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Efficacy of positive expiratory pressure in the prevention and treatment of postoperative pulmonary complications following thoracic and abdominal surgery. A systematic review and meta-analysis

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Abstract

Postoperative pulmonary complications (PPCs), including atelectasis, pneumonia, and respiratory failure, are common after thoracic and upper abdominal surgery and are associated with increased morbidity, longer hospital stays, and higher costs. This systematic review and meta-analysis investigated whether positive expiratory pressure (PEP) devices reduce PPCs after thoracic or upper abdominal surgery compared with continuous positive airway pressure (CPAP), usual care/no intervention, or other non-CPAP respiratory treatments. We searched major databases and included randomized controlled trials. A total of 12 studies were included, and 7 contributed to the meta-analysis. Across comparator-stratified analyses, PEP did not demonstrate a consistent reduction in PPCs. Compared with usual care/no intervention, pooled estimates showed no significant benefit, and results were similarly inconclusive when PEP was compared with other non-CPAP treatments; evidence vs. CPAP was limited to a single small trial. The overall certainty of evidence was low due to methodological limitations and heterogeneity in outcome definitions and intervention protocols. Overall, current evidence does not support routine use of PEP devices as a primary strategy to prevent PPCs after thoracic or upper abdominal surgery. Further well-designed trials are needed to clarify whether specific patient subgroups or standardized protocols may benefit.

Key words: positive expiratory pressure, postoperative pulmonary complications, thoracic surgery, abdominal surgery.

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Introduction

Postoperative pulmonary complications (PPCs) encompass a range of respiratory conditions typically occurring within the first postoperative week [1]. Atelectasis, pneumonia, and respiratory failure are the most common PPCs, with incidence rates ranging from 20% to 40% in patients undergoing thoracic surgeries, depending on the studied population and surgical complexity [2]. PPCs are also among the leading causes of morbidity and mortality in patients undergoing thoracic and upper abdominal surgeries [3]. These complications not only prolong hospital stays and escalate healthcare costs but also significantly impair patients' quality of life [4,5]. A systematic review assessing PPC prevalence in patients undergoing abdominal surgery reported that the presence of postoperative atelectasis and pneumonia was associated with in-hospital mortality rates as high as 30% [6]. This finding underscores the importance of effective preventive strategies to reduce PPC incidence.

Among various respiratory physiotherapy techniques, positive expiratory pressure (PEP) devices are used as part of postoperative respiratory physiotherapy following thoracic and upper abdominal surgery; however, robust data describing their dissemination and routine use specifically for PPC prevention are limited [7]. PEP devices function by applying expiratory resistance through a mouthpiece, a facial mask, or an endotracheal interface (endotracheal tube or tracheostomy cannula), generating positive pressure that promotes airway opening, improves pulmonary ventilation, and facilitates secretion clearance [8]. Additionally, the increased expiratory time due to applied resistance enhances mucus transport through prolonged air-mucus interaction, thereby aiding secretion mobilization [9]. While these devices are widely used in clinical practice, evidence on their efficacy in PPC prevention remains inconsistent. Some studies have demonstrated positive outcomes with PEP compared to standard respiratory physiotherapy techniques [10], whereas others have reported no significant differences [11].

Despite the widespread clinical use of PEP devices, the existing literature presents conflicting results and methodological gaps. To our knowledge, no updated systematic reviews have specifically examined the effectiveness of PEP devices in PPC prevention. The only available systematic review on this topic used outdated articles and showed significant methodological and structural limitations, undermining the robustness and applicability of its conclusions [7].

Therefore, this systematic review is necessary to address the fragmented nature of current evidence and provide an updated synthesis using a precise and rigorous methodology.

This systematic review aims to evaluate the effectiveness of PEP devices in the prevention and management of PPCs after thoracic or upper abdominal surgery.

Materials and Methods

This systematic review was prospectively registered on PROSPERO (24 February 2025, CRD420250633723) and is presented according to the PRISMA guidelines [12]. The systematic search was performed on 16 April 2025, with no restrictions on publication date, and included all available literature at the time, based on the predefined PICO framework (population, intervention, comparator, outcomes).

The inclusion criteria were: i) population – adults undergoing thoracic or upper abdominal surgeries; ii) intervention – use of PEP devices, including both threshold and continuous flow types; iii) comparator – not predefined; included any intervention or no intervention; iv) outcomes – studies had to report outcomes such as the reduction of PPCs; v) study type – only randomized controlled trials (RCTs) were included.

The exclusion criteria were: i) language – studies not published in English were excluded to avoid translation and interpretation issues that could compromise data accuracy; ii) accessibility – studies not available in full-text were excluded, as a critical evaluation of their methods and results would not have been possible; iii) peer review status – studies published in non-peer-reviewed journals were excluded to ensure methodological rigor.

Advanced searches were conducted in the following general and specialized search engines and associated databases: PubMed (Medline), Embase, Cochrane Library, OvID, Scopus, ProQuest (Publicly Available Content Database, SciTech Premium Collection, Science Database, Coronavirus Research Database, Psychology Database), PEDro, Cinahl (CINAHL Ultimate, Education Source Ultimate, APA PsycInfo, Psychology and Behavioral Sciences Collection, Child Development & Adolescent Studies, Business Source Complete, Library & Information Science Source, Sociology Source Ultimate).

Additionally, the bibliographies of included studies were reviewed to identify any other quantitative studies related to the review topic.

According to the PICO framework, we defined: (population) adult patients undergoing thoracic or upper abdominal surgery; (intervention) postoperative PEP systems; (comparator) no treatment/usual care or placebo (sham), other breathing exercises/respiratory physiotherapy interventions, or continuous positive airway pressure (CPAP); and (outcomes) PPCs (*e.g.*, pneumonia and atelectasis) as defined in each included study within the postoperative follow-up period. Studies were included in the meta-analysis only when they reported extractable dichotomous data (events/total per arm) for PPCs (or an equivalent PPC proxy) at a comparable timepoint within the prespecified comparator strata; otherwise, they were not pooled. The search string was tailored to meet the formatting requirements of each database/search engine without compromising its logical structure (*Supplementary Table 1*).

During the search phase, the following filters were applied (where possible, as not all search engines allowed direct implementation of these criteria) to refine the results and select only studies fully meeting the eligibility criteria: language, study type, and accessibility.

All records were imported into an Excel spreadsheet for organization and screening. Two reviewers independently evaluated the studies. In cases of disagreement regarding study inclusion, discrepancies were resolved through discussion and consensus.

Initially, titles and abstracts of the identified articles were screened to exclude duplicates and irrelevant studies. Studies passing the title and abstract screening were selected for full-text review. At this stage, the articles were assessed in detail to confirm their eligibility based on the inclusion and exclusion criteria. The total number of excluded studies, along with the reasons for exclusion (*e.g.*, incomplete data, irrelevant outcomes, or inappropriate study design), was documented. The process of study selection was summarized using a PRISMA flowchart.

Data from the included studies were extracted using a Word document and subsequently synthesized into tabular form. Two independent reviewers performed the data extraction process, working blinded to minimize bias. The extracted data included: general information about the article (author, year, and country), participant characteristics (number of participants, mean age, and sex), type of surgical intervention, type of PEP device used, comparator used in the control group, treatment modalities, frequency, and duration, primary outcomes and results reported.

In cases of discrepancies between reviewers, these were resolved through discussion and consensus.

The updated version of the Risk of Bias 2 (RoB2) tool [13], published in 2019, was used to assess the methodological quality of the included studies. The RoB2 tool evaluated five main domains: i) bias arising from the randomization process; ii) bias due to deviations from intended interventions; iii) bias due to missing outcome data; iv) bias in outcome measurement; v) bias in the selection of the reported result.

Each domain was assessed using specific questions, and the risk of bias for each domain was categorized as "low risk of bias", "some concerns", or "high risk of bias". Two independent reviewers evaluated the studies and assigned risk levels for each domain. Discrepancies were resolved through discussion and consensus. No specific adaptations to the RoB2 tool were made. The overall risk of bias was reported for all included studies.

For dichotomous outcomes (*e.g.*, PPCs, pneumonia, radiographic atelectasis), we calculated relative risk (RR) with 95% confidence intervals (CI) using a random-effects model. Continuous outcomes (*e.g.*, computed tomography (CT)-based atelectasis extent, spirometry) were not pooled with dichotomous PPC outcomes and were synthesized separately when sufficiently homogeneous; otherwise, they were narratively summarized. Heterogeneity among studies was assessed using the I^2 statistic (≥50% indicative of heterogeneity) and visual inspection of forest plots. If heterogeneity was detected, subgroup analysis was conducted.

Given the heterogeneity of comparators across trials, we prespecified comparator-stratified meta-analyses to avoid pooling clinically dissimilar contrasts. Where appropriate, results were further stratified by surgical setting (cardiac *vs.* thoracic *vs.* upper abdominal).

For studies reporting multiple intervention arms, only the relevant arms were considered. If two comparisons (*e.g.*, intervention A *vs.* placebo and intervention B *vs.* placebo) were combined in the same meta-analysis, the control group was divided to avoid double counting.

In cases where data were missing from included studies, the cor-

responding authors were contacted to verify key characteristics of the studies and obtain missing outcome data. If the authors could not be reached or failed to provide the data, the study was excluded from the meta-analysis but considered in the systematic review.

The level of statistical significance was set at $p<0.05$. All statistical data analyses were conducted utilizing IBM SPSS Statistics for Windows, version 29 (IBM Corp., Armonk, NY, USA).

Results

The initial systematic search identified a total of 2596 articles through various databases, with one additional article found in the reference list of studies being screened. In total, 2597 studies were identified. After completing the screening process (Figure 1), 12 studies were included in the systematic review as they met the eligibility criteria [10,11,14-23]. Five included studies were not entered into the meta-analysis because they did not provide extractable dichotomous data (events/total per arm) for a comparable PPC endpoint and timepoint, and/or reported outcomes mainly as continuous physiological/radiological measures or delivered multi-component interventions in which the specific contribution of PEP could not be isolated [19-23].

The 12 studies included in the review were RCTs comparing the use of PEP devices in preventing PPCs with other interventions or no treatment. These studies involved patients undergoing thoracic or upper abdominal surgery. Sample sizes ranged from 50 to 353 participants, with most studies focusing on adult and elderly patients. Some studies specifically included patients with respiratory conditions, such as chronic obstructive pulmonary disease or cystic fibrosis [10,18], while the majority involved patients undergoing cardiothoracic surgery. Regarding PEP devices, most studies utilized a PEP mask or a blow-bottle device, comparing them with methods like CPAP, inspiratory resistance-PEP (IR-PEP), or conventional respiratory exercises (deep breathing exercise). Treatment durations varied, but typically included multiple sessions repeated throughout the day. The follow-up duration varied significantly across studies, ranging from the day immediately after surgery to up to the ninth postoperative day, with most studies following up for 3-4 days. Primary outcomes included prevention of PPCs, such as atelectasis and pneumonia, evaluated primarily *via* chest X-rays, and in some cases, CT scans or thoracic ultrasound. Other frequently analyzed parameters included pulmonary function (forced vital capacity, forced expiratory volume in 1 second, total lung capacity), measured *via* spirometry, partial pressure of oxygen (PaO_2), and oxygen saturation (SaO_2), assessed through arterial blood gas analysis. Some studies also included additional outcomes, such as length of hospital stay, respiratory muscle strength, and postoperative pain, measured using numeric rating scale.

The key characteristics of all included studies are summarized in *Supplementary Table 2* and the RoB2 risk-of-bias assessment is summarized in Figure 2.

The risk-of-bias assessment revealed that most studies exhibited significant methodological limitations across several domains. Specifically, only three articles were rated as "low risk" in the first domain [11,17,18], while the remaining studies were classified as having "some concerns" due to limitations in the randomization process [10,14-16,19-23]. Regarding the second domain, all articles,

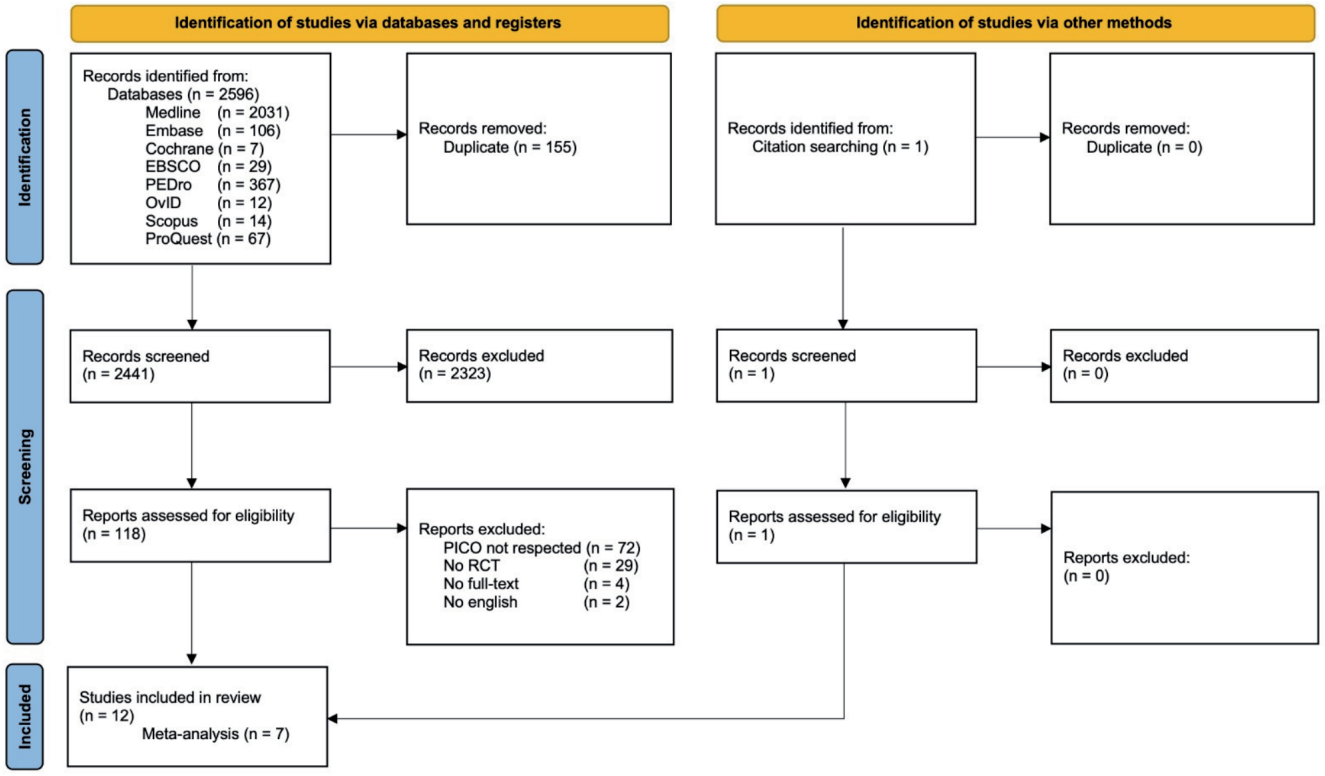

Figure 1. PRISMA flow chart.

except one rated as "high risk" due to major methodological issues, were classified as having "some concerns" due to the lack of blinding between operators and patients concerning the treatment [10].

The fifth domain also highlighted methodological issues, as only two studies had a pre-registered protocol [11,17], which is essential for preventing selective reporting bias. Overall, except for one study rated as "high risk", all other studies were classified as having "some concerns" in the "overall" domain [10].

These methodological limitations identified through the application of the RoB2 tool should be considered when interpreting the results.

Since not all articles were included in the meta-analysis, the outcomes of studies included only in the systematic review are summarized below. The exclusion of these articles from the statistical analysis was due to high methodological heterogeneity, which complicated accurate quantitative synthesis. Consequently, the outcome data for these studies are presented individually.

Across the included trials, PPCs were defined heterogeneously, ranging from "hard" respiratory support outcomes (*e.g.*, reintubation/prolonged ventilation) to composite clinical criteria and radiological endpoints (atelectasis on chest X-ray or CT-derived atelectasis area). Accordingly, results are reported below by comparator type to improve interpretability.

PEP/IR-PEP *vs.* CPAP: in the study by Fagevik Olsén *et al*. [19], PPCs were defined as the need for reintubation and prolonged artificial ventilation, and the comparison was IR-PEP *vs.* CPAP. A higher frequency of PPCs was reported in the IR-PEP group compared with CPAP (7 *vs.* 1 events; $p<0.05$).

PEP *vs.* usual care/no intervention: in a second study by Fagevik Olsén *et al.* [22], PPCs were defined using a composite clinical def-

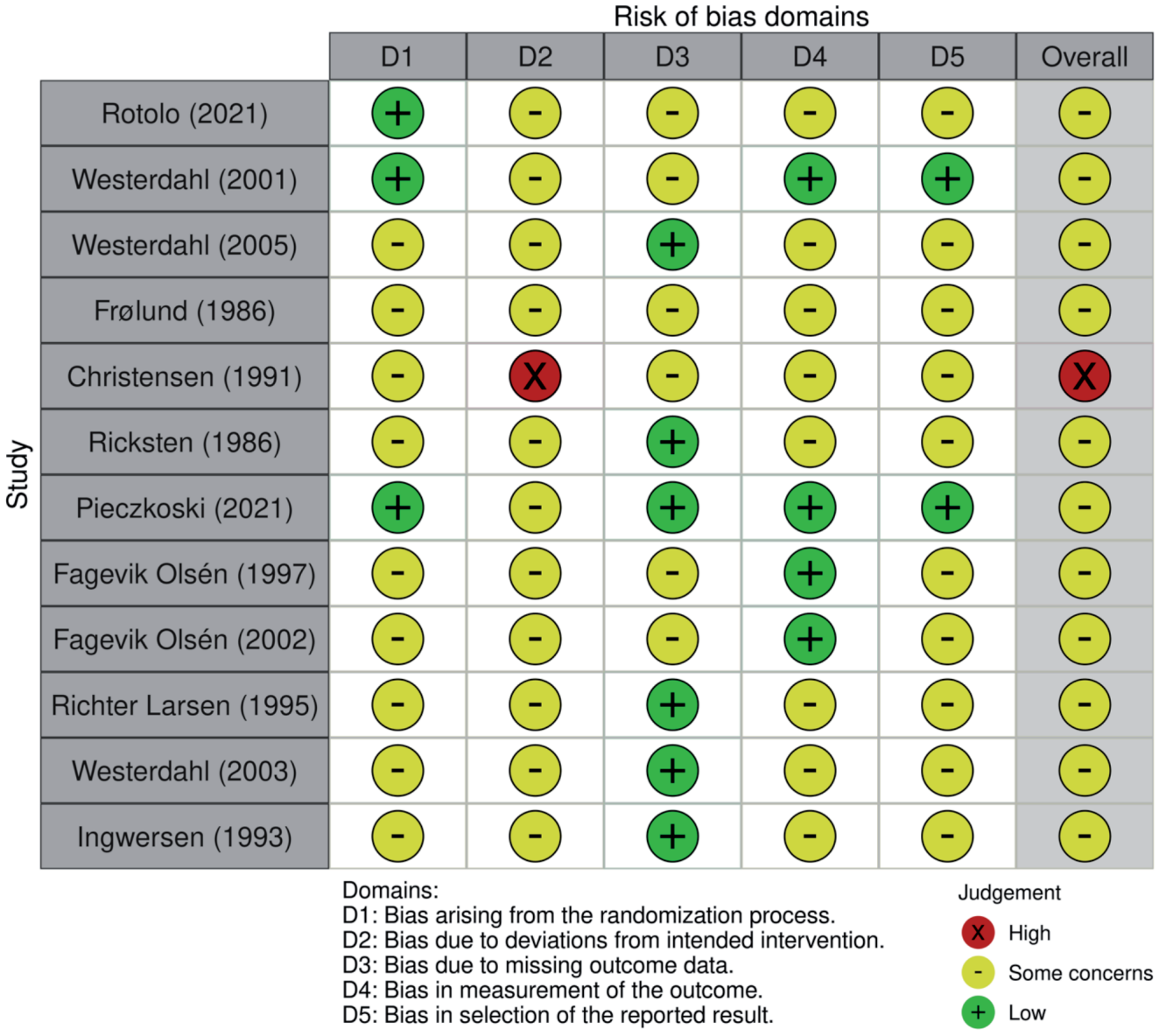

Figure 2. Assessment of risk of bias with the Risk of Bias 2 tool for the studies included in the systematic review.

inition (oxygen saturation <92% or at least two additional clinical/radiological criteria), and the PEP mask was compared with no treatment until PPC onset. This study reported a marked between-group difference, with PPCs occurring in 10/172 (6%) in the PEP group *vs.* 52/192 (27%) in the control group (p<0.001).

PEP/IR-PEP *vs.* other treatments (non-CPAP): for trials comparing PEP-based strategies against other non-CPAP interventions, no consistent advantage of PEP devices emerged. Richter Larsen *et al.* assessed PPCs primarily as radiographic atelectasis and reported similar atelectasis prevalence across PEP, IR-PEP and control groups by postoperative day 3, with only a single persistent case in the control group by day 6 [21]. Westerdahl *et al*. quantified atelec-

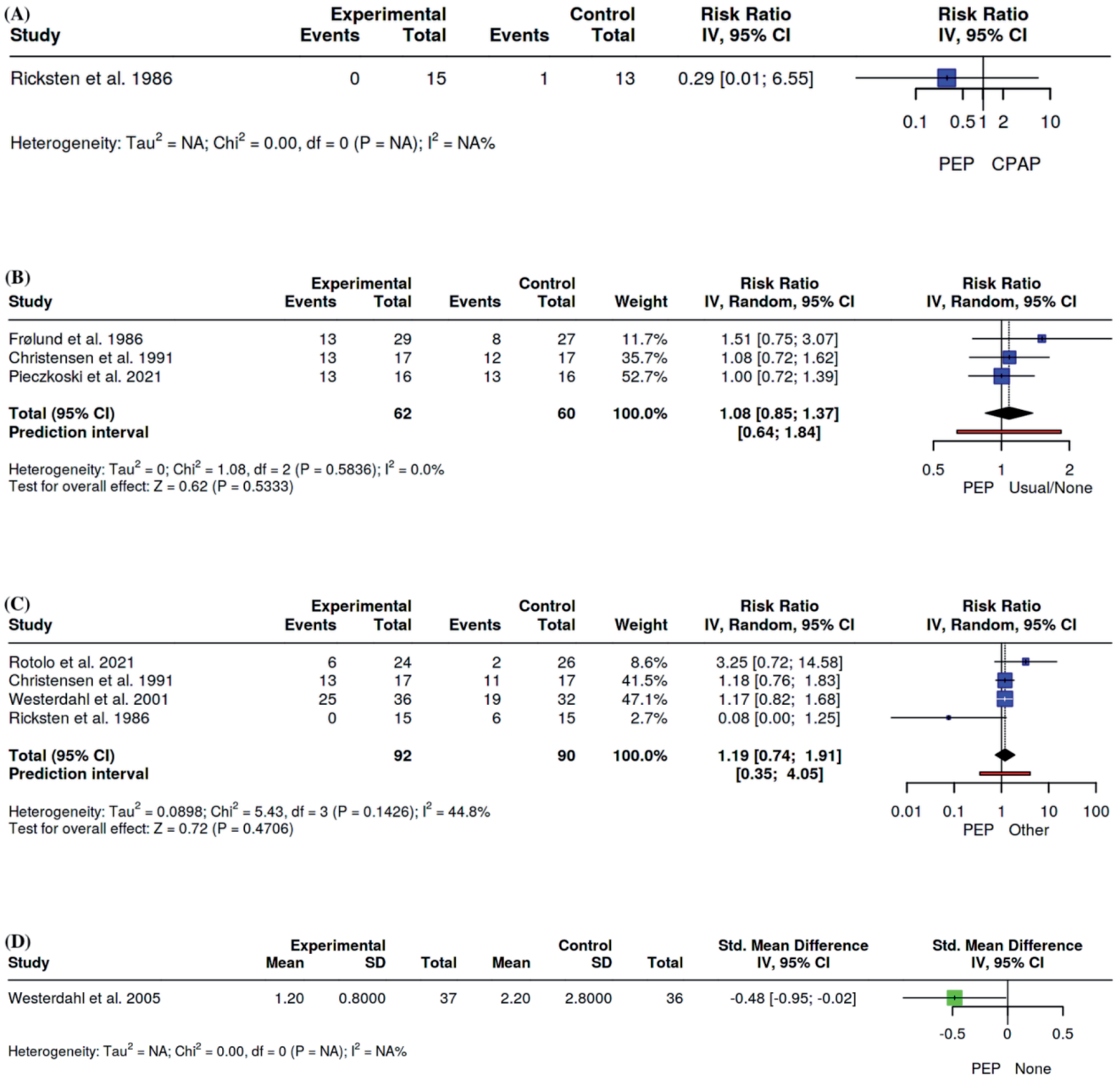

Figure 3. Forest plots of postoperative pulmonary outcomes following thoracic or upper abdominal surgery. A) Positive expiratory pressure (PEP) vs. continuous positive airway pressure (CPAP): risk of postoperative pulmonary complications (PPCs); B) PEP vs. usual care/no intervention: risk of PPCs; C) PEP vs. other non-CPAP respiratory interventions: risk of PPCs. For panels A-C, the effect measure is the risk ratio for PPC occurrence (composite endpoint including complications such as atelectasis and pneumonia, as defined in each included study), calculated using an inverse-variance random-effects model with 95% confidence intervals (CIs). D) PEP vs. no intervention: extent of postoperative atelectasis assessed by computed tomography (continuous outcome), expressed as standardized mean difference with 95% CIs (inverse-variance model). Values <1 (A-C) or <0 (D) favor PEP, whereas values >1 (A-C) or >0 (D) favor the comparator.

tasis area on CT after coronary artery bypass graft and found that atelectasis decreased after a session of deep breathing in all groups, with no between-group differences (PEP, IR-PEP, or no device) [23]. Similarly, Ingwersen *et al.* reported no significant differences in radiographic atelectasis among CPAP, PEP and IR-PEP masks [20].

Overall, differences in PPC definitions, comparators, and outcome ascertainment likely contributed to variability across trials; importantly, findings differed by comparator type, supporting the decision to avoid pooling clinically dissimilar contrasts.

To address the clinical heterogeneity of comparators across trials, meta-analyses were conducted separately by comparator type, rather than pooling all studies into a single overall estimate.

Given the heterogeneity of comparators across trials, we prespecified analyses stratified by comparator type to avoid pooling clinically dissimilar contrasts. Specifically, meta-analyses were conducted separately for: i) PEP *vs.* CPAP; ii) PEP *vs.* usual care/no intervention; iii) PEP *vs.* other treatments (non-CPAP).

PEP *vs.* CPAP*:* only one trial (Figure 3A) contributed to this comparison [14], showing an RR of 0.29 (95% CI 0.01-6.55), with no estimable heterogeneity (single-study analysis).

PEP *vs.* usual care/no intervention: 3 studies were included [10,11,15], totaling 62 participants in the PEP group and 60 in the control group. The pooled effect showed no significant difference between groups (RR 1.08, 95% CI 0.85-1.37). Heterogeneity was negligible (I^2=0%; Chi^2=1.08, p=0.58), and the prediction interval was 0.64-1.84, indicating uncertainty around the likely effect in a new setting (Figure 3B).

Westerdahl *et al.* was not informative for a dichotomous "atelectasis present/absent" endpoint (atelectasis was observed in all examined participants at POD4) and was therefore analyzed as a continuous outcome (Figure 3D) [17]. Using CT-based total atelectatic area (% total lung area), the mean difference favored PEP/deep-breathing (MD -1.00, 95% CI -1.95 to -0.05; single-study analysis).

PEP *vs.* other treatments (non-CPAP): 4 studies were included [10,14,16,18], totaling 92 participants in the PEP group and 90 in the comparator group. The pooled RR was 1.19 (95% CI 0.74-1.91), again indicating no statistically significant difference, with moderate heterogeneity (I^2=44.8%; Chi^2=5.43, p=0.14) and a wide prediction interval (0.35-4.05), consistent with variability across active comparators and study protocols (Figure 2C).

Assessment of small-study effects/publication bias (*e.g.*, funnel plots and asymmetry tests) was not performed because each comparator-specific meta-analysis included fewer than 10 studies, and pooling across different comparator types would be clinically inappropriate and potentially misleading.

Discussion and Conclusions

The individual studies included in the systematic review reported variable results regarding the efficacy of PEP devices in preventing PPCs. Studies such as that by Fagevik Olsén *et al.* demonstrated a lower prevalence of PPCs in the groups treated with PEP compared to control groups, suggesting a potential preventive effect of PEP [22]. However, other studies, such as those by Ingwersen *et al*. and Westerdahl *et al*. [20,23], found no significant differences between the PEP-treated groups and controls. This suggests that the efficacy of PEP may depend on specific factors, such as the type of surgery and the applied protocol.

Overall, our findings suggest that any potential benefit of PEP in preventing PPCs is likely to be small and may depend on the clinical context and the comparator. Across comparator-stratified analyses, we did not observe a consistent advantage of PEP over usual care/no intervention or over other active breathing strategies, while direct evidence *vs.* CPAP remains sparse. Heterogeneity in outcome definitions (clinical composites *vs*. radiological endpoints), intervention protocols, and patient populations likely contributes to the observed uncertainty and limits the strength of conclusions.

The generally low methodological quality of the included studies represents a significant limitation in interpreting the results. All studies, except one, were rated as having a moderate risk of bias; only the study by Christensen *et al*. was classified as having a high risk of bias [10]. This assessment highlights the limited reliability of the available literature, increasing the risk of overestimating or underestimating the benefits associated with PEP devices and reducing the ability to draw definitive conclusions about their efficacy.

Another factor to consider is the short follow-up duration. Most studies observed patients for very short periods, often only 2-3 days after surgery. This timeframe may be insufficient to capture all potential PPCs, many of which may manifest beyond this window. Consequently, the short follow-up may lead to underestimation of both the benefits and risks associated with PEP use, further limiting the ability to draw clinically relevant conclusions.

A methodological limitation inherent to this field is the frequent impracticability of blinding in respiratory physiotherapy trials, as the nature of the intervention and the use of devices often prevent masking of treatment allocation for both participants and providers. This common constraint may increase the risk of performance bias and, in some settings, detection bias, particularly when outcomes include subjective components or rely on clinical judgement. Therefore, findings should be interpreted in light of this limitation, and future studies should prioritize blinding of outcome assessors whenever feasible and adopt standardized, objective endpoints.

The risk of publication bias remains uncertain. The available evidence base is small and fragmented across different comparisons, with only a limited number of trials contributing to each analysis. In this context, visual and statistical approaches to detect small-study effects are unlikely to provide a reliable signal and may be driven by differences in study design and comparator type rather than by selective publication. Therefore, we cannot exclude the presence of unpublished or selectively reported studies, and this uncertainty should be considered when interpreting the overall results.

The results of this review are consistent with previous studies, such as the systematic review by Örman and Westerdahl [7], which evaluated the efficacy of PEP in patients undergoing abdominal and thoracic surgeries. That review included 6 randomized trials, 4 of which were also part of the present review [10,14,15,20]. Örman and Westerdahl identified limited evidence supporting PEP, with only 1 of 6 studies showing positive effects of PEP compared to other techniques [14], such as an improvement in the alveolar-arterial oxygen difference and a reduction in the prevalence of atelectasis. However, the overall findings of their review indicated a lack of significant differences between PEP and other techniques, such as CPAP or inspiratory resistance, suggesting that PEP may not provide superior benefits in preventing PPCs.

In addition to PEP treatment, several studies have evaluated the efficacy of alternative methods for preventing PPCs, including CPAP. The study by Matte *et al*. concluded that CPAP reduces the risk of PPCs after abdominal surgery and proves to be more effective than deep breathing exercises in patients undergoing cardiac surgery [24]. Similarly, the systematic review by Ferreyra *et al*. highlighted that CPAP use reduces the risk of PPCs in patients

undergoing abdominal surgery [25]. In the present review, control groups using CPAP often reported fewer complications than the groups treated with PEP. These findings suggest that CPAP may represent a more advantageous therapeutic choice for specific contexts and high-risk patients.

Despite a plausible pathophysiological rationale for PEP systems in the postoperative setting (*e.g.*, increasing end-expiratory lung volume, promoting collateral ventilation, and facilitating mucus mobilization), the overall findings of this review do not show a consistent reduction in PPCs [26]. This apparent discrepancy may be explained by the multifactorial pathogenesis of PPCs after thoracic and upper abdominal surgery. In the early postoperative phase, anesthesia and commonly used perioperative drugs can depress respiratory drive and muscle function, while the supine position and anesthesia-related changes reduce functional residual capacity and alter its relationship with closing capacity [27], promoting dependent airway closure and rapid formation of atelectasis, with ventilation–perfusion mismatch and hypoxemia [26,28-30]. Atelectasis is highly prevalent during anesthesia and may persist into the postoperative period, potentially acting as a substrate for impaired gas exchange and infection-related complications [26,28,29]. In addition, upper abdominal surgery can induce clinically relevant diaphragmatic dysfunction lasting several days, contributing to a restrictive ventilatory pattern and reduced inspiratory capacity [31]. In this context, the pressure levels generated by commonly used PEP devices may be insufficient to counterbalance the combined effects of diaphragmatic dysfunction [32], low tidal volumes, sedation-related hypoventilation, prolonged supine positioning, and repeated micro-atelectasis, particularly when PEP is applied intermittently, initiated late, or not titrated to lung mechanics and patient response [26-30]. Moreover, heterogeneity in PPC definitions/ascertainment and variability in intervention "dose" (frequency, duration, intensity), timing of initiation, supervision, and adherence may dilute a clinically meaningful effect in pooled analyses [26].

Despite this, PEP offers practical advantages that make it an attractive option in various clinical settings. The simplicity of administration and low cost of the device allow its use even in resource-limited facilities [33]. Improvised PEP devices, such as the "bubble-PEP" system, constructed from easily accessible materials, are often employed in these environments [34]. These alternative devices are economically advantageous compared to more sophisticated and commercial solutions while still proving effective in promoting collateral ventilation and secretion clearance. Another advantage of PEP devices is their potential for self-administration by patients, making this technique particularly useful in situations where continuous monitoring is not possible, or nursing support is limited. For instance, guidelines for PEP use highlight that patients can be trained to use the device independently [35], facilitating secretion clearance without requiring medical personnel for each session. These characteristics make PEP devices suitable not only for hospital use but also for home settings, reinforcing their value as a flexible and accessible therapeutic option for respiratory support.

However, despite its practical advantages, current scientific evidence suggests that PEP may not be the optimal preventive strategy for PPCs, raising questions about its use as a first-line therapy. Moreover, features that may initially seem advantageous, such as simplicity and low cost, could paradoxically contribute to improper or decontextualized use of the therapy.

The findings of this review highlight the need for further studies addressing the methodological limitations identified in this review to provide a more accurate evaluation of PEP's efficacy in preventing PPCs. Future research should adopt more rigorous methodological designs to minimize the risks of bias and include longer observation periods to assess the long-term effectiveness of PEP in preventing PPCs beyond the immediate postoperative period.

This systematic review highlights that, based on the existing literature, the use of PEP devices should not be considered a primary option for the prevention of PPCs following thoracic and upper abdominal surgeries. It is hoped that this analysis will stimulate further research aimed at enhancing the understanding and effectiveness of PEP treatment, while discouraging its generalized and decontextualized use. The currently available evidence does not justify the adoption of PEP devices as a first-line tool for PPC prevention in these specific surgical contexts.

References

1. Warner DO. Preventing postoperative pulmonary complications: the role of the anesthesiologist. Anesthesiology 2000;92:1467-72.
2. Agostini P, Cieslik H, Rathinam S, et al. Postoperative pulmonary complications following thoracic surgery: are there any modifiable risk factors? Thorax 2010;65:815-8.
3. Serpa Neto A, Hemmes SN, Barbas CS, et al. Incidence of mortality and morbidity related to postoperative lung injury in patients who have undergone abdominal or thoracic surgery: a systematic review and meta-analysis. Lancet Respir Med 2014;2:1007-15.
4. Lusquinhos J, Tavares M, Abelha F. Postoperative pulmonary complications and perioperative strategies: a systematic review. Cureus. 2023;15:e38786.
5. LAS VEGAS investigators. Epidemiology, practice of ventilation and outcome for patients at increased risk of postoperative pulmonary complications: LAS VEGAS – an observational study in 29 countries. Eur J Anaesthesiol 2017;34:492-507.
6. Canet J, Gallart L, Gomar C, et al. Prediction of postoperative pulmonary complications in a population-based surgical cohort. Anesthesiology 2010;113:1338-50.
7. Orman J, Westerdahl E. Chest physiotherapy with positive expiratory pressure breathing after abdominal and thoracic surgery: a systematic review. Acta Anaesthesiol Scand 2010;54: 261-7.
8. McIlwaine M, Button B, Nevitt SJ. Positive expiratory pressure physiotherapy for airway clearance in people with cystic fibrosis. Cochrane Database Syst Rev 2019;11:CD003147.
9. Andrews J, Sathe NA, Krishnaswami S, et al. Nonpharmacologic airway clearance techniques in hospitalized patients: a systematic review. Respir Care 2013;58:2160-86.
10. Christensen EF, Schultz P, Jensen OV, et al. Postoperative pulmonary complications and lung function in high-risk patients: a comparison of three physiotherapy regimens after upper abdominal surgery in general anesthesia. Acta Anaesthesiol Scand 1991;35:97-104.
11. Pieczkoski SM, de Oliveira AL, Haeffner MP, et al. Positive expiratory pressure in postoperative cardiac patients in intensive care: a randomized controlled trial. Clin Rehabil 2021;35:681-91.
12. Page MJ, McKenzie JE, Bossuyt PM, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71.
13. Sterne JAC, Savović J, Page MJ, et al. RoB 2: a revised tool

for assessing risk of bias in randomized trials. BMJ 2019; 366:l4898.
14. Ricksten SE, Bengtsson A, Soderberg C, et al. Effects of periodic positive airway pressure by mask on postoperative pulmonary function. Chest 1986;89:774-81.
15. Frølund L, Madsen F. Self-administered prophylactic postoperative positive expiratory pressure in thoracic surgery. Acta Anaesthesiol Scand 1986;30:381-5.
16. Westerdahl E, Lindmark B, Almgren SO, Tenling A. Chest physiotherapy after coronary artery bypass graft surgery: a comparison of three different deep breathing techniques. J Rehabil Med 2001;33:79-84.
17. Westerdahl E, Lindmark B, Eriksson T, et al. Deep-breathing exercises reduce atelectasis and improve pulmonary function after coronary artery bypass surgery. Chest 2005;128:3482-8.
18. Rotolo N, Cattoni M, D'Andria M, et al. Comparison of an expiratory flow accelerator device versus positive expiratory pressure for tracheobronchial airway clearance after lung cancer lobectomy: a preliminary study. Physiotherapy 2021;110: 34-41.
19. Fagevik Olsén M, Wennberg E, Johnsson E, et al. Randomized clinical study of the prevention of pulmonary complications after thoracoabdominal resection by two different breathing techniques. Br J Surg 2002;89:1228-34.
20. Ingwersen UM, Larsen KR, Bertelsen MT, et al. Three different mask physiotherapy regimens for prevention of post-operative pulmonary complications after heart and pulmonary surgery. Intensive Care Med 1993;19:294-8.
21. Richter Larsen K, Ingwersen U, Thode S, Jakobsen S. Mask physiotherapy in patients after heart surgery: a controlled study. Intensive Care Med 1995;21:469-74.
22. Fagevik Olsén M, Hahn I, Nordgren S, et al. Randomized controlled trial of prophylactic chest physiotherapy in major abdominal surgery. Br J Surg 1997;84:1535-8.
23. Westerdahl E, Lindmark B, Eriksson T, et al. The immediate effects of deep breathing exercises on atelectasis and oxygenation after cardiac surgery. Scand Cardiovasc J 2003;37:363-7.
24. Matte P, Jacquet L, Van Dyck M, Goenen M. Effects of conventional physiotherapy, continuous positive airway pressure and non-invasive ventilatory support with bilevel positive airway pressure after coronary artery bypass grafting. Acta Anaesthesiol Scand 2000;44:75-81.
25. Ferreyra GP, Baussano I, Squadrone V, et al. Continuous positive airway pressure for treatment of respiratory complications after abdominal surgery: a systematic review and meta-analysis. Ann Surg 2008;247:617-26.
26. Miskovic A, Lumb AB. Postoperative pulmonary complications. Br J Anaesth 2017;118:317-34.
27. Campbell I, Waterhouse J. Applied respiratory physiology. Anaesth Intensive Care Med 2005;6:371-5.
28. Hedenstierna G, Edmark L. Mechanisms of atelectasis in the perioperative period. Best Pract Res Clin Anaesthesiol 2010;24:157-69.
29. Magnusson L, Spahn DR. New concepts of atelectasis during general anaesthesia. Br J Anaesth 2003;91:61-72.
30. Lagier D, Zeng C, Fernandez-Bustamante A, Vidal Melo MF. Perioperative pulmonary atelectasis: part II. Clinical implications. Anesthesiology 2022;136:206-36.
31. Saraswat V. Effects of anaesthesia techniques and drugs on pulmonary function. Indian J Anaesth 2015;59:557-64.
32. Jimenez-Santana JD, Azzolina D, Scaramuzzo G, et al. Ultrasound-detected postoperative diaphragmatic dysfunction and its association with pulmonary complications. A systematic review and meta-analysis. J Clin Anesth 2025;107:112027.
33. Saliba KA, Blackstock F, McCarren B, Tang CY. Effect of positive expiratory pressure therapy on lung volumes and health outcomes in adults with chest trauma: a systematic review and meta-analysis. Phys Ther 2022;102:pzab254.
34. Santos MD, Milross MA, Eisenhuth JP, Alison JA. Pressures and oscillation frequencies generated by bubble-positive expiratory pressure devices. Respir Care 2017;62:444-50.
35. American Association for Respiratory Care. AARC clinical practice guideline: use of positive airway pressure adjuncts to bronchial hygiene therapy. Respir Care 1993;38:516-21.

Online supplementary material:

Supplementary Table 1. Search strings.

Supplementary Table 2. Overview of studies included in the systematic review.

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