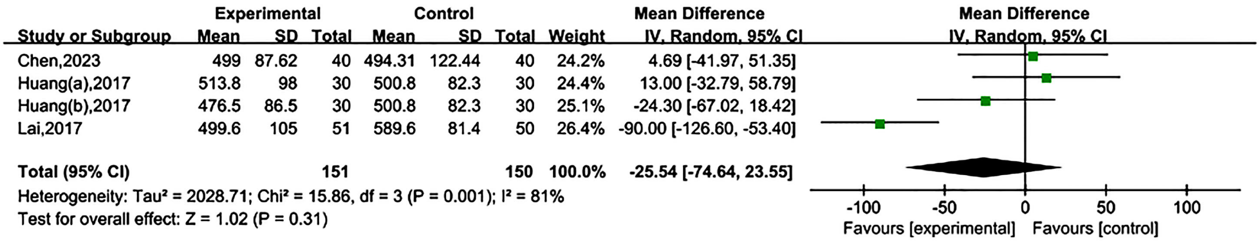

Fig. 8. Forest plot comparing absolute postoperative 6MWD between the experimental and control groups.

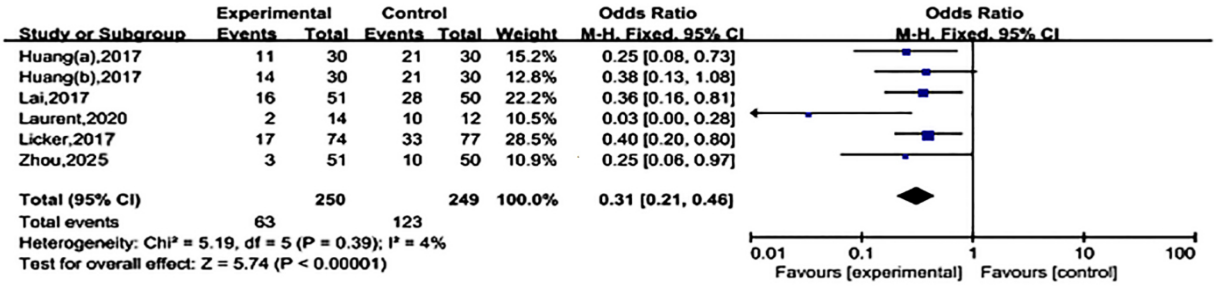

Fig. 9. Forest plot comparing incidence of pulmonary complications between the experimental and control groups.

68 in the control group. Heterogeneity analysis showed $I^2 = 0\%$ with $p = 0.90$, indicating no significant statistical heterogeneity among the included studies; therefore, a fixed-effects model was applied. The meta-analysis revealed that PRT significantly increased 6MWD in the experimental group compared with the control group (MD = 20.50, 95% CI: 11.72 to 29.28, $p < 0.00001$) (Fig. 7).

Absolute Postoperative 6MWD

Four studies reported absolute postoperative 6MWD outcomes for both the experimental and control groups [14,18,19]. In the study by Huang *et al.* (2017) [19], data were available for both a combined intervention group versus control and a single intervention group versus control; these comparisons were analyzed separately. In total, 151 patients were included in the experimental group and 150 in the control group. Heterogeneity analysis showed $I^2 = 81\%$ with $p < 0.001$, indicating substantial heterogeneity among the included studies; therefore, a random-effects model was applied. The meta-analysis demonstrated no statistically significant difference in absolute postoperative 6WMD between the experimental and control groups (MD = –25.54, 95% CI: –74.64 to 23.55, $p = 0.31$) (Fig. 8).

Incidence of Pulmonary Complications

Seven studies reported the incidence of pulmonary complications in both the experimental and control groups [18–22]. In the study by Huang *et al.* (2017) [19], data were available for both a combined intervention group versus control and a single intervention group versus control; separate analysis of these comparisons was conducted. In total, 250 patients were included in the experimental group and 249 in the control group. Heterogeneity analysis showed $I^2 = 4\%$ with $p = 0.39$, indicating no significant heterogeneity among the included studies; therefore, a fixed-effects model was applied. The meta-analysis demonstrated that PRT significantly reduced the incidence of pulmonary complications in the experimental group compared with the control group (OR = 0.31, 95% CI: 0.21 to 0.46, $p < 0.00001$) (Fig. 9).

Publication Bias

A bias check was performed on all outcome measures included in this article. The funnel plots appeared generally symmetrical, indicating no evident publication bias (Fig. 10).

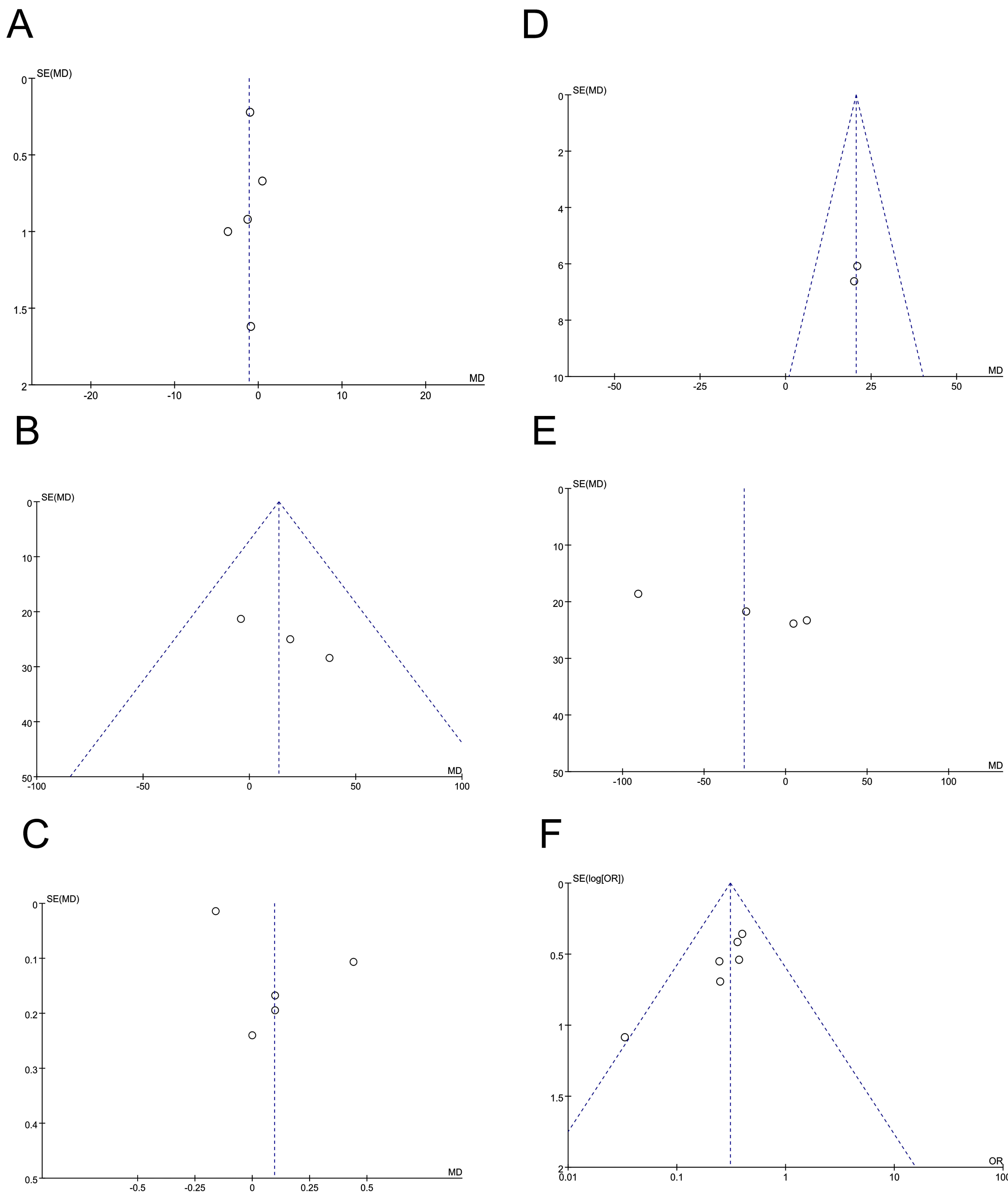

Fig. 10. Funnel plots of the experimental and control groups. (A) Funnel plot of length of hospital stay for the two groups of patients. (B) Funnel plot of PEF for the two groups of patients. (C) Funnel plot of FEV_1 for the two groups of patients. (D) Funnel plot of increase in 6MWD for the two groups of patients. (E) Funnel plot of absolute postoperative 6MWD level for the two groups of patients. (F) Funnel plot of incidence of pulmonary complications for the two groups of patients. OR, odds ratio; MD, mean difference.

Sensitivity Analysis

To evaluate the stability and reliability of the meta-analysis results for the 6MWD, a sensitivity analysis was conducted (Fig. 11). Each study was sequentially excluded, and the pooled effect size was recalculated to assess the impact of individual studies on the overall results. The analysis showed that excluding any single study did not substantially alter the direction or statistical significance of the overall effect size. The 95% confidence intervals remained within a relatively stable range (MD = –25.33, 95% CI: –94.61 to 43.94, p = 0.47), indicating that the model demonstrated good robustness.

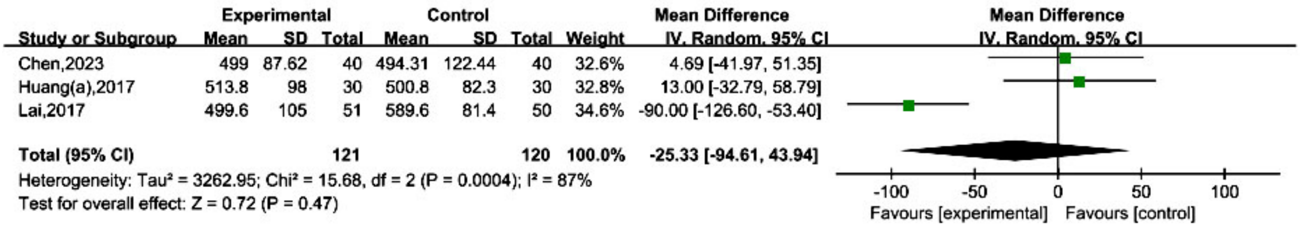

Fig. 11. Sensitivity analysis results for 6MWD between the experimental and control groups.

Discussion

Our findings indicate that PRT can substantially lower the incidence of PPCs and enhance functional recovery, as reflected by improvements in 6MWD. Conversely, no significant benefits were observed for absolute 6MWD, spirometry-based indices (FEV_1, PEF), or length of stay. The results were consistent across sensitivity tests and funnel plot evaluations, supporting their robustness. Taken together, these data underscore the potential of PRT in improving perioperative outcomes for patients undergoing thoracic surgery.

The observed reduction in PPCs aligns with previous research in thoracic and cardiothoracic surgical populations, where inspiratory muscle training and other structured interventions have been shown to decrease the incidence of postoperative pneumonia, atelectasis, and respiratory failure. For example, Assouline *et al*. [23] reported that targeted inspiratory training prior to lung resection significantly lowered PPC rates, providing physiological rationale underlying our findings. The protective effects of PRT are likely multifactorial, involving improved alveolar ventilation, enhanced cough efficiency, and better secretion clearance [24–26]. Evidence from RCTs supports these mechanisms: For instance, Ge *et al*. [24] demonstrated that inspiratory muscle training enhances tidal volume and alveolar recruitment, thereby improving oxygenation and reducing the risk of atelectasis; Dhillon *et al*. [25] reported that targeted respiratory exercises strengthen cough efficacy and promote mucus clearance, which is essential for lowering postoperative infection rates; and Moodie *et al*. [26] showed that respiratory muscle training improves inspiratory strength in ventilated patients, facilitating more effective secretion removal. These physiological improvements form the basis for the observed reduction in PPCs in our meta-analysis.

The improvement in 6MWD lends support to the functional benefits of PRT, in line with evidence from the contexts of chronic obstructive pulmonary disease and cardiac surgery, where preoperative rehabilitation improved exercise tolerance and accelerated recovery [27,28]. The link between reduced PPCs and functional recovery may be bidirectional: fewer complications enable earlier ambulation, while greater physiological reserve may enhance postoperative ventilation and airway clearance [29,30]. The absence of significant differences in absolute postoperative 6MWD likely reflects heterogeneity in baseline fitness and variations in postoperative rehabilitation intensity, particularly among patients with preserved preoperative physical function.

Despite these functional improvements, PRT did not significantly enhance FEV_1 or PEF. Similar findings in prior RCTs suggest that early postoperative spirometry is strongly affected by surgical trauma, pain, and inflammatory responses, which may mask preoperative gains [31–33]. Moreover, static spirometric indices may be less sensitive than functional tests such as 6MWD in capturing integrated recovery. Theoretically, reduced complications and improved functional capacity could shorten length of hospital stay, but no significant difference in the latter was observed in this meta-analysis. This may be attributed to the adoption of Enhanced Recovery After Surgery (ERAS) protocols in the included studies, where patient discharge could be determined by multiple factors, including wound healing, pain control, and psychosocial readiness [34,35].

The mechanisms underlying the benefits of PRT include strengthened respiratory muscles, improved tidal volume and alveolar recruitment, and enhanced cough efficacy, which collectively attenuate risks for atelectasis and infection [31,36]. By increasing functional reserve, PRT enhances tolerance to surgical stress and facilitates earlier mobilization. Clinically, these findings provide a rationale for integrating PRT into perioperative care, particularly for high-risk groups such as elderly patients, smokers, or individuals with impaired baseline pulmonary function. Given its safety, ease of execution, and low cost, PRT represents a feasible adjunct to ERAS-based thoracic surgery protocols.

Among the strengths of this study are the exclusive inclusion of RCTs and high-quality controlled studies in the analysis, the comprehensive evaluation of clinically relevant outcomes, and the incorporation of rigorous risk of bias assessment and sensitivity analyses. However, some limitations should be acknowledged. First, the number of eligible studies was relatively small, and heterogeneity was observed in some outcomes (e.g., FEV_1 and absolute 6MWD), which may restrict the strength and generalizability of the conclusions. The included studies varied in PRT protocols—including type, intensity, frequency, and precautions—which may have contributed to result heterogeneity. Future studies should adopt standardized PRT regimens to enhance comparability and reproducibility of findings. Additionally, sample sizes were relatively small for some endpoints, such as PEF and absolute postoperative 6MWD, potentially limiting statistical power. Moreover, as fewer than ten studies were included, the statistical power of funnel plot analysis and Egger's/Begg's tests was inherently limited, which should be recognized as a methodological constraint in assessing publication bias. Future large-scale, multicenter RCTs with standardized interventions are needed to determine the optimal PRT regimen and identify the patient subgroups most likely to benefit.

Conclusions

This meta-analysis demonstrates that PRT significantly reduces the incidence of PPCs and enhances functional recovery, as indicated by improvements in 6MWD change, in patients undergoing thoracic surgery. However, its effects on spirometry-based pulmonary function parameters (FEV_1, PEF), absolute postoperative 6MWD, and length of hospital stay remain inconclusive. Given its safety, ease of execution, and low cost, PRT may be considered a useful adjunct to perioperative care, particularly for high-risk patients. Further investigations could adopt large-scale, multicenter RCTs with standardized protocols to optimize PRT regimens and identify the patient subgroups for whom PRT would be most effective.

Availability of Data and Materials

The data analyzed are available from the corresponding authors upon reasonable request.

Author Contributions

YFZ, MZ, and YGD conceived and designed the study. YGD made substantial contributions to data acquisition, formal analysis, and methodology. YFZ was involved in drafting the manuscript. YFZ and MZ analyzed and interpreted the data. YGD also contributed to visualization and critical review of the manuscript. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

Not applicable.

Acknowledgment

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.4272.

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