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ORIGINAL ARTICLE

Bootstrap confidence intervals to assess risk factors for early postoperative pulmonary complications after abdominal surgery

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ABSTRACT

Importance. Early postoperative pulmonary complications (EPPCs) after abdominal surgery increase morbidity, mortality, and healthcare costs. **Objective.** This study aimed to identify risk factors for EPPCs using only easily collected clinical data from a local population. **Design, Setting, and Population** From December 1, 2020, to December 31, 2021, a single-center, prospective cohort study was conducted at Batna University Hospital in Algeria. Adult patients undergoing abdominal surgery under general anesthesia were enrolled, and ten preoperative parameters were analyzed. **Exposures.** Advanced age over 50, previous laparotomy, a history of chronic obstructive pulmonary disease, uncontrolled diabetes, urgent surgery, chronic corticosteroid use, active smoking, unbalanced diabetes, a preoperative stay of ≥3 days, obesity, and preoperative blood transfusions. **Main Outcomes and Measures** The crude associations between EPPCs and ten preoperative factors were assessed using univariate analyses. Statistical significance was defined as a two-sided p-value < 0.05 with 95% confidence intervals excluding 1. After dichotomizing all variables, associations were tested by the chi-square test, and bootstrap methods were applied to estimate 95% confidence intervals for the odds ratios. **Results.** Of 1,058 eligible patients, 741 were included, with 49 (6.6%) developing EPPCs. Among them, 20.4% had ARDS, 44.9% had pulmonary infections, and 34.7% experienced lung collapse. Half of the EPPCs cases had additional complications, mainly surgical site infections, with one EPPC-related death. Univariate analysis identified eight significant risk factors: age ≥50 (OR 4.9), anterior laparotomy (OR 3.8), COPD (OR 7.5), preoperative stay ≥3 days (OR 3.6), unbalanced diabetes (OR 4), obesity (OR 2.7), active smoking (OR 3.3), and perioperative transfusion (OR 2.6) (all p < 0.05). The bootstrap confidence intervals showed that only six factors were significantly associated. **Conclusions and Relevance.** This study applied bootstrap techniques that produced stable estimates with low bias, thus strengthening the validity of the observed associations and the reliability of the inferences. Although some of the identified factors can be modified in elective surgeries, such adjustments are generally not feasible during emergency procedures.

Keywords: abdominal hernia's surgery; gastrointestinal surgery; pulmonary complications; risk factors; bootstrap

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1. INTRODUCTION

Early postoperative respiratory complications are conditions that occur within a 30-day window following surgery. This timeframe aligns with standard postoperative monitoring periods [1]. There is no consensus on the definition of postoperative respiratory complications. To improve the standardization of clinical trials, European definitions of perioperative clinical events have been created.

EPPCs include respiratory infection, acute respiratory distress syndrome (ARDS), pleural effusion, atelectasis, pneumothorax, bronchospasm, and aspiration pneumonia. These respiratory manifestations share common pathophysiological mechanisms, including pulmonary collapse and airway contamination. They result from the combined adverse effects of anesthesia and surgery on respiratory function [2-4].

The incidence of EPPCs in patients undergoing general surgery remains high and is similar to that of cardiovascular complications in non-cardiac surgery. In abdominal surgery specifically, the incidence of EPPCs varies from 5% to 37%, which places it among the surgeries with the highest risk of respiratory complications [5]. EPPCs are the second most common medical complication after surgical site infections, and they remain challenging to predict. They are associated with an increase in morbidity and mortality. They pose a major challenge to the healthcare system by prolonging hospital stays and significantly increasing the associated financial burden. Moreover, the occurrence of EPPCs appears to be a stronger predictor of long-term mortality than cardiovascular complications [6-7]. However, no guidelines currently exist on preventive measures for patients at risk of postoperative pulmonary complications [8].

As part of efforts to improve the quality of care for patients undergoing surgery, this study aimed to identify risk factors for EPPCs using only easily collected clinical data from a local population.

2. MATERIALS AND METHODS

Study design

This single-center prospective cohort study was conducted over a one-year period, from December 1, 2020, to December 31, 2021, at Batna University Hospital in Algeria. The researchers focused on adult patients undergoing elective or emergency abdominal surgery by laparotomy under general anesthesia. The study did not include adult patients over 70 years of age, patients with COVID-19, and those who underwent traumatic abdominal surgery. The researchers excluded proctological surgery and inguinofemoral hernia surgery. Eligible patients were monitored until the 30th postoperative day.

Data analysis

Univariate analysis measured the raw association between EPPCs and ten preoperative factors, with significance defined as $p < 0.05$ and a 95% confidence interval excluding the value 1. These factors were: advanced age over 50, previous laparotomy, a history of chronic obstructive pulmonary disease (COPD), uncontrolled diabetes, urgent surgery, chronic corticosteroid use, active smoking, a preoperative stay of ≥3 days (LPS), obesity, and preoperative blood transfusions. The analysis used the Chi-square test, as all variables were transformed into binary forms. This approach also determines their risk levels using relative risk [9].

Bootstrap-derived confidence intervals (CIs) for odds ratios (ORs) provide a robust, nonparametric approach to estimating statistical uncertainty, particularly when sample size is limited. By resampling the data repeatedly, bootstrap methods capture the variability and inherent uncertainty in OR estimates more accurately than conventional parametric techniques. This approach is particularly valuable in observational studies with smaller sample sizes. In this study, bootstrap methods were applied to estimate 95% CIs of ORs, thereby improving the reliability of inference and minimizing potential bias [10–11]. Data were analyzed using SPSS version 25.0 (Cary, NC).

Ethical Considerations

This prospective observational cohort study was reviewed and approved by the Scientific Council of our Faculty of Medicine, in accordance with the ethical standards set forth in the Declaration of Helsinki. Prior to participation, all individuals provided oral informed consent after receiving detailed information about the study's objectives and procedures. All collected data were anonymized to ensure participant confidentiality. No financial compensation was offered or provided to study participants.

3. RESULTS

Flowchart

Among the 741 patients included, 49 developed EPPCs, as shown in figure 1, resulting in an incidence rate of 66 cases per 1,000 person-years (49/741 × 1,000). This corresponds to a percentage of 6.6 percent (95% confidence interval [4.8–8.4]).

Description of patients at inclusion

The main characteristics of the cohort and both groups (those with EPPCs and uncomplicated patients) are presented in Table1.

Appendicular pathology was the most frequent benign digestive condition, accounting for 45.9% (n = 340) of cases, followed by hernial pathology at 19.1% (n = 141), and biliary surgery at 9.2% (n = 68). Colorectal tumors constituted the majority of malignant digestive pathologies, representing 7.3% (n = 53) of cases.

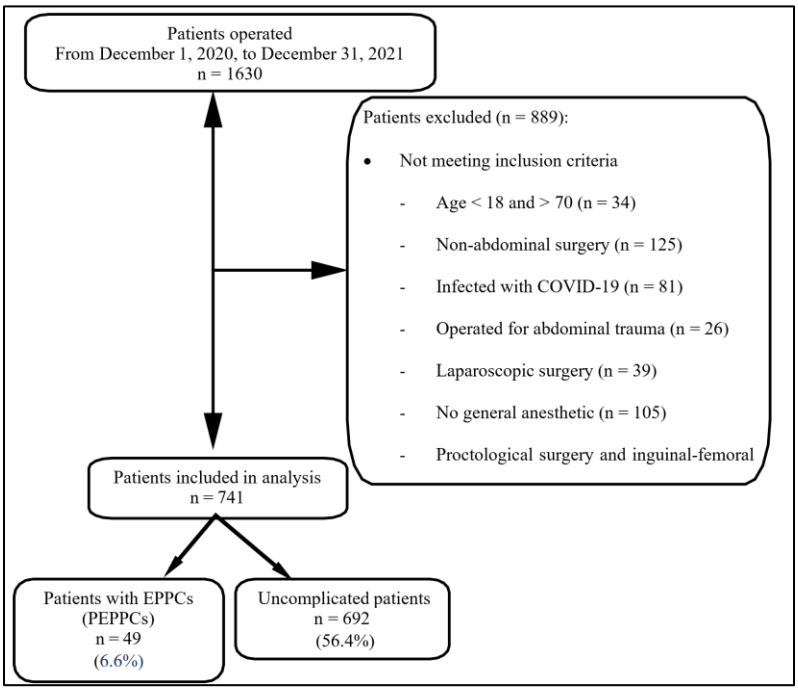


Figure 1. Patient Enrollment Flowchart.

Colorectal tumors accounted for most surgeries in patients with EPPCs, representing 22% (n = 11) of cases, followed by biliary pathologies at 18.4% (n = 9). In contrast, uncomplicated patients were most frequently operated on for appendicular pathologies, accounting for 48% (n = 332) of cases, followed by parietal hernial pathologies at 19.4% (n = 144). Early postoperative respiratory complications affected 49 patients, representing 6.6% of cases. The distribution of patients according to the three clinical forms of EPPCs is as follows: acute respiratory failure (20.4%), acute pulmonary infection (44.9%), and lung collapse (34.7%).

Most cases of EPPCs were diagnosed from the fourth postoperative day onwards, representing 67% (n = 33) of cases. Furthermore, in half of the complicated patients, EPPCs were associated with other early postoperative complications as follows: surgical wound complications (8.2%) and post-surgical leaks (12.2%).

Only one death occurred due to acute respiratory failure, despite management. This patient was a 55-year-old pre-obese man with an ASA III score, a history of COPD, and uncontrolled diabetes. He underwent emergency surgery for obstructive malignant tumors of the left colonic angle. Consequently, the postoperative mortality rate following EPPCs in the cohort is 0.1% (n = 1).

Associated factors

Highly associated factors have been identified as risk factors for the occurrence of EPPCs. Patients with a history of COPD are five times more likely to develop EPPCs. Conversely, urgent surgery and chronic corticosteroid use are not associated with EPPCs ($p > 0.05$). The main results of the univariate analysis are presented in figure 2.

Among all tested factors, only six had bootstrap-derived confidence intervals that excluded one, indicating statistically significant associations with low bias (table 2).

Table 1. Characteristics of the cohort and of two subgroups: PEPPCs and uncomplicated patients.

Characteristic		Cohort n= 741	PEPPCs n= 49	Uncomplicated patients n = 692
Age years median (IQR)*		48 (20.5)	58 (14.5)	46 (20.5)
Age bracket n (%)	(18–49)	432 (58.8)	12 (24.5)	424 (61.3)
	(50–59)	166 (22.4)	16 (32.7)	150 (21.7)
	(60–69)	139 (18.8)	21 (42.9)	118 (17.1)
	Age ≥ 50 years	305 (41.2)	37 (75.5)	268 (38.7)
Gender	Female n (%)	491 (66.3)	27 (55.1)	464 (67.1)
	Male n (%)	250 (33.7)	22 (44.9)	228 (32.9)
	Sex ratio (M/F)	0.5	0.8	0.5
BMI Kg/m2 median (IQR)*		26.8 (6.2)	31.9 (9.2)	26.8 (6.2)
Corpulence n (%)	Underweight ≤ 18.5	19 (2.6)	2 (4.1)	17 (2.5)
	Normal weight (18.5–24.9)	181 (24.4)	8 (16.3)	173 (25)
	Pre-obesity (25.0–29.9)	241 (32.5)	8 (16.3)	233 (33.7)
	Class 1 obesity (30.0–34.9)	192 (25.9)	17 (34.7)	175 (25.3)
	Class 2 obesity (35.0–39.9)	94 (12.7)	10 (20.4)	84 (12.1)
	Class 3 obesity ≥ 40.0	14 (1.9)	4 (8.2)	10 (1.4)
	BMI≥ 30 kg/m2	300 (40.5)	31 (63.3)	269 (38.9)
ASA n (%)	ASA I	68 (9.2)	2 (4.1)	66 (9.5)
	ASA II	229 (30.9)	9 (18.4)	220 (31.8)
	ASA III	113 (15.2)	8 (16.3)	105 (15.2)
	ASA IV	300 (40.5)	29 (59.2)	271 (39.2)
	ASA V	31(4.2)	1 (2)	30 (4.3)
	ASA≥ III	444 (59.9)	38 (77.6)	406 (58.7)
Surgery n (%)	Planned	157 (21.2)	15 (30.6)	142 (20.5)
	Urgent	584 (78.8)	34 (69.4)	550 (79.5)
Operated digestive pathology n (%)	Benign pathology	630 (85)	32 (65.3)	598 (86.4)
	Malignant pathology	66 (8.9)	12 (24.5)	54 (7.8)
	Parietal pathology	45 (6.1)	5 (10.2)	40 (5.8)

*As the distribution is non-gaussian, quantitative variables are reported as median (interquartile range (IQR)), and non-parametric tests are used to compare samples. Kolmogorov-Smirnov normality test for sample > 50, $p < 0.05$.

4. DISCUSSION

Three key conclusions can be drawn from these results. First, the predominant profile of the local population with EPPCs consists of individuals over 50 years old, with no gender predominance, obesity, and poor systemic health status, as defined by an ASA score of 3 or higher. These patients often underwent emergency surgery for benign digestive conditions.

Second, the observed EPPCs incidence of 6.6% in our relatively small and heterogeneous surgical cohort aligns with the range documented in previous studies [12]. In contrast, the thirty-day mortality rate due to EPPCs was lower than that reported in the literature. A result attributable to the early and optimal management of respiratory failure.

Third, besides the established EPPCs risk factors, our study identified three additional strong risk factors: unbalanced diabetes, previous laparotomy, and a preoperative stay of ≥3 days. Urgent surgery was not a significant factor, likely because it was overrepresented in both the complicated and non-complicated groups, which masked its potential association. This represents a confounding bias due to homogeneity or lack of variability. To overcome this bias, future studies should include populations with sufficient variability or analyze subgroups with different distributions of this variable [13]. This approach is feasible with large samples in multicenter observational studies.

Chronic Obstructive Pulmonary Disease has been identified in many studies as a strong risk factor for EPPCs. Indeed, patients with COPD have a five-fold increased risk of developing EPPCs. This predisposition to EPPCs is favored by advanced age, smoking, and prolonged operative times. Therefore, it is recommended to consider preoperative smoking cessation for at least eight weeks, associated with perioperative respiratory rehabilitation [14–16].

Active smoking is a well-established risk factor for early postoperative pulmonary complications following abdominal surgery. Numerous studies demonstrate that smokers experience markedly higher rates of pneumonia, atelectasis, and respiratory failure—

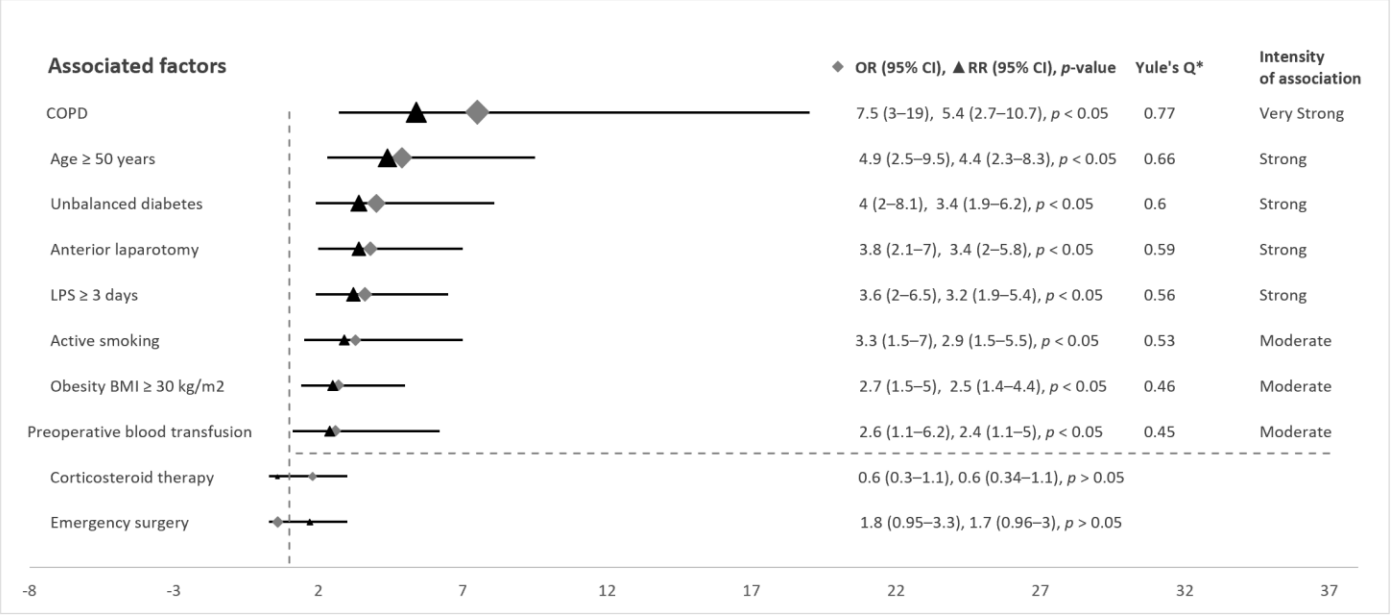
active smoking nearly doubles the risk of these outcomes. Mechanistically, tobacco smoke impairs mucociliary clearance, promotes chronic airway inflammation, and induces immunodeficiency. Although smoking cessation 24 hours before surgery may confer some benefit, a longer preoperative abstinence period is preferable [17].

Table 2. Bootstrapa for Risk Estimation

Associated factors	OR	Bias	Standard Error	95% BCa Confidence Interval[b]
COPD	7.5	0.7	4.3	(2.5–18.3)
Age ≥ 50 years	4.9	0.5	2.2	(2.5–11.7)
Unbalanced diabetes	4	0.1	1.5	(1.8–7.4)
Anterior laparotomy	3.8	0.2	1.3	(2–7.2)
LPS ≥ 3 days	3.6	0.2	1.2	(2–6.6]
Active smoking	3.3	0.2	1.4	(1–6.7)
Obesity	2.7	0.2	0.9	(1.4 –5.3)
Preoperative blood transfusion	2.6	0.2	1.3	(1–5.9)

a. Unless otherwise stated, the bootstrap results are based on 1,000 bootstrap samples.
b. 95% Bias-Corrected and accelerated (BCa) Confidence Interval.

Figure 2. The forest plot shows the results of the univariate analysis.



* https://www.aly-abbara.com/utilitaires/statistiques/khi_carre_rr_odds_ratio_ic.html

However, in our single-center prospective cohort, smoking status was not significantly associated with EPPCs. This discrepancy may reflect two limitations: low variability in smoking status, which precluded robust comparisons between smokers and non-smokers, and a low overall incidence of EPPCs, which diminished statistical power to detect an effect. To overcome these constraints, larger multicenter observational studies—or an extended inclusion period—are warranted to increase sample size and event counts. Additionally, rigorous adjustment for potential confounders such as age, respiratory comorbidities, and body mass index is essential to isolate the independent impact of active smoking.

Obese patients are at a particularly high risk for respiratory complications during the perioperative period. They often experience post-extubation respiratory distress due to atelectasis or airway obstruction, largely because increased intra-abdominal pressure reduces

pulmonary capacity. Moreover, conditions frequently seen in obese patients, such as sleep apnea, obesity hypoventilation syndrome, chronic obstructive pulmonary disease, and asthma, further elevate the risk of respiratory complications. Therefore, optimal management strategies are essential to prevent EPPCs [18–19].

Current literature shows that a prolonged preoperative stay (≥3 days) increases the risk of surgical site infections [20]. However, this factor is rarely linked to EPPCs. Our study found a significant association between extended preoperative stays and EPPCs, suggesting a novel or context-specific finding. Further research is needed to determine if this association is unique to our local population or has broader applicability.

Uncontrolled diabetes impairs immune function, heightens inflammatory responses, and causes microvascular complications, all of which can increase the risk of early postoperative pulmonary complications (EPPCs). In a retrospective study, Tan et al. (2021) found that patients with poorly controlled diabetes undergoing colorectal surgery experienced significantly higher rates of postoperative pneumonia compared to those with controlled diabetes. These findings support the recommendation of perioperative glycaemic control to minimize respiratory risks [21].

Preoperative blood transfusions may predispose patients to EPPCs through immunosuppression and can trigger transfusion-related acute lung injury (TRALI), leading to immediate respiratory issues. Thus, transfusions are a potential risk factor for respiratory complications in abdominal surgery, warranting further study and targeted preventive strategies [22–24]. However, in our single-center prospective cohort, smoking status was not significantly associated with EPPCs. The absence of association in our study does not mean that transfusions are indifferent to risk, but rather that there was a lack of power, variability, and confounder control to reveal the effect. A larger study (multicenter or prolonged) with detailed collection of transfusion indications and volumes and rigorous adjustment for severity factors would be necessary to properly test this hypothesis.

Additionally, advanced age over 50 is widely recognized as a risk factor for postoperative respiratory complications, even when accounting for age-related comorbidities [25].

Anterior laparotomy is linked to more postoperative respiratory complications than minimally invasive techniques. Greater surgical trauma and pain may impair diaphragmatic function and reduce pulmonary ventilation, increasing the risk of postoperative pulmonary complications. These findings highlight the benefits of minimally invasive surgery in reducing respiratory morbidity after abdominal surgery [26].

Its prospective design allowed for rigorous data collection on postoperative complications in a real-world surgical setting. Furthermore, this study applied bootstrap techniques that yielded stable estimates with low bias, thus strengthening the validity of observed associations and the reliability of inferences. However, two key limitations must be acknowledged. First, the single-center nature of the study limits generalizability due to potential institutional biases and a patient population skewed toward emergency procedures. Second, the relatively small sample size, particularly for rare outcomes like EPPCs, reduced statistical power to detect weaker associations (e.g., smoking status). Future multicenter studies with larger cohorts and balanced inclusion of elective surgeries are needed to confirm these findings and refine risk stratification models.

5. CONCLUSION

The six identified risk factors are clinically relevant because they primarily reflect key patient characteristics, including age, history of abdominal surgery, body mass index, the presence of comorbidities (such as diabetes and COPD), and preoperative length of stay. It should be noted that some factors can be modified in elective surgery. However, during emergency procedures, this modifiability is limited.

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