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Repercussions of pneumoperitoneum for laparoscopic cholecystectomy on mechanical power with volume-controlled ventilation

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Abstract

Background
The installation of pneumoperitoneum alters mechanical ventilation mechanics, which can lead to an increase in mechanical power and lead to Ventilator-Induced Lung Injury (VILI) and postoperative pulmonary complications and reintubation. Aim: To analyse the repercussions of pneumoperitoneum on mechanical power during general anaesthesia for cholecystectomy, verify changes in the parameters of the components of ventilatory mechanics and their repercussions on mechanical power before, during and after pneumoperitoneum emptying.

Methods
Analytical, cross-sectional and observational study carried out between 2022 and 2023, in Sixty patients undergoing general anaesthesia for video laparoscopic cholecystectomy. The parameters of the components of the ventilatory mechanics were collected, such as RR, VT, Ppeak, Plateau, PEEP, ΔP, resistance and compliance, and the mechanical power during the intraoperative period, ten minutes before the pneumoperitoneum was performed, during the pneumoperitoneum and ten minutes after the pneumoperitoneum. When the hypothesis of equality of means in the three evaluation moments was rejected, these moments were compared two by two considering the LSD test. $P < 0.05$ indicated statistical significance.

Results
The variables RR, Pplateau, ΔP, and compliance showed significant differences in three-by-three comparisons ($P < 0.001$) but not PEEP ($P = 0.217$) and VT ($P = 0.338$). The parameters Ppeak, resistance and mechanical power, in addition to presenting significant differences in the three-by-three comparisons ($P < 0.001$) also presented significant differences in the two-by-two comparison before and during, before and after, during and after the pneumoperitoneum.

Conclusion
Pneumoperitoneum during cholecystectomy surgery resulted in an increase in mechanical power above values considered protective during volume-controlled ventilation, due to reduced compliance and increased resistance, which tend to normalize after emptying.

Keywords: mechanical ventilation; mechanical power; video laparoscopy; pneumoperitoneum

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Introduction

The treatment for choledocholithiasis is performed through the surgical procedure of cholecystectomy. [1] Laparoscopic surgery is a procedure that allows for better visualization of the abdominal cavity compared to open laparotomy, being less invasive and thus ensuring reduced postoperative pain and accelerating patient recovery, leading to a shorter hospital stay. The creation of a pneumoperitoneum using carbon dioxide becomes necessary, resulting in an increase in intra-abdominal pressure to 15 mmHg, [2] which, when combined with the Trendelenburg position, can cause ventilatory alterations. [3]

Mechanical ventilation is the method of respiratory support chosen for patients with acute lung injury or exacerbated chronic lung injury, and in surgeries with general anesthesia. [4] The concept of protective ventilation can be applied to the field of intraoperative mechanical ventilation, [5] which can reduce Ventilator-Induced Lung Injury (VILI) that is dependent on the ventilatory strategy used. [6] Intraoperative protective ventilation concepts should be applied by limiting values of tidal volume (VT), plateau pressure (Pplateau), positive end-expiratory pressure (PEEP), driving pressure (ΔP), respiratory rate (RR), peak inspiratory pressure (Ppeak), and flow ($\dot{V}$). [5]

In the concept of protective ventilation to reduce VILI, it is recommended that, if possible, the physiological RR be maintained, between 12-16 bpm, with an inspiration-expiration ratio of 1:2 to 1:3, [7] the VT between 6-8 ml/kg of predicted weight in healthy lungs and in Respiratory Distress Syndrome (ARDS) it is limited to below 6 ml/kg. [8] The Plateau pressures obtained by the 3-second inspiratory pause to below 30 cmH_2O [7] with ΔP less than 15 cmH_2O. [9,10] PEEP in healthy lungs can be initially set at 5 cmH_20, [11] the $\dot{V}$ between 40 and 60 liters per minute with an expected compliance of 50-80 ml/cmH_2O. [11]

Mechanical power was introduced as a unifying component, which measures the amount of energy that the ventilator transfers to the lung parenchyma. [12] Experimentally, a threshold of up to 12 Joules per minute [13] has been reliably demonstrated, and that above this value it is related to edema and VILI. [14,15] The installation of pneumoperitoneum alters mechanical ventilation mechanics, a fact that could generate an increase in mechanical power and consequently in the energy delivered in each ventilatory cycle and lead to VILI [16] and postoperative pulmonary complications and reintubation. [17]

This research aims to analyze the repercussions of pneumoperitoneum on mechanical power during general anesthesia for cholecystectomy. To verify changes in the parameters of the components of ventilatory mechanics such as RR, VT, Ppeak, Pplateau, PEEP, ΔP, resistance, compliance and their repercussions on mechanical power before, during and after emptying the pneumoperitoneum.

Methods

Analytical, cross-sectional and observational study carried out between 2022 and 2023 at the São José dos Pinhais Hospital and Maternity Hospital in Brazil, approved by the Ethics Committee of the Health Department of São José dos Pinhais under opinion number 5,566,034.

All 60 patients were informed about the research and agreed to participate by signing the Informed Consent Form (ICF). Relevant information for the study, such as age, gender, comorbidities, history of smoking and alcohol consumption, were collected, and the parameters of the components of ventilatory mechanics such as RR, VT, Ppeak, Plateau, PEEP, ΔP, resistance, compliance were calculated, and mechanical power was calculated using the Gattinoni formula [12] intraoperatively ten minutes before the pneumoperitoneum, during the pneumoperitoneum and ten minutes after the pneumoperitoneum.

The inclusion criteria are: patients over 18 years of age, undergoing general anesthesia, undergoing video laparoscopic abdominal surgery, absence of acute lung disease, and mechanical ventilation performed in VCV mode.

The exclusion criteria are: refusal to sign the informed consent form, refusal to participate, or withdrawal of consent at any stage of the study.

The collected data were digitized in an Excel® table and the statistical analysis to describe the quantitative variables considered the mean, median, minimum and maximum values, and standard deviation. The analysis of variance for repeated measures was used to compare the three assessment moments in relation to the variables of interest. The null hypothesis of the mean of the parameters being the same at the three assessment moments was tested versus the alternative hypothesis of at least one of the moments having a mean different from the others. When the hypothesis of equality of means at the three assessment moments was rejected, these moments were compared two by two using the LSD test. P values less than 0.05 indicated statistical significance.

Results

In the statistical analysis of the three moments of the mechanical ventilation components, it was detected: RR with a significant difference in the values of the three moments (P < 0.001), however in the comparison of the moments two by two of this parameter, there was no statistical difference between before and during pneumoperitoneum by the LSD test (P = 0.061); VT no significant difference was detected in the values of the three moments (P = 0.338). Ppeak with a significant difference in the values of the three moments (p<0.001), as well as in the comparison of the moments two by two of this parameter. Pplateau with a significant difference in the values of the three moments (P < 0.001), however in the comparison of the moments two by two of this parameter, there was no statistical difference between before and after pneumoperitoneum by the LSD test (P = 0.137). PEEP without significance in the values of the three moments (P = 0.217). ∆P a significant difference was detected in the values of the three moments (P <0.001), however when comparing the moments two by two of this parameter, there was no statistical difference between before and after pneumoperitoneum by the LSD test (p=0.555). Compliance with significant difference in the values of the three moments (P <0.001), however, when comparing the moments two by two of this parameter, there was no statistical difference between before and after pneumoperitoneum by the LSD test (P = 0.993). Resistance with significant difference in the values of the three moments (P < 0.001), as well as in the comparison of the moments two by two of this parameter. Mechanical power with significant difference in the values of the three moments (P < 0.001), as well as in the comparison of the moments two by two of this parameter. Table 1 presents the descriptive statistics of this variable at each of the evaluation moments, as well as the P-value of the statistical test.

Table 1- Values of the mechanical ventilation components, before, during and after pneumoperitoneum.

RR	**n**	**Mean**	**Median**	**Minimum**	**Maximum**	**Standard Deviation**	**P*-value**
Before	60	14.6	14.0	12.0	20.0	1.6	
During	60	15.0	15.0	12.0	19.0	1.6	< 0.001
After	60	15.5	16.0	10.0	20.0	1.8	
VT	**n**	**Mean**	**Median**	**Minimum**	**Maximum**	**Standard Deviation**	**P*-value**
Before	60	0.41	0.40	0.28	0.61	0.06	
During	60	0.41	0.41	0.31	0.60	0.06	0.338
After	60	0.42	0.41	0.30	0.61	0.07	
Ppeak	**n**	**Mean**	**Median**	**Minimum**	**Maximum**	**Standard Deviation**	**P*-value**
Before	60	17.9	17.0	13.0	30.0	4.0	
During	60	23.4	23.0	17.0	32.0	4.0	< 0.001
After	60	18.9	18.0	12.0	30.0	3.9	
Pplateau	**n**	**Mean**	**Median**	**Minimum**	**Maximum**	**Standard Deviation**	**P*-value**
Before	60	13.2	12.5	9.2	20.8	3.0	
During	60	17.2	16.5	10.3	24.7	3.2	< 0.001
After	60	13.6	12.6	6.9	20.6	3.0	
PEEP	**n**	**Mean**	**Median**	**Minimum**	**Maximum**	**Standard Deviation**	**P*-value**
Before	60	5.1	5.0	3.0	8.0	0.7	
During	60	5.2	5.0	3.0	8.0	0.8	0.217
After	60	5.3	5.0	3.0	11.0	1.2	
ΔP	**n**	**Mean**	**Median**	**Minimum**	**Maximum**	**Standard Deviation**	**P*-value**
Before	60	8.1	7.3	4.2	16.4	2.9	
During	60	12.0	11.6	5.3	19.7	3.2	< 0.001
After	60	8.2	7.5	5.9	14.6	3.1	
Compliance	**n**	**Mean**	**Median**	**Minimum**	**Maximum**	**Standard Deviation**	**P*-value**
Before	60	0.041	0.042	0.017	0.070	0.012	
During	60	0.027	0.027	0.016	0.039	0.007	< 0.001
After	60	0.041	0.038	0.016	0.182	0.022	

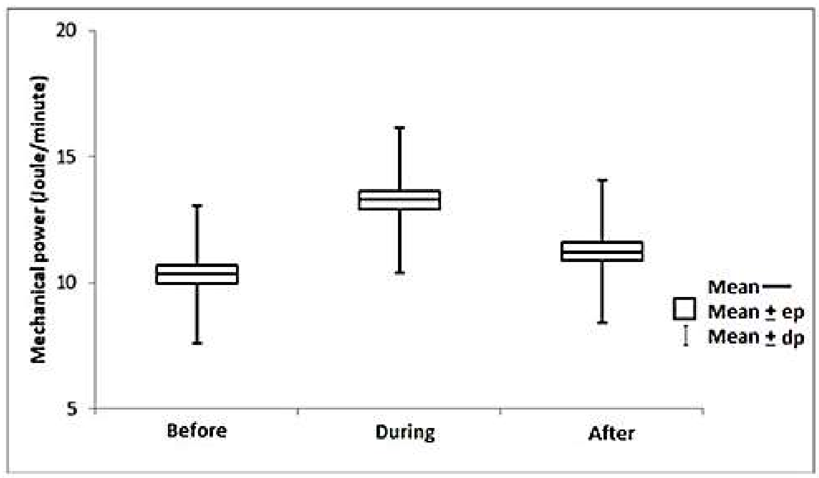
Resistance	n	Mean	Median	Minimum	Maximum	Standard Deviation	P*-value
Before	60	0.27	0.26	0.18	0.47	0.06	
During	60	0.35	0.34	0.27	0.48	0.06	< 0.001
After	60	0.29	0.28	0.15	0.52	0.07	
Mechanical power	**n**	**Mean**	**Median**	**Minimum**	**Maximum**	**Standard Deviation**	**P*-value**
Before	60	10.3	9.9	5.1	19.7	2.7	
During	60	13.3	13.0	7.5	21.4	2.9	< 0.001
After	60	11.2	10.6	6.3	22.5	2.8	

(*) Analysis of Variance Model for Repeated Measures; P < 0.05

Table 2: Two-by-two comparison of mechanical moments. (*) LSD test; p <0.05

Moments for comparison	P*-value
Before x During	< 0.001
Before x After	0.003
During x After	< 0.001

Figure 1: Box-plot of mechanical power moments before, during and after power pneumoperitoneum.



Discussion

Physiological RR should be maintained between 12-16 per minute with an inspiration-expiration ratio of 1:2 to 1:3, [7] This is in line with the mean values used in this study, in which it was also observed that RR increased gradually without exceeding physiological values, even 10 minutes after the pneumoperitoneum was emptied, possibly related to the adjustment of the ventilator to compensate for hypercapnia.

As expected, there was no significant difference between the three VT moments, as the VCV mode was used, which uses a constant flow to obtain the desired tidal volume. [18] It was demonstrated that in VCV mode with constant VT, VILI can occur due to the increase in ΔP, [10] which is in line with this study that demonstrated an increase in ΔP only during pneumoperitoneum, although without reaching values outside the protective ventilation range.

Continuous monitoring of mechanical ventilation can reduce the possible post operative respiratory complications. [19] An increase in Pplateau was demonstrated during pneumoperitoneum, [20,21] in agreement with our study, in which an increase in both Ppeak and Pplateau was observed during the pneumoperitoneum period associated with an increase in resistance with a reduction in compliance, respectively, and without reaching values higher than those considered for protective ventilation. They demonstrated an increase in resistance during pneumoperitoneum [19] and a gradual reduction in compliance as the pneumoperitoneum was created [22] and it was observed that it returned to previous values with its emptying, as well as Pplateau, but not Ppeak, possibly due to the persistence of the increase in resistance at higher values even after 10 minutes of pneumoperitoneum emptying. PEEP should initially be set at 5 cm H_2O, [11] which coincides with this study, where the mean initial PEEP was 5.1 cm H_2O, with no statistical difference between the three moments analyzed (P = 0.217). There are still discrepancies regarding the minimum and maximum amount of PEEP used, since patients who are able to achieve greater lung recruitment benefit from using PEEP up to 15 cmH_2O, but patients who are unable to achieve lung recruitment experience higher lung tension when using high PEEP. [23]

In a study conducted by Karalapillai D et al, MP was associated with patient outcomes in the first seven postoperative days, and it was reported that increased MP was associated with a higher risk of pulmonary complications and acute respiratory failure in the postoperative period. Mechanical power during pneumoperitoneum remained above the values considered protective ventilation, with an average of 13.3 joules per minute, in agreement with another study that demonstrated a significant increase after pneumoperitoneum was created in VCV mode compared to values after anesthetic induction, however, they did not reach clinically significant values equal to or greater than 12 joules per minute. [10] In our study, we observed that the increase in mechanical power during pneumoperitoneum above the level considered protective ventilation resulted from an increase in RR, Peak, Plateau, ΔP, and resistance, with a reduction in compliance. Ten minutes after the pneumoperitoneum was emptied, the values decreased but remained high in relation to the values prior to the pneumoperitoneum, due to the increase in RR and resistance, which did not return to the values prior to the pneumoperitoneum.

Despite the temporary increase in mechanical power, none of the postoperative patients presented respiratory complications till discharge from the hospital. However, this study is limited by its performance in a single center with a relatively small sample, in which ventilation modalities or parameters of the ventilation components that were used were not compared.

Conclusion

Pneumoperitoneum during cholecystectomy surgery resulted in an increase in mechanical power above values considered protective during volume-controlled ventilation, due to reduced compliance and increased resistance, which tend to normalize after emptying.

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