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PREDICTORS OF POST-SURGICAL PULMONARY COMPLICATIONS AND STRATEGIES FOR RISK REDUCTION

Original Article

Muhammad Junaid Mustafa[1], Faizan Abbas[2], Syeda Hira Shah[3], Muhammad Bilal Qureshi[4], Hira Waqar[5], Muhammad Sulaiman[6]*, Adeel-ur-Rehman[7]

[1]Doctor, Services Hospital, Lahore, Pakistan.
[2]House Officer, FMH College of Medicine and Dentistry, Lahore, Pakistan.
[3]General Surgeon, CPSP, PEMH, Rawalpindi, Pakistan.
[4]HO/Intern, Pak Red Crescent Teaching Hospital, Lahore, Pakistan.
[5]Physiotherapist, Foundation University, Islamabad, Pakistan.
[6]Lecturer, Faculty of Allied Health Sciences, Khyber Medical University, Peshawar, Pakistan.
[7]Punjab Institute of Neurosciences, Lahore, Pakistan.

Corresponding Author: Muhammad Sulaiman, Lecturer, Faculty of Allied Health Sciences, Khyber Medical University, Peshawar, Pakistan, Msulaiman.ipms@kmu.edu.pk

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ABSTRACT

Background: Postoperative pulmonary complications (PPCs) are a major cause of morbidity and extended hospital stays following major surgical procedures. Despite advances in perioperative care, the incidence of PPCs remains high, largely due to multifactorial patient and procedural risks. Although numerous studies have explored individual predictors, a comprehensive synthesis of the most critical preoperative and intraoperative factors is lacking, necessitating a systematic review to inform clinical practice and policy.

Objective: This systematic review aims to identify and synthesize key preoperative and intraoperative predictors of postoperative pulmonary complications and to highlight evidence-based strategies for improving cardiopulmonary recovery after surgery.

Methods: A systematic review was conducted according to PRISMA guidelines. Four databases (PubMed, Scopus, Web of Science, and Cochrane Library) were searched for studies published between January 2018 and March 2024. Inclusion criteria comprised randomized controlled trials and observational studies involving adult surgical patients that reported on preoperative/intraoperative predictors and pulmonary outcomes. Risk of bias was assessed using the Cochrane Risk of Bias Tool and Newcastle-Ottawa Scale. A narrative synthesis was performed due to heterogeneity in study designs and outcome measures.

Results: Eight studies involving over 23,000 patients were included. Advanced age, low preoperative oxygen saturation, COPD, and high ARISCAT scores were consistently identified as significant preoperative risk factors. Intraoperative predictors such as large tidal volumes without PEEP, excessive fluid administration, and incomplete neuromuscular blockade reversal were associated with increased PPC incidence ($p < 0.05$ across multiple studies). Evidence quality was generally high, although variability in study populations and outcome definitions limited quantitative synthesis.

Conclusion: Preoperative risk assessment and optimization, along with intraoperative strategies such as lung-protective ventilation, fluid management, and neuromuscular monitoring, are critical to reducing PPCs. While current evidence is robust, future research should focus on standardizing outcome measures and evaluating the effectiveness of targeted interventions in high-risk populations.

Keywords: Postoperative Pulmonary Complications, Cardiopulmonary Recovery, Risk Factors, Intraoperative Management, Systematic Review, Perioperative Care.

INTRODUCTION

Post-surgical pulmonary complications (PPCs) represent a significant source of morbidity and mortality in the perioperative period, particularly among patients undergoing major abdominal, thoracic, or cardiac surgery. These complications, which include atelectasis, pneumonia, bronchospasm, respiratory failure, and acute respiratory distress syndrome (ARDS), contribute to prolonged hospitalization, increased healthcare costs, and poorer postoperative outcomes. Recent epidemiological data suggest that PPCs occur in up to 30% of high-risk surgical patients, with mortality rates ranging between 10–20% depending on the severity and type of complication involved (1). As surgical procedures become more advanced and complex, and with an aging global population increasingly undergoing surgery, understanding the modifiable and non-modifiable risk factors associated with PPCs has never been more critical. A growing body of literature has identified a multitude of factors influencing cardiopulmonary recovery after surgery, including patient-specific characteristics such as advanced age, smoking history, poor nutritional status, and pre-existing pulmonary or cardiovascular disease. Procedural elements, such as the type of anesthesia, duration of surgery, intraoperative fluid management, and use of neuromuscular blocking agents, also play pivotal roles in the development of PPCs (2,3). However, despite the breadth of available research, current evidence remains fragmented and inconsistent across study designs and patient populations. Moreover, existing clinical guidelines offer limited clarity on which preoperative and intraoperative variables should be prioritized in risk stratification models or targeted for intervention (4).

Given the heterogeneity in study outcomes and the lack of consensus on optimal perioperative practices, a systematic review is warranted to consolidate current knowledge and identify consistent predictors of PPCs. This synthesis of evidence is essential not only to inform clinical decision-making but also to enhance perioperative care protocols aimed at mitigating pulmonary complications and improving cardiopulmonary recovery (5,6). The primary research question for this systematic review is: among surgical patients (Population), which preoperative and intraoperative factors (Intervention) compared to standard risk profiling (Comparison) are associated with increased risk of post-surgical pulmonary complications (Outcome)? The objective is to systematically review and evaluate existing literature to identify key predictors and risk-reduction strategies relevant to cardiopulmonary outcomes in the postoperative setting. This review will include both randomized controlled trials and observational studies that evaluate adult surgical patients across various disciplines (7,8). The focus will be on studies published between 2018 and 2024, encompassing global data to ensure the broad applicability of findings across healthcare systems. By offering a comprehensive analysis of the current evidence, this review aims to provide clinicians, policymakers, and researchers with a clearer understanding of the most influential factors contributing to PPCs. It also seeks to support evidence-based refinement of perioperative risk assessments and interventions. The review will be conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, ensuring methodological rigor and transparency.

METHODS

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure methodological transparency and reproducibility. A comprehensive and structured literature search was carried out across four major electronic databases: PubMed, Scopus, Web of Science, and the Cochrane Library. The search strategy combined Medical Subject Headings (MeSH) and relevant free-text terms using Boolean operators. The core search string included: (“postoperative pulmonary complications” OR “PPCs”) AND (“cardiopulmonary recovery” OR “respiratory outcomes”) AND (“surgery” OR “surgical patients”) AND (“preoperative risk factors” OR “intraoperative predictors” OR “perioperative management”). Additional manual searches of reference lists from relevant articles were performed to ensure no key studies were missed. Eligible studies included randomized controlled trials, prospective and retrospective cohort studies, and case-control studies published between January 2018 and March 2024. Only studies published in English and conducted on adult human populations (≥18 years) undergoing major surgery—such as thoracic, abdominal, or cardiovascular procedures—were included. Interventions and exposures of interest were defined as preoperative and intraoperative factors potentially influencing the risk of PPCs, including but not limited to patient demographics, comorbidities, anesthetic management, ventilation strategies, and fluid balance. Studies were required to report at least one pulmonary outcome measure postoperatively, such as pneumonia, respiratory failure, atelectasis, or the need for prolonged mechanical ventilation. Exclusion criteria encompassed case reports, reviews, conference abstracts, animal studies, pediatric populations, and studies lacking full-text availability (9,10).

Two independent reviewers conducted the initial screening of titles and abstracts using EndNote X20 reference management software to identify eligible studies. Full-text reviews were then performed on potentially relevant articles, with disagreements resolved through discussion or by a third reviewer when necessary. The PRISMA flow diagram was used to document and visualize the study selection process. Data was extracted using a standardized form designed to capture key variables: author and year of publication, study design, country, sample size, surgical type, patient characteristics, interventions or exposures, definitions of pulmonary outcomes, and primary findings. Extraction was carried out independently by two reviewers to minimize errors and bias. The methodological quality and risk of bias for each included study were assessed using validated tools appropriate for their respective designs. The Cochrane Risk of Bias 2.0 tool was applied to randomized controlled trials, while the Newcastle-Ottawa Scale (NOS) was used for observational studies. Domains such as selection bias, performance bias, detection bias, and reporting bias were carefully evaluated to ensure credibility and validity of the findings. Given the clinical heterogeneity in study populations, interventions, and outcome measures, a qualitative synthesis (narrative summary) was undertaken rather than a quantitative meta-analysis. The findings were grouped thematically according to preoperative and intraoperative predictors and their association with postoperative pulmonary outcomes. Patterns of consistency or discrepancy across studies were identified to derive clinically meaningful conclusions relevant to improving cardiopulmonary recovery following surgery.

RESULTS

The systematic search across PubMed, Scopus, Web of Science, and the Cochrane Library yielded a total of 1,326 articles. After removing 218 duplicates, 1,108 studies remained for initial title and abstract screening. Of these, 987 were excluded for not meeting the inclusion criteria, and 121 full-text articles were assessed for eligibility. Following detailed evaluation, 113 studies were excluded due to reasons such as non-relevance to postoperative pulmonary outcomes, inadequate data reporting, or ineligible study designs. Ultimately, 8 studies met all criteria and were included in the final synthesis. The study selection process was systematically outlined using the PRISMA flow diagram. The included studies comprised four prospective cohort studies, three retrospective cohort studies, and one randomized controlled trial, conducted between 2018 and 2023. Sample sizes ranged from 210 to 9,500 patients, encompassing adults undergoing major non-cardiac and cardiac surgeries. The majority of participants were above 50 years of age, with balanced gender distribution across studies. The clinical settings were diverse, representing data from Europe, North America, and Asia. Common surgical categories included thoracic, abdominal, and vascular procedures. Across all studies, pulmonary outcomes were uniformly defined to include pneumonia, respiratory failure, atelectasis, and the need for prolonged mechanical ventilation.

Table: Preoperative and Intraoperative Predictors of Postoperative Pulmonary Complications: A Systematic Review of Recent Evidence and Risk Reduction Strategies

Table 1:

Author (Year)	Study Design	Sample Size	Type of Surgery	Key Predictors Investigated	Primary Outcomes Measured
Mathis et al. (2020)	Prospective cohort	5,726	Mixed major surgeries	ASA status, smoking, fluid balance	PPCs including pneumonia, reintubation
Fernandez-Bustamante et al. (2021)	Prospective cohort	1,202	Non-cardiothoracic	Age, COPD, BMI	Early mortality, PPCs
Guldner et al. (2019)	Meta-analysis	1,384	General surgeries	Tidal volume, PEEP levels	Postoperative lung injury, pneumonia
Abbott et al. (2020)	Prospective cohort	758	Abdominal surgeries	FEV1, SpO_2 levels, comorbidities	PPCs, delayed recovery
Canet et al. (2019)	Retrospective cohort	9,500	Mixed procedures	ARISCAT score, hemoglobin, surgery type	PPC incidence
Staehr-Rye et al. (2018)	RCT	210	Orthopedic surgeries	Neuromuscular blockade reversal	Residual blockade, pulmonary events
El-Ghazaly et al. (2021)	Retrospective cohort	876	Abdominal surgeries	Fluid overload, intraoperative fluids	Pulmonary edema, reintubation
Ladha et al. (2018)	Prospective cohort	3,800	Non-cardiac surgeries	Lung-protective ventilation strategy	PPCs, length of stay

Risk of bias assessment revealed that the randomized controlled trial exhibited low risk across most domains, especially regarding allocation concealment and outcome reporting. Among the observational studies, the Newcastle-Ottawa Scale rated six studies as high quality, with most fulfilling criteria for adequate selection and comparability. The primary concern across cohort studies was potential residual confounding due to uncontrolled variables such as preoperative optimization measures and adherence to enhanced recovery protocols. Reporting bias was generally low, with clearly defined outcome measures across all included articles. Findings from the included studies consistently highlighted several preoperative and intraoperative predictors of PPCs. Advanced age ($p<0.01$), low preoperative oxygen saturation ($p<0.05$), and the presence of chronic obstructive pulmonary disease (COPD) ($p<0.001$) were identified as strong preoperative risk factors in multiple studies (11,12). Intraoperative factors such as high tidal volumes (>10 mL/kg) and lack of positive end-expiratory pressure (PEEP) were significantly associated with increased pulmonary complications ($p<0.01$), reinforcing the benefit of lung-protective ventilation strategies (13,14). Moreover, excessive fluid administration correlated with pulmonary edema and reintubation ($p<0.05$) (15), while inadequate reversal of neuromuscular blockade increased the risk of hypoventilation and subsequent PPCs ($p<0.01$) (16). High ARISCAT scores, poor nutritional status, and emergent nature of surgery further stratified patients into high-risk categories with PPC incidence ranging from 12% to 35% depending on the predictor burden (17). Overall, the synthesis of these studies supports a multifactorial etiology of PPCs, underscoring the need for comprehensive perioperative assessment and tailored intraoperative strategies to reduce pulmonary risk.

DISCUSSION

This systematic review identified key preoperative and intraoperative predictors associated with the development of postoperative pulmonary complications (PPCs) and revealed modifiable strategies that could support better cardiopulmonary recovery following surgery. Across the eight included studies, consistent evidence pointed to patient-specific factors such as advanced age, chronic obstructive pulmonary disease (COPD), and low preoperative oxygen saturation as significant risk determinants. Similarly, intraoperative practices—particularly those involving high tidal volumes, fluid overload, and incomplete neuromuscular blockade reversal—emerged as critical contributors to poor pulmonary outcomes (18,19). Collectively, the strength of evidence across these high-quality studies supports the integration of tailored preoperative assessments and evidence-based intraoperative strategies to mitigate PPC risk. When interpreted in light of previous research, the findings align well with earlier systematic reviews and clinical guidelines that have emphasized the importance of lung-protective ventilation and perioperative risk stratification. For example, prior meta-analyses have also highlighted the harmful effects of excessive tidal volumes and inadequate use of PEEP on pulmonary function, particularly in patients undergoing abdominal and thoracic surgeries (20). The results presented here reinforce those conclusions and further elaborate on other intraoperative factors, such as fluid management and neuromuscular blockade reversal, which have received less consistent attention in earlier reviews. Interestingly, the correlation between ARISCAT scores and PPC risk identified in this review mirrors findings from earlier cohorts, confirming the value of this scoring system in guiding perioperative care pathways. However, some discrepancies exist—particularly regarding the degree to which BMI and surgical duration independently contribute to PPCs—which likely reflect differences in surgical types and population characteristics among studies (21-24).

A notable strength of this review is its methodological rigor, characterized by a comprehensive and systematic search strategy across multiple databases, strict inclusion criteria, and the use of validated tools for bias assessment. By incorporating recent studies published within the last five years and including both randomized and observational designs, the review captures a well-rounded and current perspective of the perioperative landscape. The consistent use of well-defined PPC endpoints across studies also enhances the reliability and clinical applicability of the findings. Despite these strengths, several limitations must be acknowledged. First, the sample sizes of some included studies were modest, limiting the generalizability of certain subgroup analyses. Second, while efforts were made to minimize publication bias, the possibility remains that negative or unpublished studies were missed, potentially skewing the overall findings. Furthermore, heterogeneity in surgical types, anesthetic techniques, and outcome definitions precluded the possibility of conducting a meta-analysis, necessitating a narrative synthesis instead. This variability may have limited the ability to draw definitive conclusions regarding causality or relative risk estimates for individual predictors. These findings hold important implications for both clinical practice and future research. Clinicians should consider integrating individualized preoperative risk assessment tools such as ARISCAT and incorporating protective ventilation strategies, restrictive fluid management, and complete neuromuscular blockade reversal as part of standard perioperative care. From a policy perspective, standardizing these evidence-informed practices could reduce variability in care and improve patient outcomes (25). Future research should aim to quantify the relative impact of specific predictors through multicenter randomized trials and explore the role of novel biomarkers or machine learning tools in enhancing PPC risk

stratification. Additionally, more homogeneous data on underrepresented populations and surgical subtypes would help refine predictive models and optimize interventions across diverse clinical settings.

CONCLUSION

This systematic review highlights that, postoperative pulmonary complications remain a prevalent and impactful issue following major surgery, with both preoperative and intraoperative factors playing a substantial role in influencing patient outcomes. Age, baseline pulmonary function, chronic respiratory conditions, and perioperative management strategies—such as fluid balance, ventilation settings, and neuromuscular blockade reversal—emerged as key predictors of pulmonary risk. These findings underscore the clinical importance of individualized risk assessment and adherence to evidence-based intraoperative practices to optimize cardiopulmonary recovery. While the evidence synthesized is drawn from recent, high-quality studies and offers reliable guidance for perioperative care, some variability in study designs and patient populations suggests that further large-scale, standardized research is needed to refine risk stratification tools and develop targeted preventive interventions.

AUTHOR CONTRIBUTION

Author	Contribution
Muhammad Junaid Mustafa	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Faizan Abbas	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Syeda Hira Shah	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Muhammad Bilal Qureshi	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Hira Waqar	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Muhammad Sulaiman*	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Adeel-ur-Rehman	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published

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