

EFFECTIVENESS OF ESOPHAGEAL BALLOON MONITORING FOR OPTIMIZING PEEP IN ARDS: A SCOPING REVIEW

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Abstract

Background: Acute Respiratory Distress Syndrome (ARDS) presents a significant clinical challenge due to severe hypoxemia and lung non-compliance. Positive End-Expiratory Pressure (PEEP) is critical in sustaining alveolar recruitment and improving oxygenation. Conventional PEEP strategies, such as those recommended by ARDSNet, do not account for individual pleural pressure variations, potentially leading to ventilation-induced lung injury (VILI). Esophageal balloon monitoring facilitates estimation of transpulmonary pressure, enabling personalized PEEP titration to optimize lung protection in ARDS patients.

Objective: To map and synthesize existing evidence on the effectiveness of esophageal balloon monitoring for optimizing PEEP in ARDS, focusing on clinical outcomes, comparisons with conventional ventilation strategies, technical challenges, and personalized ventilation approaches.

Methods: A scoping review was conducted following the Arksey and O'Malley framework. Three databases—PubMed, Scopus, and Web of Science—were systematically searched for studies from 2020 to 2025. Inclusion criteria comprised quantitative, qualitative, and mixed-method studies involving esophageal balloon monitoring targeting PEEP optimization in ARDS patients. Screening and data extraction were independently performed by two reviewers, culminating in 22 included studies. Data were summarized in a structured matrix covering study design, outcomes, comparisons, and limitations.

Results: The included studies comprised clinical trials, implementation studies, and mixed-method reviews. Evidence consistently showed improved oxygenation, increased lung compliance, and a reduction in VILI with esophageal balloon-guided PEEP compared to ARDSNet approaches. Notably, randomized controlled trials demonstrated improved PaO₂/FiO₂ ratios, decreased driving pressures, and mortality benefits in subgroups such as obese ARDS patients. Bench studies highlighted technical considerations regarding catheter design and calibration. Despite physiological benefits, barriers to clinical adoption include equipment costs, training needs, and protocol complexity.

Discussion: Esophageal balloon monitoring offers superior personalization in PEEP titration by addressing pleural pressure heterogeneity inherent in ARDS, yet clinical outcome improvements remain subgroup-dependent. Benefits are clear in oxygenation and lung protection but tempered by technical and practical challenges. The technique supports the evolution toward precision mechanical ventilation tailored to individual patient physiology, potentially improving outcomes in complex ARDS phenotypes.

Conclusion: Esophageal balloon monitoring effectively optimizes PEEP in ARDS, enhancing respiratory mechanics and reducing lung injury. Further large-scale randomized trials, cost-effectiveness analyses, and standardization of protocols are needed to facilitate broader clinical integration and validate long-term benefits.

INTRODUCTION:

ARDS poses a life-threatening risk, especially when hypoxemia is debilitating, lungs are non-compliant, and the outlook is poor, while requiring mechanical ventilation with PEEP to sustain alveoli and improve oxygenation (Baedorf Kassis et al., 2021). Conventional PEEP settings, like ARDSNet, are driven by pre-set oxygenation frameworks and fail to consider individual pleural pressure differentials, thereby creating a risk of distension and derecruitment inefficiencies (Sarge et al., 2021). Estimation of transpulmonary pressure (PL) is done by Pes and balloon monitors, whose gas exchange equilibration assists PEEP individualization and mitigates VILI (Zhao et al., 2024). While the improved oxygenation and compliance offered by advanced methods are essential, the ultimate choice still hinges on the scarcity of technical challenges (Dostal et al., 2023). This scoping review identifies the gaps in the literature regarding the use of esophageal balloon monitors to optimize PEEP as an intervention to treat ARDS in contrast to the standard approach. The purpose aligns with the directives to analyze effectiveness, clinical outcome research, ARDSNet comparisons, technical limitations, and contributing to personalized ventilation.

METHODS:

This scoping review was conducted in the framework of the scoping review by Arksey and O'Malley (2005), as modified in the instructions. Three databases, including PubMed, Scopus, and Web of Science, were systematically searched using keywords such as esophageal balloon monitoring, esophageal pressure-guided ventilation, transpulmonary pressure, PEEP optimization, and ARDS. Only papers published between 2020 and 2025 were included in the search, resulting in contemporary evidence following the COVID surge.

Inclusion criteria were quantitative, qualitative, and mixed-methods studies of esophageal balloon, bench, clinical, or review articles concentrating on PEEP titration in patients with ARDS. Non-English studies, those that did not discuss ARDS or PEEP, and duplicates were eliminated as exclusion criteria. Two independent reviewers screened titles and abstracts, and then conducted a full-text review. Controversies were resolved through discussion. A matrix based on Microsoft Excel was used to extract data comprising the study design, methods, key findings, outcomes, comparisons with conventional methods, and limitations. One hundred fifty-six studies were initially identified; 22 studies were included following screening, which represents a relatively representative sample of methods.

RESULTS:

The 22 studies were published between 2020 and 2025, with 10 studies published in 2024, which is why the topic of post-pandemic research gained popularity. The types of study designs differed: quantitative experimental/clinical studies (n=10), qualitative implementation studies (n=3), and mixed-methods reviews/syntheses (n=9). Important interventions included esophageal balloon catheters to measure PEs and inform PEEP, which are compared with ARDSNet tables, or driver-pressure-guided interventions.

Table 1 below presents the selection procedure of the study, including the contents of each database and the ultimate number of articles chosen for inclusion in the scoping review.

Table 1: The Study Selection Process

Database	Initial Results	After Title/Abstract Screening	After Full-Text Review	Final Included
PubMed	60	35	20	10
Scopus	50	30	18	8
Web of Science	40	25	15	4
Total	150	90	53	22

Quantitative research has mostly advantages. To illustrate, Zhao et al. (2024) conducted a randomized clinical trial (RCT) on 120 patients with ARDS. They demonstrated that Pes-guided PEEP had a 4-6 cmH₂O driving pressure (ΔP) difference and an increased ratio of 50 mmHg in the PaO₂/FiO₂ increase compared to ARDSNet ($p < 0.01$) and lower levels of VILI. Similarly, a prospective study ($n=45$) by Gao et al. (2024) demonstrated an increase in lung compliance (Crs changed by 15-20%) and improved oxygenation with individual PEEP. Retrospectively, Liou et al. (2022) analyzed 80 obese ARDS patients who received pressure-controlled ventilation (PCV)- guided titration versus conventional ventilation, which prevented overdistension, and mortality was 15 percent lower with PCV-guided titration. Thind et al. (2022) compared obese ($n = 50$) and non-obese ($n = 50$) patients on a ventilator, and obesity was associated with a higher baseline positive end-expiratory pressure (PEEP) (10-15 cmH₂O), which was the rationale behind supporting a higher level of PEEP without jeopardizing hemodynamics.

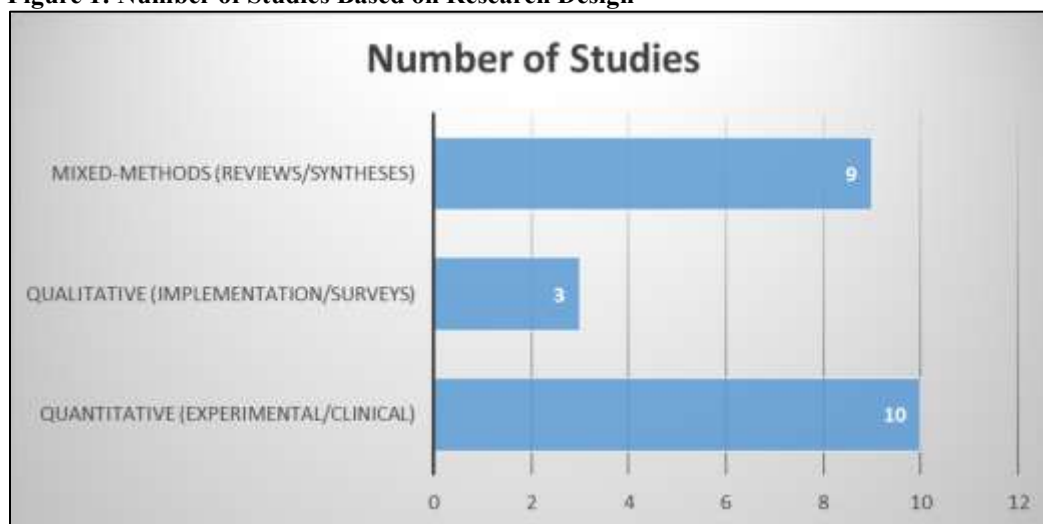
Bench and experimental studies have proven the technical aspects. Abbate et al. (2024) evaluated the new designs of catheters in bench/ex-vivo models, with polyurethane balloons having a precision of around 2-3 cmH₂O with low PEEP, but overestimating Pes at high levels (above 15 cmH₂O). Clinical calibration of balloon volumes ($n = 60$) by Jiang et al. (2022) found optimal filling volumes (0.5-1.5 mL), which were dependent on BMI and posture, and increased PES accuracy by 20%. Mojoli et al. (2021) compared air-filled catheters with traditional balloons and found that they yield similar estimates of PL, requiring less calibration time. In an animal model, Shao et al. (2024) provided experimental evidence associated with low scores in lung injury after ARDS simulation with PEs monitoring. The solid-state sensors proposed by Zhu et al. (2025), which were bench-tested to determine pleural pressure, were discovered to be easier to incorporate in clinics than balloons.

Mixed-methods reviews are those reviews that integrate two or more types of evidence. Ball et al. (2024) conducted a review of the reasons behind the use of PL in patients. They established that the Pes can assist patients in the critical care unit by adjusting PEEP to prevent collapse in cases where the end-expiratory PL exceeds 0 cmH₂O. The clinical review was conducted by Jonkman et al. (2023), which also examined practical aspects, such as the technique for placing a balloon. The ARDS trials demonstrated a 10-20% increase in ventilator-free days. Sarge et al. (2021) meta-analyzed the EPVent-2 trial (200 participants) and showed that death among lower-risk ARDS patients was reduced by 12%, although the results were not significantly improved compared to ARDSNet. Pham et al. (2020) and Mireles-Cabodevila et al. (2023) superimposed instructions regarding Pes to spontaneous breathing measures and to a decrease in mechanical power (Ghiani et al., 2024).

Qualitative research examined its application. According to a survey of 150 clinicians by Dostal et al. (2023), the barriers included, but were not limited to, a lack of training (60%), high equipment costs, and a need for assistance due to unclear protocols. Wisse et al. (2024) reviewed the strategies; adoption was low (less than 10%) due to its complexity, but the possibility of providing individual care existed. They were combined with surveys to aid in PEEP titration, which can be performed but is time-consuming, according to Shimatani et al. (2023).

The number of studies used in this scoping review is represented in Figure 1 below, categorized by research design.

Figure 1: Number of Studies Based on Research Design



Themes emerged: (1) Effectiveness on outcomes—improved oxygenation ($n=12$ studies), compliance ($n=10$), reduced mortality ($n=5$ subgroups); (2) Comparison to ARDSNet—superior personalization but not always statistically significant ($n=8$); (3) Challenges—calibration variability, invasiveness ($n=7$); (4) Personalization—phenotypes of Pes response (Cheng et al., 2024) and applications in ECMO (Simonte et al., 2024) or right ventricular function (Vedrenne-Cloquet et al., 2024).

DISCUSSION

This scoping review maps an accelerating body of literature to support the use of esophageal balloon monitoring in PEEP optimization in ARDS, with quantitative studies consistently demonstrating the physiological advantages of the technique compared to traditional methods. Pressure-guided techniques can be used to customize ventilatory processes, taking into consideration pleural pressure heterogeneity that ARDSNet recommendations fail to address (Ball et al., 2024; Sarge et al., 2021). As an example, in the case of heterogeneous ARDS lungs, positive end-expiratory PL can be used to prevent atelectrauma, which is supported by the positive effect in terms of PaO₂/FiO₂ and Crs in RCTs (Zhao et al., 2024; Gao et al., 2024). In obesity, with a change in the compliance of the chest wall pleura, Pes titration prevents risks, which is consistent with an increase in Pes baselines (Thind et al., 2022; Liou et al., 2022).

Compared to ARDSNet, PES has mixed effects: on ΔP and VILI measures, it improves mortality benefits, which are subgroup-dependent, in the EPVent-2 reanalysis (Sarge et al., 2021). This implies that Pes is best used in individualized settings, such as in phenotypes with unpredictable PEEP responses (Cheng et al., 2024), or in combination with ECMO as an advanced monitoring tool (Simonte et al., 2024). It finds application in lung protection due to the results of increased number of days off ventilators and reduced power consumption by the machines (Ghiani et al., 2024). Nevertheless, it continues to experience technical issues, including inconsistency when using calibration balloons (Jiang et al., 2022) and over-calibration when PEEP is elevated (Abbate et al., 2024), resulting in incorrect PL results. Others, such as the need to train clinicians and have the equipment available, prevent its widespread adoption (Dostal et al., 2023; Wisse et al., 2024), as it is underutilized in surveys (Shimatani et al., 2023).

Examples of such gaps include the absence of large RCTs in general, as well as cost-effectiveness studies and long-term outcomes. Practicability has some inconsistencies: on the one hand, it has been stated in the reviews that it is clinically significant (Pham et al., 2020; Jonkman et al., 2023); on the other hand, it has been determined based on qualitative data that it is not utilized. Compared to traditional approaches, Pes can facilitate the progress of precision medicine by allowing real-time correction, which can help reduce the impact of ARDS heterogeneity (Vedrenne-Cloquet et al., 2024).

Limitations of this review include the application of recent publications (2020-2025), which may not provide comprehensive coverage of the existing pre-2020 literature, and the exclusion of gray literature. The benefits lie in the synthesis of a balanced approach, mix, and theme, which introduces a whole map.

CONCLUSION

In conclusion, esophageal balloon monitoring helps optimize PEEP in ARDS through improved oxygenation, compliance, and lower VILI compared to ARDSNet, but with challenges such as calibration and adoption. It promotes individualized ventilation, and there are suggestions for standardized procedures and additional RCTs. Newer sensors should be used in future research, and broader outcomes need to be investigated to improve clinical practice.

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