

Original Article

Postoperative pulmonary complications in emergency abdominal surgery. A prospective international cohort study

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ABSTRACT

Background: Emergency abdominal surgery is a high-risk procedure often performed on high-risk patients. The incidence of Postoperative pulmonary complications (PPCs) in emergency abdominal surgery is not well established yet. Several factors, such as the ventilatory approach, may be associated with PPCs but data on patients undergoing emergency abdominal surgery is scarce. The primary aim of the study was to describe the incidence of PPCs during the first 7 postoperative days.

Methods: Prospective international cohort study including all consecutive patients > 18 y/o undergoing emergency abdominal surgery. From April to June 2023 each hospital selected a single 7-day period for the recruitment with a 7-day follow-up. The PPCs included the following international standard definitions for the primary outcome: acute respiratory failure; pneumothorax; weaning failure; acute respiratory distress syndrome; pulmonary infection; atelectasis; pleural effusion; bronchospasm; aspiration pneumonia; pulmonary thromboembolism; and pulmonary edema.

Results: 45 hospitals from 5 geographical areas participated in the study with 507 patients included in the final analysis. A total of 114 (22.5%) patients developed PPCs and 38 (7.5%) developed severe PPCs. The multivariate analysis showed that the independent risk factors for PPCs were: high ARISCAT score (Odds Ratio: 2.67; 95%CI 1.06–6.86), laparotomy (OR: 2.29; 95%CI 1.06–5.01), and postoperative positive air-test (OR: 2.05; 95%CI 1.02–4.24). Conversely, neuromuscular block reversal was associated with a reduced risk of PPCs (OR: 0.36; 95%CI 0.16–0.82).

Conclusion: Incidence of PPCs in patients undergoing emergency abdominal surgery is significant. Among the modifiable risk factors, a lack of neuromuscular block reversal and postoperative positive air test were associated with the increased incidence of PPCs.

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1. Introduction

Emergency abdominal surgery is a high-risk intervention, especially in sicker patients. Half of those patients develop postoperative complications and their perioperative risk of death is increased up to five times than in non-emergency surgeries [1,2].

Postoperative pulmonary complications (PPCs) are the most frequent complications after emergency and non-emergency abdominal surgery, with a significant impact on morbidity, mortality, and use of health care system resources [3–6]. Several

studies, like ARISCAT or LAS VEGAS, have shown that emergency abdominal surgery is an independent risk factor for PPCs [6,7]. It is well known that patients undergoing scheduled abdominal surgery have an incidence of PPCs as high as 40% in randomized clinical trials [9–11]. However, the incidence of PPCs in emergency abdominal surgery is not well established ranging from 5% to 48% [3–13], depending on the definitions used.

In recent years, several studies have attempted to investigate perioperative characteristics of patients associated with high risk for developing PPCs, to reduce their occurrence by identifying potential preventive strategies [7,8]. In general, identified risk factors can be classified into two categories: (i) non-modifiable factors (inherent to the applied surgical procedure and/or to the patient's underlying condition), and (ii) modifiable factors. Examples of the latter include length of surgery, preoperative

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hemoglobin levels, and perioperative ventilatory management. To reduce PPCs, several clinical investigations have explored different lung-protective ventilation strategies [9–12]. However, data on patients undergoing emergency abdominal surgery is scarce.

The aim of this study is to describe the incidence of PPCs according to definition criteria by the joint task force of the European Society of Anesthesiology and the European Society of Intensive Care Medicine [14] in patients undergoing emergency abdominal surgery. We also aimed to characterize the ventilatory management and to analyze the association between perioperative factors, including ventilatory variables and PPCs. The primary outcome of the study was the incidence of PPCs during the first seven postoperative days.

2. Material and methods

2.1. Study design and participants

This study, named “Postoperative Pulmonary Complications in Emergency Abdominal Laparotomy/laparoscopy (PEAL)”, was a prospective international cohort study. It has been designed in compliance with the fundamental principles established in the Declaration of Helsinki and the Convention of the European Council related to human rights and biomedicine. The final protocol was approved by the Ethics Committee in all participating centers (HCB/2020/003 on 2020/05/21). Informed consent was obtained from all patients or relatives and the study followed the strengthening reporting of observational studies in epidemiology (STROBE) statement [15]. Hospitals and investigators from the iPROVE Research Network Group were invited to participate. Participating patients and clinicians did not receive any economic compensation.

2.2. Procedures and outcomes

All consecutive adult (>18 y/o) patients undergoing emergency abdominal surgery who signed the informed consent were included. No specific exclusion criteria were defined in order to avoid selection bias in the analysis of the association between perioperative risk factors and PPCs. From April to June 2023, each hospital selected a single 7-day period for patient enrollment. Followed by a 7-day follow-up period after the day of enrollment Data was collected using REDCap (Research Electronic Data Capture) while being de-identified before entry. Data monitoring was performed by the site principal investigator. The clinical management of all included patients was based on the local protocols of each participating center.

The primary outcome of the study was the incidence of PPCs during the first seven postoperative days. Secondary outcomes included: the association between perioperative factors and PPCs, as well as the incidence of non-pulmonary postoperative complications within seven days after surgery and their association with perioperative factors.

2.3. Outcome variables (postoperative pulmonary and systemic complications)

PPCs were defined as: 1) acute respiratory failure; 2) pneumothorax; 3) weaning failure; 4) acute respiratory distress syndrome (ARDS); 5) pulmonary infection; 6) atelectasis; 7) pleural effusion; 8) bronchospasm; 9) aspiration pneumonitis; 10) pulmonary thromboembolism; and 11) pulmonary edema. PPCs from 1 to 5 were considered severe PPCs as previously described [16]. Secondary outcomes included: 1) cardiac ischemia; 2) *de novo* arrhythmia; 3) heart failure; 4) sepsis; 5) septic shock; 6) acute

renal failure; 7) surgical wound infection; 8) urinary infection; 9) delirium, 10) multisystem organ failure; 11) paralytic ileus; 12) postoperative hemorrhage; and 13) anastomotic dehiscence. Pulmonary and non-pulmonary postoperative complications followed standard definitions (Table S1 and S2, Supplementary Appendix) [14].

2.4. Perioperative variables

The following baseline variables were recorded preoperatively: age, sex, height, weight, body mass index, American Society of Anesthesiologists (ASA) physical status [17], and Charlson comorbidity index (classified as $\leq$ or >4) [18], Clinical Frailty Scale (classified as $\leq$ or >4) [19], ARISCAT risk score which includes age, preoperative hemoglobin, previous lung infection (1 month before surgery), preoperative oxygenation and duration of surgery, and the surgical incision [20], air-test [21], surgical risk stratified by surgical level, according to the degree of risk and surgical difficulty (Table S3, Supplementary Appendix) [22], type of intervention (laparotomy or laparoscopy), and medical history. Perioperative variables included (intraoperative and immediate postoperative period): duration of surgery, surgical position (supine, Trendelenburg, reverse Trendelenburg), depth of anesthesia monitoring, neuromuscular (and if pharmacological neuromuscular blockade reversal was given) and temperature monitoring, use of regional anesthesia, volume of fluids, transfusion requirements, need of vasoactive drugs, hemodynamics (cardiac index if monitored and mean arterial pressure), and antibiotic prophylaxis.

Ventilatory parameters: arterial blood gases, SpO₂, FiO₂, tidal volume (Vt), positive end-expiratory pressure (PEEP), respiratory rate (RR), plateau pressure (Pplat), driving pressure (DP) (calculated as Pplat minus PEEP), and respiratory system compliance (Crs) were recorded at three different time-points [T1: post-induction, T2: intraoperative, 60 min after intubation (used as reference value for the analysis), and T3: pre-extubation]. T1 and T3 provide information on ventilatory management and respiratory mechanics and gas exchange at the beginning and end of surgery under the same conditions. T2 provides the same information but under the specific surgical conditions to which the patient is subjected (surgical technique, positioning, etc.). Other relevant included data were the use of recruitment maneuvers (RM), postoperative air-test, and the use of non-invasive respiratory support in the postoperative period (prophylactic or for rescue therapy).

2.5. Statistical analysis

We estimated the minimum number of patients needed for a pre-planned multiple logistic regression for a response defined by the PPCs as a binary event. Based on previous literature [23,24], and similar studies [11], we assumed that around 10 explanatory variables would be required to explain the outcome. For a power of at least 80%, a minimum of 100 events would be required. The prevalence of such adverse events in this population has been described as around 50% [12]. Therefore, we aimed at enrolling a total minimum number of 285 patients.

We reported patients' characteristics, perioperative variables, and PPCs as mean and standard deviation (SD) when normally distributed and as median and interquartile range when non-normally distributed; categorical variables were reported as proportions (%) of values. Any missing data or outliers were individually revised for completion or correction or finally left as missing data. Bivariate analysis was used to assess the relationship between PPCs with patients' characteristics and perioperative variables. Comparisons were made by using the χ^2 test or Fisher's exact test for categorical variables and the Kruskal-Wallis and *t*-

test to assess their differences, depending on their distribution. Multivariate analysis, through logistic regression, included clinically relevant variables that presented a $p < 0.01$ value in the bivariate analysis on which an intervention was physiologically plausible. When two or more co-linear variables (*i.e.*, Pplat, DP, respiratory compliance) met these premises, only one with the least missing data was selected. In case of no differences in missing data, the one with the greatest clinical relevance based on previously published data was selected. It is important to emphasize that we only considered patients with completed data in all selected variables for the multivariate analysis. All analyses were performed with the statistical R software (version 4.2.3).

3. Results

A total of 45 hospitals from 5 countries (Spain, Italy, Canada, Turkey, and Chile) participated in the study with 507 patients included in the final analysis (Fig. 1). Patient's characteristics and surgeries are described in Tables 1 and S1. The mean age was 55 (20) y/o with no difference between sex [247 (50.3%) males vs. 244 (49.7%) females]. Two-hundred and thirty-two (54%) patients had a moderate-to-severe risk of PPCs based on ARISCAT score, 187 (27%) had an ASA III/IV, and 294 (59%) had laparoscopic surgeries (Table 1). The mean duration of surgery was 95 (58) minutes (Table 1). As previously defined, 60 min after intubation time (T2) was used as reference values for ventilatory management. Mean Vt was 7.7 (1.9) mL/kg predicted body weight and FiO₂ of 50% was used (Tables 2 and S2). Mean PEEP values were 6 (2) cmH₂O, and in 163 (33%) patients RM were performed (Tables 2 and S2). Mean Pplat and DP were 18 (4) and 12 (4) cmH₂O, respectively. 402 patients were extubated in the OR and 83 in the ICU (22 missing values). No association with severe PPCs was found (OR 0.55; CI: 0.17–2.46, $p = 0.326$). During the immediate postoperative period, 227 (51%) out of 507 total patients had a positive air test and 29 (6%) developed an acute hypoxemic respiratory failure (Table 2). The respiratory support required for those patients is presented in Table S5.

A total of 114 (22.5%) patients developed at least one PPC within 7 days after surgery and 38 (7.5%) patients developed severe PPCs. Daily distribution is shown in Fig. S1. In patients who underwent more aggressive surgeries (surgery level > II, supplementary appendix), the incidence increased to 32% (Tables 3 and S4). The most common PPC were atelectasis and acute respiratory failure (Table 3). Non-pulmonary PPCs were also common (Table 4). A

Table 1

Patients characteristics.

Variable	True values	Mean (SD) or N (%)
Age (yr)	507	55 (20)
Gender (male, %)	491	247 (50.3)
Height (cm)	503	166 (13)
Weight (kg)	503	73 (15)
BMI (kg m ⁻²)	502	26 (7)
Medical history (%)		
Hypertension	495	185 (37.4)
Coronary artery disease	494	25 (5.1)
Dyslipidemia	493	131 (26.6)
Diabetes type II	491	76 (15.5)
Chronic pulmonary obstructive disease	491	41 (8.4)
Obstructive sleep apnoea	493	22 (4.5)
Chronic renal failure	493	54 (11.0)
Chronic liver failure	493	10 (2.0)
Smoker	490	121 (24.7)
Oncological	495	75 (15.2)
Immunosuppression	491	30 (6.1)
Neuromuscular disease	493	10 (2.0)
ASA physical status		
ASA I	494	101 (20.4)
ASA II		206 (41.7)
ASA III		141 (28.5)
ASA IV		46 (9.3)
Frailty (CFS > 4)	466	60 (12.9)
Charlson > 4	450	119 (26.4)
ARISCAT score	507	
Mild (<26 points)	507	230 (45.4)
Moderate (26–44 points)		116 (22.9)
Severe (>44 points)		161 (31.8)
SpO ₂ (FiO ₂ 0.21)	467	96.4 (3.6)
Positive Air-Test	467	221 (47.3)
Preoperative Hb (g/dl)	496	11.8 (8.5)
Lung infection during the last month	494	29 (5.9)
Type of surgery		
Laparoscopy	495	294 (59.4)
Surgical level		
First	507	170 (33.5)
Second		7 (1.4)
Third		111 (21.9)
Fourth		219 (43.2)
Surgeries		
Appendectomy	507	157 (31.0)
Gastrointestinal perforation		140 (27.6)
Gastrectomy		67 (13.2)
Small bowel resection		53 (10.5)
Colorectal resection		42 (8.3)
Cholecistectomy		25 (4.9)
Intestinal adhesiolysis		16 (3.2)
Hemoperitoneum		7 (1.4)

Data are reported as mean (SD) or n (%). True values: Number of patients analysed. BMI = body mass index. ASA = American Society of Anaesthesiology clinical status. ARISCAT: Assess respiratory risk in surgical patients in Catalonia. SpO₂: peripheral oxyhaemoglobin saturation. FiO₂: Inspiratory oxygen fraction. Hb: Haemoglobin. Positive Air-Test: SpO₂ < 97% while breathing room air.

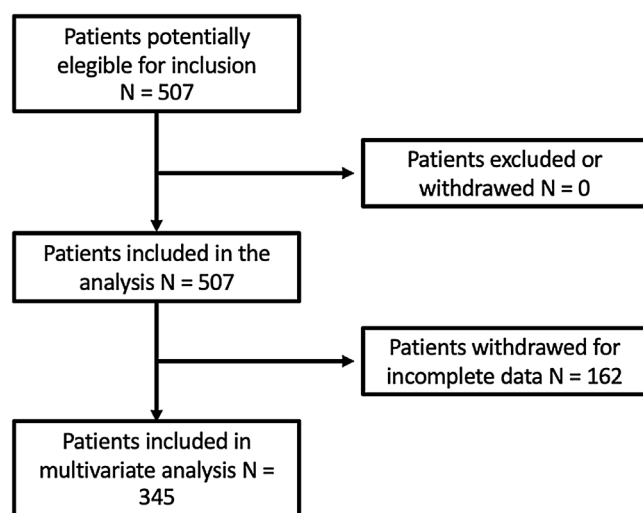


Fig. 1. Flow chart of the study.

total of 121 (23%) patients required ICU admission postoperatively of which 68 (13%) were unplanned (Table S5). The univariate analysis showed that in this population age, medical history of hypertension, coronary artery disease, COPD, ASA physical status, Clinical Frailty scale, Charlson comorbidity index, ARISCAT score, preoperative SpO₂, preoperative lung infection, preoperative air-test, laparotomy, surgical risk, duration of surgery, surgical position, absence of neuromuscular block reversal, volume of fluids, use of vasoactive drugs and the postoperative air-test were associated with PPCs ($p < 0.001$) (Table 4). Ventilatory parameters associated with PPCs were: FiO₂, Pplat, DP, Crs ($p < 0.001$), and the use of RM ($p = 0.025$). Multivariate analysis identified as independent risk factors for PPCs (Table 4): high ARISCAT score (OR: 2.7; 95%CI 1.06–6.86), laparotomy (OR: 2.3; 95%CI 1.06–5.01) and postoperative positive air-test (OR: 2.0; 95%CI 1.02–4.24) (Fig. 2).

Table 2
Perioperative characteristics.

Variable	M (SD) or n (%)
Surgical position	
Supine	297 (60,4)
Trendelenburg	141 (28,7)
Reverse trendelenburg	54 (11,0)
Intraoperative variables	
Tidal volume to predicted body weight (m/kg)	7,7 (1,9)
Respiratory rate (bpm)	14 (2)
Inspiratory oxygen fraction (%)	50 (11)
Positive end expiratory pressure (cmH ₂ O)	6,2 (2,0)
Recruitment maneuvers	163 (33,0)
Plateau pressure (cmH ₂ O)	18,7 (4,8)
[†] Driving pressure (cmH ₂ O)	12,4 (4,4)
Dynamic respiratory system compliance (mL/cmH ₂ O)	40 (15)
Peripheral oxyhaemoglobin saturation (0.21 FiO ₂) (%)	94,7 (7,5)
[‡] Partial pressure of arterial oxygen (mmHg)	151 (51)
[‡] Partial pressure of carbon dioxide (mmHg)	41 (8)
[§] pH	7,33 (0,08)
Mean arterial pressure (mmHg)	79 (15)
Anaesthetic management	
Depth of anesthesia monitoring	371 (75,3)
Neuromuscular blockade	479 (96,8)
Quantitative Neuromuscular Monitorization	120 (24,3)
Neuromuscular reversion reversion	405 (82,2)
TOFr > 0,9 before extubation	184 (41)
[§] Temperature monitoring	114 (23,1)
Regional analgesia	50 (10,2)
Antibiotic prophylaxis	470 (94,9)
Crystalloids, milliliters	1028 (6693)
Red blood cells transfusion	41 (8,1)
[‡] Vasoactive drugs	127 (74,2)
[‡] Duration of surgery, min	95 (58)
Patients extubated in the operating room	402 (82,9)
Postoperative hours at PACU	
Prophylactic use of HFNT or NIV	0 (0)
[‡] Positive Postoperative Air-Test	227 (51,2)
Acute respiratory Failure	29 (6,0)

Data are reported as mean (SD) or n (%). TOFr: train of four ratio. PACU: Postanaesthesia care unit. HFNT: high flow oxygen therapy. NIV: non-invasive ventilation.

[†] Driving pressure was calculated as plateau pressure minus positive end-expiratory pressure. Plateau pressure was determined at the end of the inspiratory pause (time of 5%–10% of inspiratory time).

[‡] Patients with intraoperative arterial line.

[‡] Vasoactive drugs: Patients who received vasopressors and/or inotropes not related to the recruitment manoeuvres.

[§] Temperature recorded at the end of surgery.

[‡] Defined as the time between skin incision and closure of the incision.

[#] Defined as SpO₂ < 97% while breathing room air.

Conversely, neuromuscular block reversal was associated with a reduced risk of PPCs (OR: 0.36; 95%CI 0.16–0.82).

4. Discussion

In this prospective multicenter international observational study of patients undergoing emergency abdominal surgery from 5 different countries, we observed that 22% of patients developed at least one PPC during the first seven postoperative days, increasing up to 32% in higher-risk surgeries. A higher ARISCAT score, the surgical technique (laparotomy), and the presence of a postoperative positive air test were independent risk factors for PPCs. Intraoperative neuromuscular block reversal was associated with protective effects. This prospective study provides novel and relevant information regarding the relation between baseline characteristics, intraoperative management, and ventilatory management, and the incidence of PPCs in patients undergoing emergency abdominal surgery.

Previous studies have reported a wide range of incidence of PPCs (5%–48%) after emergency abdominal surgery [2,12,13]. Those

Table 3
Outcomes.

Postoperative pulmonary complications	
Patients with any PPCs during the first 7 postoperative days	114 (22,5)
Patients with severe PPCs	38 (7,5)
Atelectasis	50 (9,9)
Pleural effusion	25 (4,9)
Bronchospasm	3 (0,6)
Aspiration pneumonia	2 (0,4)
Pulmonary edema	11 (2,2)
Respiratory infection	13 (2,7)
Pneumothorax	0
Mild acute respiratory failure	34 (6,7)
Severe acute respiratory failure	12 (2,4)
Weaning failure	8 (1,6)
ARDS	19 (3,7)
Systemic postoperative complications	
Surgical Site Infection	39 (7,7)
Urinary Infection	3 (0,6)
Acute Kidney Injury	50 (9,9)
Septic Shock	37 (7,3)
Cardiac Failure	12 (2,4)
De novo Arrhythmia	15 (3,0)
Myocardial ischemia	1 (0,2)
Delirium	20 (3,9)
Paralytic ileus	42 (8,3)
Postoperative hemorrhage	15 (3,0)
Anastomotic leakage	9 (1,8)
Multiorgan failure	23 (4,5)

All outcomes are within the first 7 postoperative days. Composite of severe PPCs includes: Severe respiratory failure (need for noninvasive or invasive ventilation), pneumothorax (Chest radiography with air in the pleural space with no vascular bed surrounding the visceral pleura), weaning failure (Reintubation within the first 48 h after postoperative extubation), ARDS (Berlin definition criteria) and pulmonary infection (Presence of a new pulmonary infiltrate and/or progression of previous pulmonary infiltrates on a chest radiograph plus at least two of the following criteria: (a) leukocytosis with >12,000 WBC/mm³ or leukopenia with <4000 WBC/mm³, (b) fever > 38.5 °C or hypothermia < 36 °C, and (c) increased secretions with purulent sputum and a positive bronchial aspirate). All PPCs include severe plus the other reported PPCs: atelectasis (Combination of SpO₂ ≤ 96% during the air test and chest radiography with lung opacification with shift of the mediastinum, hilum, or hemidiaphragm towards the affected area, and compensatory overinflation in the adjacent non-atelectatic lung), mild acute respiratory failure (Mild: Requirement for CPAP or HFNC), Pleural effusion (Chest radiography with the presence of costophrenic angle blunting, displacement of adjacent anatomical structures, and blunting of the hemidiaphragmatic silhouette in the supine position), Bronchospasm (Presence of expiratory wheezing treated with bronchodilator), Pulmonary edema (Fluid accumulation in the alveoli due to poor cardiac function diagnosed with chest radiography of lung ultrasound.), Pulmonary thromboembolism (A new blood clot or thrombus within the pulmonary arterial system). Definition of systemic complications are described in Table S1. PPCs: Postoperative pulmonary complications. ARDS: acute respiratory distress syndrome.

differences may be explained by several factors, such as the characteristics of the patient population, type of surgery, or definition of PPCs [14,25]. Recently, the prospective multicenter observational ALPINE study reported an incidence of 48% of PPCs using the same definition criteria and follow-up period as we did [12]. The higher proportion of lower-risk surgeries - first level - included in our study, such as appendectomies or ovarian torsions, may account for the observed differences, among other factors. Accordingly, we found that the PPC incidence in more complex surgeries (surgery levels > II) such as Intestinal adhesiolysis, anastomotic dehiscence, and hemoperitoneum exceeded 30%.

The impact of PPCs on morbidity, mortality, and use of health care system resources, mainly related to an increased hospital length of stay, has been well described in the literature, including this specific population [4–6,12,26]. Factors associated with PPCs include non-modifiable and modifiable factors. The recognition and characterization of these risk factors could help to improve perioperative anesthetic management and pathways in higher-risk patients, thereby enhancing postoperative outcomes. Most non-modifiable variables were independently associated with PPCs in

Table 4
Univariate and Multivariate analysis using PPCs as outcome.

Variable	No PPCs, N = 393	PPCs, N = 114	Univariate analysis P value	Multivariate analysis	
				Odds ratio (95% confidence interval)	P value
Age (yr)	52 (20)	64 (18)	<0,001		
Gender (male, %)	49 (50)	54 (50)	0,370		
Height (cm)	167 (11)	164 (17)	0,110		
Weight (kg)	73 (14)	72 (18)	0,597		
BMI (kg m ⁻²)	26 (7)	26 (5)	0,860		
Medical history (%)					
Hypertension	118 (31)	67 (58)	<0,001		
Coronary artery disease	11 (2,9)	14 (12,3)	<0,001		
Dyslipidemia	87 (23)	44 (38,6)	<0,001		
Diabetes type II	43 (11)	22 (29)	<0,001		
Chronic pulmonary obstructive disease	20 (5,3)	21 (18)	<0,001	2,35 (0,87–6,28)	0,087
Obstructive sleep apnoea	13 (3,4)	9 (8,0)	0,04		
Chronic renal failure	26 (6,9)	28 (24)	<0,001		
Chronic liver failure	1 (0,3)	9 (7,9)	<0,001		
Smoker	89 (22)	32 (28)	0,341		
Oncological	45 (11,8)	30 (26,3)	<0,001		
Immunosuppression	20 (5,3)	10 (8,8)	0,176		
Neuromuscular disease	(1,6)	4 (3,5)	0,202		
ASA physical status					
ASA I	99 (26)	2 (1,8)	< 0,001		
ASA II	174 (45,7)	32 (28,3)			
ASA III	90 (23,6)	51 (45,1)			
ASA IV	18 (4,7)	28 (24,8)			
Frailty (CFS > 4)	28 (7,9)	32 (28)	<0,001	1,29 (0,57–2,81)	0,537
Charlson > 4	60 (17,4)	59 (56,2)	<0,001		
ARISCAT score					
Mild (<26 points)	216 (55,0)	14 (12,3)	<0,001		
Intermediate (26–44 points)	51 (13,0)	665 (57,0)		1,24 (0,54–2,91)	0,613
Severe (>44 points)	126 (32,1)	35 (30,7)		2,67 (1,06–6,86)	0,038
Peripheral oxyhaemoglobin saturation (FIO ₂ 0.21)	96,1 (2,9)	92,8 (13,3)	<0,001		
Preoperative Hb (g/dl)	11,6 (7,2)	12,5 (11,9)	0,328		
Lung infection during the last month	14 (3,7)	15 (3,2)	<0,001		
Positive Air-Test	156 (43)	65 (61)	0,002		
Type of surgery					
Laparotomy	114 (29)	87 (76)	<0,001	2,29 (1,06–5,01)	0,035
Surgical level					
First	164 (41,7)	6 (5,3)	<0,001		
Second	60 (15,3)	51 (44,7)			
Third	16 (4,2)	53 (46,5)			
Fourth	3 (0,8)	4 (3,5)			
Intraoperative					
Duration of surgery	86 (49)	126 (72)	<0,001		
Surgical position					
Supine	199 (52,6)	98 (86,0)	<0,001		
Trendelenburg	130 (34,4)	11 (9,6)			
Reverse Trendelenburg	49 (13,0)	4 (4,4)			
Recruitment maneuvers	115 (30)	48 (42)	0,025		
Neuromuscular reversion	338 (88)	67 (59)	<0,001	0,36 (0,16–0,82)	0,015
Locoregional anesthesia	37 (9,8)	13 (11)	0,738		
Crystalloids, mL	934 (627)	1340 (804)	<0,001	1,01 (1,00–1,01)	0,006
Red blood cell trasfusion	17 (4,3)	24 (21)	<0,001		
Use of vasoactive drugs	60 (15)	67 (58)	<0,001		
Intraoperative physiological parameters					
Tidal volume	462 (55)	468 (56)	0,521		
Respiratory rate	13 (1)	13(2)	0,098		
Inspiratory oxygen fraction	50 (10)	62 (19)	<0,001	1,00 (0,97–1,03)	0,824
Positive end-expiratory pressure	5,5 (1,4)	5,7 (1,9)	0,566		
Plateau pressure	15 (4)	19 (4)	<0,001		
Driving pressure	10 (3)	13 (4)	<0,001	1,01 (0,94–1,09)	0,693
Dynamic respiratory system compliance	48 (17)	38 (13)	<0,001		
Peripheral oxyhaemoglobin saturation (FIO ₂ 0.21)	96 (2)	91 (14)	<0,001		
Positive Postoperative Air-Test	160 (40)	67 (58)	<0,001	2,05 (1,02–4,24)	0,047

Data in the univariate analysis is reported as mean (SD) or n (%). BMI = body mass index. ASA = American Society of Anaesthesiology clinical status. ARISCAT: Assess respiratory risk in surgical patients in Catalonia. Positive Air-Test: SpO₂ < 97% while breathing room air.

the univariate analysis, although in the multivariate analysis only remained significant the ARISCAT scale, as previously described [7], which includes age, preoperative hemoglobin, previous lung infection (1 month before surgery), preoperative oxygenation, duration of surgery, and the surgical technique (laparotomy).

Consistent with previous studies suggesting that less invasive surgery, such as laparoscopy, results in a lower incidence of PPCs mainly due to reduced incisional pain and diaphragmatic dysfunction [27], we found that laparotomy was an independent risk factor in the multivariate model. In contrast to previous

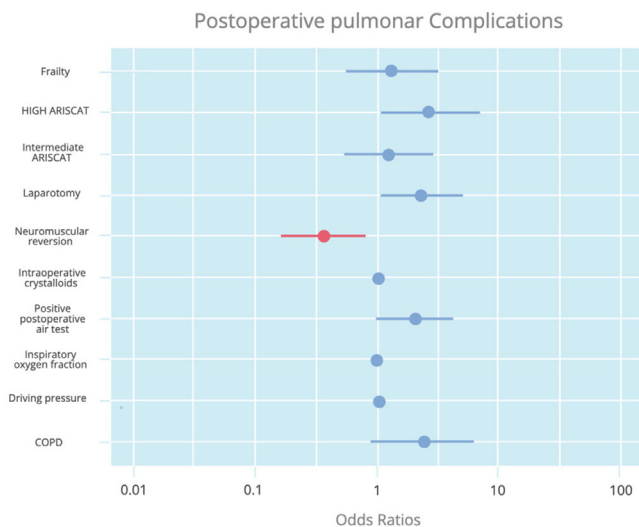


Figure 2. Multivariate analysis for Postoperative Pulmonary Complications

Fig. 2. Multivariate analysis for postoperative pulmonary complications.

studies on this population, frailty was an independent risk factor for PPCs in the univariate analysis but not in the multivariate model [28]. Although there is no direct collinearity, the weight of the ARISCAT score, which includes age and SpO₂, could have influenced the multivariate analysis. Although COPD it's a well-known risk factor for PPCs in emergency abdominal surgeries [29], was not significant in our multivariate analysis. It is our impression that the impact of COPD on PPCs was offset by the dominance of other factors.

Among the modifiable factors, the neuromuscular block reversal was associated with a lower risk of PPCs in the univariate and multivariate analysis. The residual neuromuscular blocking is a well-known anesthesia-related modifiable factor for PPCs [30]. Its postoperative consequences include respiratory muscle dysfunction, impaired hypoxic ventilatory response, and upper airway dysfunction. Reversal of neuromuscular block might reduce PPCs in different surgeries and its use is currently recommended in clinical guidelines [31]. However, this association was not previously reported in patients undergoing emergency abdominal surgery. A modifiable factor was intraoperative fluid administration: lower volumes of crystalloids were associated with a lower risk of PPCs. As previously shown, large fluid administration impairs patient outcomes. Fernandez-Bustamante *et al.* [6] found an association between intraoperative fluid administration and PPCs in a prospective observational study including several scheduled surgeries. Finally, we found an association between a positive postoperative air test and PPCs. The assessment of SpO₂ measured at room air, a reliable diagnosis of perioperative atelectasis [32]. The air test is a helpful technique for predicting PPCs since atelectasis promotes another kind of PPCs by several mechanisms [21].

Intraoperative ventilatory management impacts respiratory mechanics, which is one of the most important modifiable factors associated with PPCs. Lung-protective ventilation aims to minimize lung injury induced by mechanical ventilation, trying to avoid its two main mechanisms: tidal overdistension secondary to the use of high volumes or pressures and atelectrauma produced by repetitive alveolar opening and closure. In a similar population, the ALPINE study reported that higher peak pressure and inspiratory oxygen fraction (FiO₂) were associated with an increased risk of PPCs [12]. However, the association with other variables also related to PPCs, such as plateau pressure, driving pressure (DP), or the ventilatory approach (which includes Vt, RMs, and PEEP) was

not reported [33,34]. Noticeably, most of our patients were ventilated with a Vt < 8 mL/kg, which precludes us from finding any association between Vt and PPCs. Nevertheless, two randomized controlled trials have recently shown no impact of higher Vts (≈10 mL/kg) on PPCs compared to the recommended 6–8 mL/kg PBWs [35–37]. Similar findings were found by the ALPINE [12] and LAS VEGAS [5] observational studies with no association between Vt and PPCs. General anesthesia requiring mechanical ventilation also promotes intraoperative atelectasis, increasing the risk of PPCs [21]. The open lung strategy (OLA), is a strategy that combines an RM to open collapsed alveoli, followed by PEEP to prevent re-collapse, and homogenize the lung by decreasing the risk of lung injury and therefore PPCs. Physiologically, this is reflected in an increase in respiratory system compliance and a decrease in driving pressure. Although our analysis showed that patients without PPCs had lower driving pressure, we did not find any association between the open lung approach (OLA) and PPCs. This finding is in line with a meta-analysis that included three randomized controlled trials in patients undergoing scheduled abdominal surgeries [38]. In our opinion, there are some possible reasons explaining this lack of association. First, the type of RM applied was not described and the effectiveness of the maneuver (*i.e.*, the reversal or reduction in lung collapse) was not assessed. Second, individualized PEEP titration maximizes the physiological and clinical benefits of RM [10,16,39], enhancing lung protective effects. In the current analysis, no data regarding individualized PEEP was reported, so it is unknown to what extent an effective OLA strategy was achieved. In contrast to previous studies [5,12], in our study, all patients received PEEP with no differences between PEEP levels in patients who did and did not develop PPCs. Therefore, we could not analyze the association between the use of PEEP and the development of PPCs. Finally, prophylactic postoperative respiratory support was not used in any of the included patients. Data suggests that a perioperative care bundle, which includes an intraoperative OLA and a postoperative individualized respiratory support could have the greatest protective effect [10,38]. This finding could be especially relevant in patients at high risk for developing postoperative atelectasis since neglecting its management could counterbalance the potential benefits obtained from an intraoperative lung-protective strategy.

We acknowledge some strengths of this study including the use of validated definition criteria for PPCs and the analysis of all modifiable and non-modifiable factors associated with PPCs [14]. Most of the outcome variables included are considered anesthesia-related severe morbidity [40]. Its international multi-center design makes the results generalizable to other countries and the short recruitment period minimized variations in anesthetic management. There are also some limitations. First, our methodology did not allow us to establish cause-effect relationships. Second, the unblinded nature of this prospective observational study may have influenced the ventilatory strategy. Third, the absence of recording of some intra- and postoperative variables, such as the presence of intrinsic PEEP or cumulative fluid balance, among others, could have affected the final results as they might influence PPCs and statistical analysis. However, we have included the variables of the highest interest and with the greatest relevance as described in previous studies. Fourth, in order to reduce the risk of lack of statistical power in the multivariate analysis, we decided, in case of co-linearity, that variables with fewer missing values prevailed over those with higher clinical relevance. Although this could lead to biased results, selection based on missing values was not performed in the final analysis. Fifth, the exclusion of those patients with missing values in any of the selected variables may have generated a bias in the final results. Finally, the inclusion of a considerable number of low-risk surgeries (first-level) may have influenced the incidence of PPCs

and the results of the multivariate analysis, mainly in relation to modifiable factors, and specifically the effect of ventilatory settings on PPCs.

On the basis of the results from this study, future studies aiming to reduce PPCs in patients undergoing emergency abdominal surgery should focus on the modifiable risk factors found in our analysis, such as the use of neuromuscular blocker reversal or the use of perioperative ventilatory strategies that minimize the risk of impaired postoperative oxygenation. In addition, our results could help improve the accuracy of sample size estimation for future trials.

5. Conclusion

In conclusion, we found that patients undergoing emergency abdominal surgery have a significant incidence of PPCs. Among the modifiable risk factors, a lack of neuromuscular block reversal and postoperative positive air test were associated with the increased incidence of PPCs. Most patients were ventilated with a lung protective strategy. However, RMs were applied only in one-third of the patients and were not associated with PPCs.

CRediT authorship contribution statement

- substantial contribution to conception and design, acquisition of data, or analysis and interpretation of data: all authors
- drafting the article or revising it critically for important intellectual content: all authors
- final approval of the version to be published: all authors
- agreement to be accountable for all aspects of the work thereby ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: all authors.

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Declaration of competing interest

The authors declare that they have no conflict of interest.

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Appendix B. Supplementary data

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