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Mechanical power and postoperative pulmonary complications in patients undergoing major abdominal surgery

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ABSTRACT

Aims: Postoperative pulmonary complications (PPCs) are a major cause of perioperative morbidity and mortality in patients undergoing major abdominal surgery. Although various factors contribute to PPCs, intraoperative mechanical ventilation strategies play a critical role. Mechanical power, a parameter encompassing factors like tidal volume and respiratory rate, has emerged as a potential risk factor for ventilator-associated lung injury (VILI). This study aims to investigate the relationship between intraoperative mechanical power and PPCs.

Methods: This prospective, observational study included 207 patients aged 18 years and older undergoing elective major abdominal surgery between April and December 2022. Mechanical power was calculated using a simplified formula based on ventilator parameters recorded at 15-minute intervals. PPCs were evaluated within 24 hours postoperatively, following the European Perioperative Clinical Outcome (EPCO) guidelines. Primary outcome was the relationship between intraoperative mechanical power and PPCs, with secondary outcomes assessing the incidence of specific PPCs.

Results: PPCs occurred in 22.2% (n=46) of the patients. The mean mechanical power was 8.99 J/min in patients with PPCs and 8.56 J/min in those without, with no statistically significant difference. Atelectasis was the most common PPC. Factors such as chronic obstructive pulmonary disease (COPD), prolonged surgery, and higher ASA scores were associated with increased PPC risk.

Conclusion: Although no significant association between mechanical power and PPCs was found in this study, the findings underscore the importance of considering mechanical power in intraoperative ventilation strategies to reduce the risk of ventilator-associated lung injury. Further large-scale, prospective studies involving diverse patient populations are essential to clarify the role of mechanical power in minimizing PPCs and improving perioperative outcomes. Careful selection and management of ventilation strategies, with a focus on optimizing mechanical power, remain crucial in reducing PPC incidence and enhancing patient care.

Keywords: Lung injury, ventilators-mechanical, perioperative care, ventilator-induced lung injury

INTRODUCTION

Postoperative pulmonary complications (PPCs) are a significant cause of perioperative morbidity and mortality.[1] It is estimated that more than 200 million major surgeries are performed worldwide annually.[2] Various studies have shown that pulmonary complications are more common than cardiac complications and significantly increase hospital costs.[3] Studies indicate an incidence rate of up to 23%.[4] Respiratory tract infection, respiratory failure, pleural effusion, atelectasis, pneumothorax, bronchospasm, and aspiration pneumonitis are among the components of PPCs defined by the European Perioperative Clinical Outcome (EPCO) (Table 1).[5] The causes of these complications are multifactorial. The type of surgical procedure, the anesthesia method used, and preoperative risk factors specific to patients play a role. In addition to their multifactorial etiology, PPCs are associated with numerous preoperative, intraoperative, and postoperative risk factors. Miskovic and Lumb[4,6] categorized these factors as patient-related, procedure-related, and laboratory testing-related, and then examined non-modifiable and modifiable risk factors such as age, smoking, comorbidities, chronic lung disease, and type of surgery. Among the modifiable risk factors are intraoperative mechanical ventilator strategies. Intraoperative ventilation strategies are important for preserving patients' lungs and reducing ventilation-related complications during surgery. Ventilator-associated lung injury (VILI) resulting from the use of mechanical ventilation is a significant concern with potential morbidity and mortality. Volutrauma, barotrauma, atelectotrauma, and biotrauma are the four classic mechanisms of VILI. The necessity of using lung-protective ventilation strategies to prevent VILI is widely accepted. Factors contributing to VILI are diverse and interact with each other, including tidal volume, peak pressure, plateau pressure, positive end expiratory pressure (PEEP), flow rate, and respiratory rate. Mechanical power, which encompasses all these factors, has emerged as a parameter considered in mechanical ventilator therapy in intensive care units (ICU) in recent years.

Table 1. Definitions of postoperative pulmonary complications

Respiratory infection	Patient has received antibiotics for a suspected respiratory infection and met one or more of the following criteria: new or changed sputum, new or changed lung opacities, fever, white blood cell count>12x10^9/L
Respiratory failure	Postoperative PaO_2<8kPa (60 mmHg) on room air, a PaO_2:FiO_2 ratio< 40kPa (300 mmHg) or arterial oxyhemoglobin saturation measured with pulse oximetry <90% and requiring oxygen therapy
Pleural effusion	Chest radiograph demonstrating blunting of the costophrenic angle, loss of sharp silhouette of the ipsilateral hemidiaphragm in upright position. Evidence of displacement of adjacent anatomical structures or (in supine position) a hazy opacity in one hemithorax with preserved vascular shadows
Atelectasis	Lung opacification with a shift of the mediastinum, hilum or hemidiaphragm toward the affected area, and compensatory over-inflation in the adjacent non-atelectatic lung
Pneumothorax	Air in the pleural space with no vascular bed surrounding in the visceral pleura
Bronchospasm	Newly detected expiratory wheezing treated with bronchodilators
Aspiration pneumonitis	Acute lung injury after the inhalation of regurgitated gastric contents

PaO_2: partial pressure of arterial oxygen, FiO_2: Fraction of inspired oxygen

The parameter initially proposed by Gattinoni et al.[7] represents the energy delivered to the respiratory system during mechanical ventilation. Due to the complexity of the initial formula, there have been difficulties in its application, leading to the development of simplified formulas. The formula developed by Giosa et al.[8] stands out for its effectiveness in volume-controlled ventilation and ease of use. Experimental and clinical studies have shown that the threshold value for the relationship between mechanical power and mortality ranges from 11.3 J/min to 17 J/min.[9-11] While there is research on mechanical power in ICUs, there is a lack of an adequate number of studies in patients undergoing mechanical ventilation in operating rooms. The aim of this study was to examine the correlation between intraoperative mechanical power exerted on the lungs and the occurrence of PPCs in patients undergoing major abdominal surgery. As a secondary objective, we aimed to identify specific factors, such as patient-related characteristics that may influence the relationship between mechanical power and PPCs. Additionally, we sought to evaluate the potential impact of mechanical power on different types of pulmonary complications, with the goal of optimizing ventilator settings to reduce the incidence of these complications.

METHODS

After obtaining written informed consent and approval from the ethics committee, patients aged 18 years and older undergoing elective major abdominal surgery with intraoperative volume-controlled ventilation were included in the study. The study was conducted prospectively and observationally between April 2022 and December 2022. All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki. Routine preoperative anesthesia assessment was performed, and all patients were evaluated for age, gender, height, weight, and The American Society of Anesthesiologists (ASA) classification. Risk factors related to PPCs were queried. Mechanical ventilation parameters were recorded at 15-minute intervals until the 60th minute. Mechanical power was calculated using a simplified formula based on parameters obtained from the mechanical ventilator (minute ventilation x (Peak pressure+PEEP+Inspiratory flow rate / 6) / 20). The presence of pulmonary complications was evaluated at postoperative 24 hours. Pulmonary complications were assessed based on the definition framework prepared by EPCO (Table 1).[5] The primary outcome of this study is to evaluate the relationship between intraoperative mechanical power applied to the lungs and PPCs in patients undergoing major abdominal surgery. Secondary outcomes include assessing the incidence of specific PPCs such as atelectasis, bronchospasm, pleural effusion, and pneumonia.

Existing literature lacks studies assessing PPCs in humans through the lens of 'Mechanical Power'. Therefore, an effect size (d) of 0.50, indicative of a moderate effect, was utilized for the Student t-test. With a Type 1 error rate set at 0.05 and a power of 0.90, a total sample size of 172 individuals was calculated using a two-tailed hypothesis. Sample size calculation was performed using G-Power 3.1 software. To account for potential data loss, it was planned to recruit at least 10% more participants than the calculated sample size.

The analysis process was conducted using the Statistical Package for Social Science (SPSS) 24.0 program. Normality of distribution was assessed using the Kolmogorov-Smirnov test, histograms, and Skewness-Kurtosis coefficients. Categorical measurements were presented as numbers and percentages. For continuous measurements, mean and standard deviation were presented for those showing normal distribution, while median and minimum-maximum values were presented for those not showing normal distribution. Binary analyses for normally distributed data were evaluated using the student t-test, while binary analyses for non-normally distributed data were evaluated using the Mann Whitney U test. Pearson's chi-square test was applied to assess the relationship between categorical variables. A Type I error level of 0.05 was considered.

RESULTS

216 patients who underwent major abdominal surgery were included in the study. Statistical analysis and evaluation were performed for a total of 207 patients (Figure 1). PPCs were observed in 22.2% (n=46) of the included patients at 24 hours, while it was not observed in 77.8% (n=161) of the patients (Figure 2). When examining the demographic data of the patients, it was observed that there were more female individuals, with an average age of 59 years, and body mass index ranging from 20 to 35 kg/m^2. It was observed that atelectasis was the most common component in patients with

PPCs (Table 2). When the relationship between demographic and clinical characteristics of the patients and PPCs was examined, it was found that PPCs was more frequently observed in patients with a diagnosis of chronic obstructive pulmonary disease (COPD), those planned for postoperative ICU admission in preoperative evaluation, those with a surgical duration of more than two hours, and those with a higher ASA score (Table 3, Table 4, Table 5). The mean mechanical power value was calculated as 8.99 J/min for patients with PPCs and 8.56 J/min for those without PPCs. The relationship between PPCs components and mechanical power is shown in Table 6.

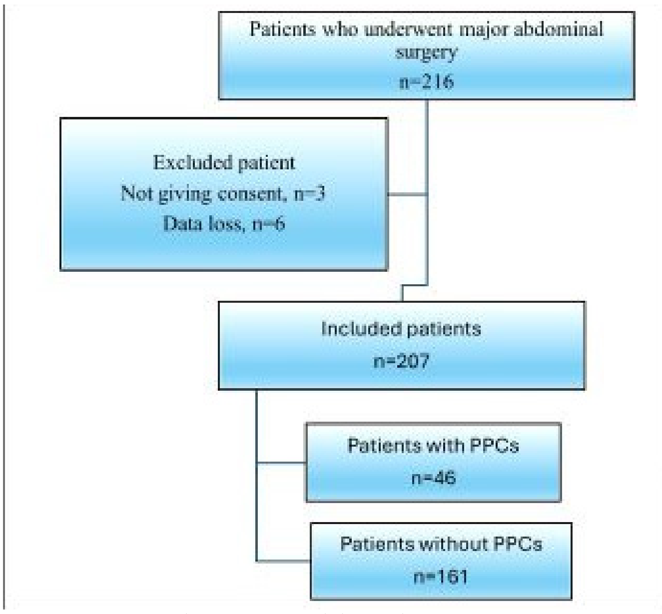

Figure 1. Patients undergoing major abdominal surgery

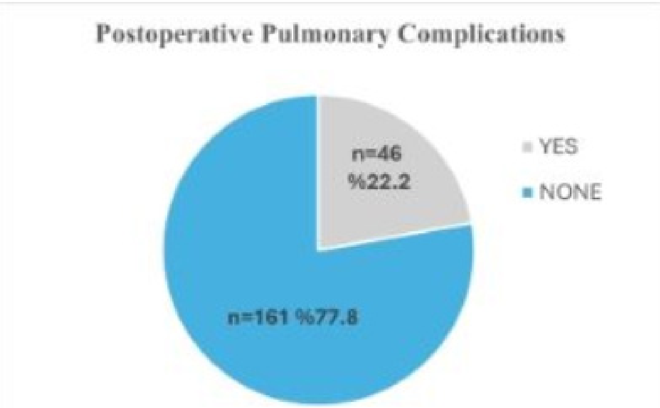

Figure 2. Postoperative pulmonary complications

Table 2. Distribution of postoperative pulmonary complications components

PPCs components	n (%)
Respiratory failure	25 (12.1)
Bronchospasm	5 (2.4)
Pulmonary infection	4 (1.9)
Pneumonia	18 (8.7)
Atelectasis	35 (16.9)
Pneumothorax	0 (0)
Aspiration pneumonia	0 (0)
Pleural effusion	20 (9.7)
Pulmonary edema	0 (0)

PPCs; postoperative pulmonary complications

Table 3. Patient-related factors and postoperative pulmonary complications

Clinical features		(%)	Postoperative pulmonary complications, (%)		
		Sum n=207	Yes n=46	None n=161	p
Gender	F	128 (61.8)	26 (20.3)	102 (79.7)	0.400
	M	79 (38.2)	20 (25.3)	59 (74.7)	
Smoking	Yes	58 (28.0)	13 (22.4)	45 (77.6)	1.000
	None	149 (72.0)	33 (22.1)	116 (77.9)	
COPD	Yes	16 (7.7)	8 (50.0)	8 (50.0)	0.010
	None	191 (92.3)	38 (19.9)	153 (80.1)	
BMI (kg/m^2)	0-30 (kg/m^2)	165 (79.8)	35 (21.2)	130 (78.8)	0.628
	>30 (kg/m^2)	42 (20.2)	11 (26.2)	31 (73.8)	

COPD; Chronic obstructive pulmonary disease, BMI; body mass index

DISCUSSION

In this study, the relationship between intraoperative mechanical power applied to the lungs and PPCs was investigated in patients undergoing major abdominal surgery. Pulmonary complications were observed in 22.2% of the patients at 24 hours. The mean mechanical power value was 8.99 J/min in patients with pulmonary complications, while it was 8.56 J/min in patients without pulmonary complications. There was no statistically significant difference. Additionally, a statistically significant difference was observed in ASA scores, COPD, surgical duration, and the parameter of planning postoperative ICU admission in preoperative evaluation, which were found to be associated with an increased risk of PPCs.

PPCs incidence rates vary due to factors such as different definitions in the literature, sample size, and surgical characteristics, ranging from 5.8% to 39%.[1,12,13] The formation of PPCs is associated with numerous risk factors. Literature suggests that both male and female genders have higher rates of PPCs occurrence in studies conducted on gender-related factors.[14,15] Another risk factor is inadequate postoperative analgesia. We believe that adequate analgesia was achieved in our study; therefore, no relationship was found between analgesia practices and PPCs. Ineffective postoperative analgesia can lead to complications, prolonged hospital stays, increased intensive care needs, decreased patient satisfaction, and chronic pain development.[16]

While there are studies indicating an association between smoking and PPCs, we did not reach a significant conclusion.[17,18] COPD has been identified as a risk factor for PPCs in 13 out of 15 studies in a review conducted by Smetana et al.[17] In another study, abnormal findings in lung examination (such as decreased breath sounds, prolonged expiration, crackles, wheezing, or rhonchi) were reported as the strongest determinants of postoperative pulmonary complication rates.[19] Decreased lung volumes after surgery are the main cause of PPCs. Obesity can lead to restrictive pulmonary physiology and further decrease lung volumes and postoperative deep breathing ability. However, studies evaluating postoperative PPCs have not found morbid obesity to be an increased risk factor.[17,20]

The ASA score aims to classify patients' health status based on their physical condition and comorbidities, and a high ASA score has been associated with an increased risk of PPCs.[21] This suggests that patients with higher ASA scores generally have more serious comorbidities, which may result in weaker

Table 4. Perioperative factors and postoperative pulmonary complications, (%).

Clinical features		(%)	Postoperative pulmonary complications, (%)		
		Sum n=207	Yes n=46	None n=161	p
PPI use	Yes	22 (10.6)	7 (31.8)	15 (68.2)	0.279
	None	185 (89.4)	39 (21.1)	146 (78.9)	
Steroid use	Yes	2 (1.0)	1 (50.0)	1 (50.0)	0.396
	None	205 (99.0)	45 (22.0)	160 (78.0)	
Preoperative antibiotic use	Yes	167 (80.7)	40 (24.0)	127 (76.0)	0.312
	None	40 (19.3)	6 (15.0)	34 (85.0)	
Postoperative analgesia	Epidural pca	3 (1,4)	0	3 (100)	0.639
	Iv pca	2 (1.0)	0	2 (100)	
	Oral	15 (7.2)	2 (13.3)	13 (86.7)	
	Parenteral	113 (54.6)	26 (23.0)	87 (77.0)	
	Regional block	10 (4.8)	1 (11.1)	8 (88.9)	
	Multimodal	64 (30.9)	17 (26.2)	48 (73.8)	
ASA score	1	18 (3.9)	0	8	0.005
	2	106 (51.2)	17 (16.0)	89 (84.0)	
	3	89 (43.0)	26 (29.2)	63 (70.8)	
	4	4 (1.9)	3 (75.0)	1 (25.0)	

PPI; proton pump inhibitor, pca; patient-controlled analgesia, ASA; American Society of Anaesthesiologists

Table 5. surgery related factors and postoperative pulmonary complications

Clinical features	(%)	(%)	Postoperative pulmonary complications, (%)		
		Sum n=207	Yes n=46	None n=161	p
Bowel resection	Yes	83 (40.1)	21 (25.3)	62 (74.7)	0.483
	None	124 (59.9)	25 (20.2)	99 (79.8)	
Nasogastric tube	Yes	137 (66.2)	33 (24.1)	104 (75.9)	0.468
	None	70 (33.8)	13 (18.6)	57 (81.4)	
Planning postoperative intensive care unit admission in preoperative evaluation	Yes	152 (73.4)	43 (28.3)	109 (71.7)	**0.001**
	None	55 (26.6)	3 (5.5)	52 (94.5)	
Surgical time	0-120 dk	69 (33.3)	6 (8.7)	63 (91.3)	**0.002**
	>120 dk	138 (66.7)	40 (29.0)	98 (71.0)	
Surgical method	Laparoscopic	45 (33.3)	7 (15.5)	38 (84.4)	0.391
	Open	148 (76.7)	34 (22.9)	114 (77.0)	
Incision site	Upper abdominal	48 (23.1)	13 (27.1)	35 (72.9)	0.468
	Lower abdominal	159 (76.8)	33 (20.8)	126 (79.2)	

Table 6. Relationship between mechanical power and postoperative pulmonary complications components

		Mechanical power average value (j/min)	Mean rank (SD)	p
PPCs	Yes	8.99	(2.53)	0.290
	None	8.56	(2.42)	
Respiratory failure	Yes	9.3	114.1	0.368
	None	8.6	102.6	
Bronchospasm	Yes	10.1	144.4	0.127
	None	8.6	103.0	
Pulmonary infection	Yes	9.4	128.0	0.418
	None	8.6	103.5	
Pneumonia	Yes	9.1	111.3	0.584
	None	8.6	103.3	
Atelectasis	Yes	9.1	113.3	0.311
	None	8.6	102.1	
Pleural effusion	Yes	0.0	97.3	0.599
	None	8.6	104.7	
Pneumothorax	Yes	0.0		
	None	8.6	104.7	
Pulmonary edema	Yes	0.0		
	None	8.6	104.7	
Aspiration pneumonia	Yes	0.0		
	None	8.6	104.7	

PPCs; postoperative pulmonary complications respiratory functions. In our study, similar to the literature, PPCs was observed in 16% of patients with ASA II score, 29.2% of patients with ASA III score, and 75% of patients with ASA IV score ($p<0.005$). While higher ASA scores may increase the risk of pulmonary complications, other factors should also be considered. Therefore, it is important to make an individual assessment considering factors such as the patient's overall health status, anesthesia risk, and surgical planning.

Surgical field is one of the most important factors in predicting PPCs risk; the incidence of complications is inversely proportional to the distance of the surgical incision from the diaphragm.[22] For 11 studies conducted on patients undergoing esophagectomy, the postoperative pulmonary complication rate was 18.9%; for 16 studies on patients undergoing abdominal aortic aneurysm repair, the postoperative pulmonary complication rate was 25.5%; for six studies involving head and neck surgery patients, the postoperative pulmonary complication rate was 10.3%; for five studies examining hip surgery, the PPCs rate was 5.1%; and for two studies involving gynecological or urological procedures, the postoperative pulmonary complication rate was 1.8%.[17] In the same review conducted by Smetana et al.,[17] the postoperative pulmonary complication rates for upper abdominal and lower abdominal surgery were 19.7% and 7.7%, respectively. In our study, we included 207 patients who underwent major abdominal surgery, with 48 of them undergoing upper abdominal surgery. PPC was observed in 27.1% of patients undergoing upper abdominal surgery and in 20.8% of patients undergoing lower abdominal surgery.

The concept of mechanical power encompasses the main factors contributing to VILI, including elements such as tidal volume and driving pressure. Recent studies suggest that respiratory rate, a significant component of high mechanical power in patients under general anesthesia, is associated with PPCs.[23] It has been shown that a doubling of respiratory rate leads to a 1.4-fold increase in mechanical power.[24] Studies have demonstrated the relationship between mechanical power and mortality in patients with and without ARDS.[25,26] The threshold value at which the harmful effects of mechanical power occur is not yet fully established. In patients with ARDS, it has been shown that energy levels exceeding 17 J/min increase mortality.[25] Another study found an increase in 28-day mortality at mechanical power levels exceeding 22 J/min.[27] In a large multicenter retrospective cohort study involving approximately 230,000 intraoperative patients, the mean mechanical power value was 7.67 J/min for patients with PPCs and 6.62 J/min for those without PPCs, indicating that higher mechanical power values during ventilation are associated with a higher likelihood of PPCs.[28] In a retrospective study involving 3,000 ICU patients conducted by Şentürk et al.,[11] the median mechanical power value was found to be 11.3 J/min, with mortality rates of 35.4% for mechanical power <11.3 J/min and 49.1% for mechanical power >11.3 J/min ($p<0.001$). In our study, the mean mechanical power value was 8.99 J/min for patients with PPCs and 8.56 J/min for those without PPCs.

Limitations

One of the strengths of our study is its prospective design and data collection during the surgical procedure. However, there are several limitations to consider. The absence of a randomized controlled design is a primary limiting factor. Other limitations include the heterogeneity of the patient population, the single-center setting, the lack of assessment of preoperative respiratory function, and the restriction to a specific surgical procedure group or age range could have enhanced the study's validity by minimizing confounding variables and ensuring a more homogeneous patient population.

CONCLUSION

This study explored the relationship between intraoperative mechanical power applied to the lungs and PPCs in patients undergoing major abdominal surgery. Although no statistically significant association was found between mechanical power values and PPCs, the findings highlight the importance of optimizing intraoperative ventilation strategies to mitigate VILI. The use and management of mechanical power in the operating room may play a key role in reducing the risk of VILI, but more definitive evidence is required. Future prospective studies involving more diverse and extensive patient populations are needed to better understand the role of mechanical power in preventing PPCs. These studies may provide valuable insights that can guide adjustments in ventilator parameters to minimize lung injury, reduce morbidity and mortality, and optimize the use of healthcare resources. Incorporating mobile applications or mechanical ventilator software to calculate mechanical power may further enhance the precision and effectiveness of these strategies.

ETHICAL DECLARATIONS

Ethics Committee Approval

After obtaining written informed consent and approval from the ethics committee, patients aged 18 years and older undergoing elective major abdominal surgery with intraoperative volume-controlled ventilation were included in the study. The study was conducted prospectively and observationally between April 2022 and December 2022.

Informed Consent

All patients signed and free and informed consent form.

Referee Evaluation Process

Externally peer-reviewed.

Conflict of Interest Statement

The authors have no conflicts of interest to declare.

Financial Disclosure

The authors declared that this study has received no financial support.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper, and that they have approved the final version.

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