Are alveolar recruitment maneuvers and peep ventilation effective in the intraoperative period of laparoscopic bariatric surgery? A systematic review

As manobras de recrutamento alveolar e a ventilação peep são eficazes no período intra-operatório da cirurgia bariátrica laparoscópica? Uma revisão sistemática

Son efectivas las maniobras de reclutamiento alveolar y la ventilación del peep en el período intraoperatorio de la cirugía bariátrica laparoscópica? Una revisión sistemática

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Abstract
The purpose of the study is to systematically review about alveolar recruitment maneuvers followed by mechanical ventilation with PEEP guided by electrical impedance tomography (EIT) in laparoscopic bariatric surgery. Metodology: The primary outcomes were: regional pulmonary ventilation (regional impedance variation), end-expiratory lung impedance, and end-expiratory lung volume. Results: The survey identified three eligible studies. The sample consisted of 136 participants of both genders. The alveolar recruitment maneuver (ARM) was performed through the mechanical ventilator and using the EIT in the patient's chest. The studies showed moderate to high risk of bias, and the quality of the evidence was classified as very low quality due to the methodological limitations found and absence of directionality. Conclusion: ARM with PEEP guided by EIT does not significantly improve the respiratory system mechanics in the intraoperative period in obese patients undergoing laparoscopic bariatric surgery.
Keywords: Obesity; Electrical impedance; Respiration artificial; Positive pressure respiration.

Resumo

O objetivo do estudo é revisar sistematicamente sobre as manobras de recrutamento alveolar seguidas de ventilação mecânica com PEEP guiada por tomografia de impedância elétrica (TIE) em cirurgia bariátrica laparoscópica. Metodologia: Os desfechos primários foram: ventilação pulmonar regional (variação regional da impedância), impedância pulmonar expiratória final e volume pulmonar expiratório final. Resultados: A pesquisa identificou três estudos elegíveis. A amostra foi composta por 136 participantes de ambos os sexos. A manobra de recrutamento alveolar (MRA) foi realizada através do ventilador mecânico e utilizando-se o TIE no tórax do paciente. Os estudos apresentaram risco de viés de moderado a alto, e a qualidade da evidência foi classificada como qualidade muito baixa devido às limitações metodológicas encontradas e ausência de direcionamento adequado. Conclusão: A MRA com PEEP guiada pela TIE não melhora significativamente a mecânica do sistema respiratório no período intraoperatório em pacientes obesos submetidos à cirurgia bariátrica laparoscópica.

Palavras-chave: Obesidade; Impedância elétrica; Respiração artificial; Respiração com pressão positiva.

Resumen

El objetivo del estudio es revisar sistemáticamente las manos de reclutamiento alveolar seguidas de ventilación mecánica con PEEP guiada por tomografía de impedancia eléctrica (TIE) en cirugia bariátrica laparoscópica. Metodologia: Os desfechos primários foram: ventilación pulmonar regional (variação regional da impedância), impedância pulmonar expiratória final y volumen pulmonar expiratório final. Resultados: A pesquisa identificou três estudos elegíveis. A mostra foi composta por 136 participantes de ambos sexos. Una manobra de recrutamento alveolar (MRA) para realizar a través de un ventilador mecánico y utilizando-se o TIE no tórax do paciente. Os estudos apresentaram risco de viés de moderado a alto, e a qualidade da evidência foi classificada como qualidade muito baixa devido às limitações metodológicas encontradas e ausência de direcionamento adequado. Conclusión: A MRA com PEEP guiada pela TIE não melhora significativamente a mecânica do system respiratório no period intraoperatório em pacientes obesos submetidos à cirurgia bariátrica laparoscopic.

Palabras clave: Obesidad; Impedancia eléctrica; Respiración artificial; Respiración con presión positiva.

1. Introduction

The number of obese patients undergoing laparoscopic bariatric surgery has been increasing worldwide, with around 120 million people being clinically classified as obese (Owen et al., 2018, Panagiotou et al., 2018). Although this population has healthy lungs (Aldenkortt et al., 2012), the changes induced by obesity (Aldenkortt et al., 2012, Eichler et al., 2017) the induction of general anesthesia, mechanical ventilation and pneumoperitoneum management (Andersson et al., 2005) during laparoscopic surgery make these patients prone to perioperative complications, leading to a significant reduction in functional residual capacity (FRC), hypoxemia and formation of atelectasis in the dependent lung regions (Aldenkortt et al., 2012, Reinius et al., 2009). In this context, it is recommended that alveolar recruitment maneuvers (ARMs) and positive end-expiratory pressure (PEEP) be used in bariatric surgery to prevent the risk of atelectasis and to keep the alveoli open according to the "open lung" concept (Aldenkortt et al., 2012). However, there are controversies in the handling of these conducts, mainly regarding the risk of alveoli hyperdistension in non-dependent pulmonary areas (Nestler et al., 2017).

In this context, electrical impedance tomography (EIT) emerges as a non-invasive functional imaging technology which enables monitoring alveolar ventilation free of radiation, and also identifying pulmonary regions with atelectasis and hyperdistension (Costa et al., 2009, Gómez-Laberge et al., 2012; Mansouri et al., 2021) EIT enables bedside monitoring by means of indices such as impedance variation (Δz), end-expiratory lung volume (EELV), and center of gravity (CoG) (Stanliewicz-Rudnicki et al., 2015).

Studies have shown that mechanical ventilation with PEEP guided by EIT has proven to be a valuable method of optimizing PEEP in obese patients submitted to laparoscopic bariatric surgery (Eichler et al., 2017, Nestler et al., 2017, Stanliewicz-Rudnicki et al., 2016). However, it is unclear whether ARM followed by mechanical ventilation with PEEP and guided by EIT in the intraoperative period affects the distribution of pulmonary ventilation in this population. This strategy is expected to optimize a more homogeneous distribution of ventilation and minimize the risk of postoperative respiratory complications.

Therefore, a systematic review with a possible meta-analysis was performed to evaluate the effectiveness of ARM followed by mechanical ventilation with PEEP guided by EIT in obese patients undergoing laparoscopic bariatric surgery.

2. Methodology

2.1 Study identification and selection

A search was performed in the following electronic databases: Cochrane Central Register of Controlled Trials (CENTRAL), MEDLINE (via PUBMED), Latin American and Caribbean Health Sciences Literature (LILACS), Scielo, Physiotherapy Evidence Database (PEDro), CINAHL, Web of Science, Scopus and CAPES. The search strategy included articles which met the following eligibility criteria: randomized controlled clinical trials, obese patients over 18 years of age of both genders undergoing laparoscopic bariatric surgery under mechanical ventilation, recruitment maneuvers, positive end-expiratory pressure, and electrical impedance tomography. The following keywords were used: "bariatric surgery", "recruitment maneuver", "electrical impedance tomography", "laparoscopic surgery", "mechanical ventilation", "obese", "obesity", "respiration artificial", "positive end expiratory pressure", "overweight", and combinations thereof, without linguistic restriction or year of publication.

Two independent reviewers evaluated the titles and abstracts of articles found in the surveys in relation to the eligibility criteria. If there were disagreements between the reviewers, a third reviewer (DCB) was asked to resolve possible contradictions in the choice of articles. The potentially relevant titles and abstracts found in the database search were stored for further detailed analysis of the full text. The excluded studies were categorized according to the exclusion motif and presented in the flowchart (Figure 1). Duplicate items were removed during evaluation of study characteristics. If there was a need for incomplete information or data, the authors of the original studies were contacted by e-mail and asked for additional information. The present study was recorded in the PROSPERO International Prospective Register of Systematic Reviews under registration number CRD42018106220.

2.2 Evaluation of the study characteristics

2.2.1 Quality

The included studies were evaluated using the Cochrane Risk of Bias Tool, which classifies the risk of bias as high, low or unclear. The risk of bias was considered high if a methodological procedure was not described, unclear if the description was unclear, and low if the procedure was described in detail.

The *Grading of Recommendations Assessment, Development and Evaluation (GRADE)* was used to analyze the quality of the evidence. This tool considered study limitations, consistency, targeting, accuracy, and publication bias. An evaluation of these criteria guides the classification of the evidence into one of four quality levels: high, moderate, low and very low.

2.2.2 Participants

The studies were included if participants were older than 18 years of age, involved both genders, undergoing laparoscopic bariatric surgery, ARM, and mechanical ventilation with PEEP, guided by EIT.

2.2.3 Intervention

The experimental intervention of this study was ARM and mechanical ventilation with PEEP guided by EIT. The data extracted on the intervention were the indices evaluated by this equipment, distribution of pulmonary ventilation by regions of

interest (ROIs) and compliance of respiratory mechanics. The control group performed ARM and without PEEP, without ARM and with PEEP, or without ARM and without PEEP.

2.2.4 Outcome Measures

The primary endpoint measures were regional pulmonary ventilation (regional impedance variation - Δz), end-expiratory lung impedance (EELI), end-expiratory lung volume (EELV). The measure for regions of interest (ROIs) was given by the distribution of ventilation by lung regions and expressed in %. All pulmonary ventilation measures were evaluated by EIT. Dynamic compliance was assessed by EIT or mechanical ventilator and expressed in ml/cmH$_2$O.

Secondary outcomes were pulmonary pressures and vital signs. The pulmonary pressure measurements were: driving pressure (Δp), positive end-expiratory pressure (PEEP) and plateau pressure (P$_{plat}$), each of which was evaluated by the mechanical ventilator and expressed in cmH$_2$O. The vital signs measures were: blood pressure (BP) and heart rate (HR), evaluated by the bedside monitor and expressed in mmHg and beats per minute (bpm).

2.2.5 Data analysis

Data extracted from the studies such as continuous variables were evaluated, grouped using meta-analysis and expressed as mean difference with a 95% confidence interval. Meta-analyzes were performed using the Review Manager (RevMan) version 5.3, as well as the bias risk graph and Microsoft Excel 14.7 for Mac.

3. Results

3.1 Study identification and selection

The search resulted in 64,564 potentially relevant articles. Of these, 64,430 were excluded by titles and abstract for not presenting the keywords of the previously established search strategy. After removal of studies by titles and abstract, 135 articles were excluded for being duplicates, leaving 9 to be evaluated in the full version. Among the articles obtained in full text, one was excluded due to having an ineligible study population (Corley et al., 2011), two due to an ineligible intervention (i.e. laparoscopic cholecystectomy surgery) (Karsten et al., 2011, Karsten et al., 2014) and two because they are only available in summary form [one in Clincal Trial (Brandão et al., 2018) and the other in European Society of Intensive Care Medicie (ESICM) (Simon et al., 2013)]. Finally, we did not succeed in extracting the data for the meta-analysis for a single title since the data were unavailable for consultation, even through email contact with the author (Nestler et al. 2014). The remaining three studies were included in the systematic review (Eichler et al., 2017, Nestler et al, 2017, Stankiewicz-Rudnicki et al 2016), including relevant data from 136 obese patients who met all inclusion criteria (Figure 1).

Figure 1: Flowchart of studies according to PRISMA.
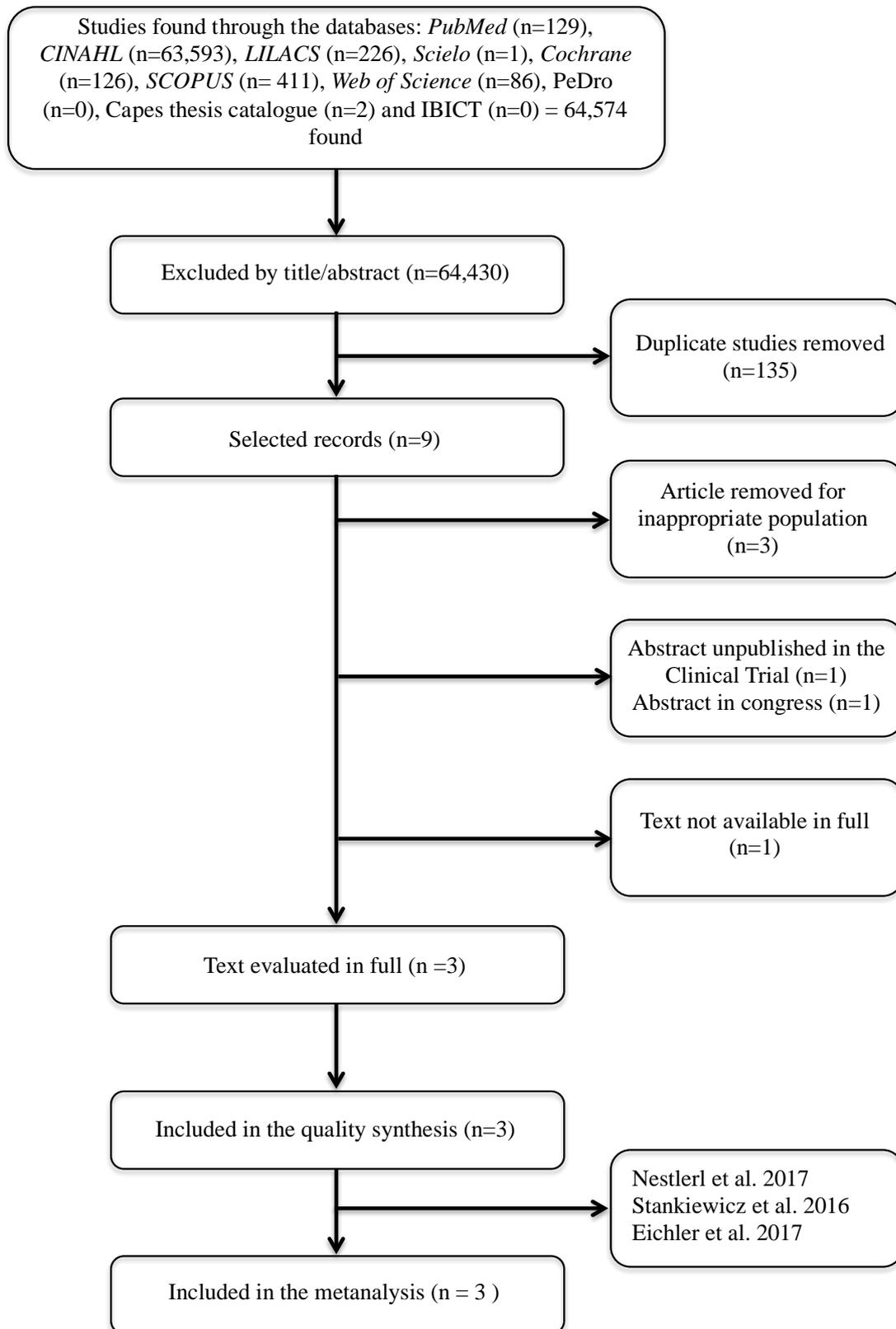
Source: Authors.

3.2 Characteristics of the included studies

The characteristics of the study are presented in Table 1.

Table 1: Summary of included studies (n=3).

Study	Participants	Intervention	Outcome measures
Nestlerl et al.	n = 50 Age (years) = 19 to 63 Gender = 16 M, 34 F	Exp = elective laparoscopic surgery under mechanical ventilation, followed by ARM and PEEP titrated by EIT †. Con = without ARM and PEEP fixed at 5 cmH2O.	* Gas exchange * Regional distribution of ventilation * EELV * (PaO2 / FiO2)
Eichler et al.	n = 37 Age (years) = not informed Gender = 13 M, 24 F	Exp = laparoscopic bariatric surgery, under mechanical ventilation, followed by ARM and PEEP guided by esophageal pressure (PL between -1 and 1 cmH2O) †. Con = with ARM and PEEP fixed at 10 cmH2O.	* Regional distribution of ventilation * Arterial blood gas
Stankiewicz-Rudnicki et al.	n = 49 Age (years) = 18 to 65 Gender = 15 M, 34 F	Exp = Laparoscopic gastric banding surgery or laparoscopic vertical gastrectomy, under mechanical ventilation, followed by ARM and PEEP titrated at 10 cmH2O †. Con = without ARM and PEEP fixed at 0 cmH2O.	* Regional distribution of ventilation * Respiratory system mechanics * Atelectasis

Legend: Con = control group, Exp = experimental group, F = female, M = male, EELV = end-expiratory lung volume, PaO2/FiO2 = oxygenation index. †Electrical Impedance Tomography.

Source: Authors.

3.3 Risk of bias

Regarding randomization and allocation, the main methodological limitation for two studies (Eichler et al., 2017, Stankiewicz-Rudnicki et al., 2016) was the lack of clarity about the type of randomization, if obtained through software, random numbers or other methods, constituting a high risk of bias. For one of the three studies (Nestler et al., 2017), randomization was performed using a stochastic minimization algorithm, stratified by age (< 45 vs ≥ 45 years) to ensure distribution by age, gender, and risk of pulmonary complications, by applying the ARISCT-Score (< 45 vs ≤ 45 points). The use of allocation concealment was clear in one of the three studies [11], reporting the use of sequentially numbered and sealed envelopes; however, it was not made clear whether the envelopes were opaque and therefore was considered to be a risk of uncertain bias.

Two studies (Eichler et al., 2017, Nestler et al., 2017) were homogeneous at the beginning of the study. One (Stankiewicz- rudnicki et al., 2016) of the three studies did not calculate the sample size assuming that a minimum of 32 patients would be sufficient, and the Shapiro-Wilk test revealed that the data had no normal distribution at individual moments in each group; therefore all data were presented as box plots or median (interquartile range). In relation to blinding, two studies (Eichler et al., 2017, Nestler et al., 2017) did not mention blinding of participants or collaborators, constituting a high risk of bias. Only one (Nestler et al., 2017) of the three studies reported that the data were stored in an electronic case report, managed and analyzed by independent researchers; however, the authors did not assure that the blinding improbability was broken, and therefore it was classified as a risk of uncertain bias.

Regarding the intention-to-treat analysis, the data loss was balanced between the groups with similar reasons in one (Nestler et al., 2017) of the three studies, and was presented in its selection and results flowchart, and therefore was considered as having a low risk of bias. For the other two studies (Eichler et al., 2017, Nestler et al., 2017), the main limitation was

insufficient reporting on the exclusions of losses in the final analysis which allowed for judgment and were therefore classified as risk of uncertain bias.

Regarding the selective report, we did not obtain enough information to enable judgment for all the studies, and therefore we consider this a risk of uncertain bias. The risk of bias analysis is presented in Figure 2.

Figure 2: Risk of bias analysis of included studies.

Source: Cochrane Risk of Bias Tool.

3.4 Participants

The three included studies had a total of 136 patients including both genders and ages between 18 and 63 years. All studies were performed in obese patients undergoing laparoscopic bariatric surgery.

3.5 Intervention

All of the studies (Eichler et al., 2017, Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016) used mechanical ventilators with tidal volume (VT) of 8 ml/kg predicted body weight and inspiratory oxygen fraction (FiO$_2$) above 40%, but with different ventilatory modes. Nestler et al. (2017) used volume controlled mode, Eichler et al. (2017) used pressure controlled mode and Stankiewicz-Rudnicki et al. (2016) reported that the patients were ventilated after intubation with predicted VT and did not specify the ventilatory mode.

For all 3 studies (Eichler et al., 2017, Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016) , pulmonary ventilation distribution images were obtained by the EIT (PulmoVista™ Drager Medical) through a belt with 16 electrodes connected to the patients' thorax. Only the study by Nestler et al. (2017) does not clarify the amount of electrodes that was used. For some studies, the belt fixation with the electrodes was in different regions. While it was not clear for Nestler et al. (2017), in Eichler

et al. (2017) the electrodes were connected at a level above the intermamillary line and in Stankiewicz-Rudnicki et al. (2016), they were placed in the 3rd intercostal space. In addition, 20 of the 37 patients included in the study of Eichler et al. (2017) were evaluated by EIT.

The three studies (Eichler et al., 2017, Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016) used ARM, however, they were performed in different protocols with different peak pressure and PEEP. In Nestler et al. (2017), the PEEP$_{IND}$ group received ARM with a peak pressure of 50 cmH$_2$O and PEEP of 30 cmH$_2$O, followed by a decreasing PEEP titration, during which the PEEP was adjusted to 26 cmH$_2$O and gradually decreased by 2 cmH$_2$O every 3 minutes. PEEP corresponding to the lowest regional ventilation delay index (RVDI) based on EIT was identified as PEEP$_{IND}$. In the study by Eichler et al. (2017), a nasogastric tube with an esophageal balloon was installed, being positioned at the middle level of the esophagus (after disappearance of cardiac noise, the tube was retracted by another 1 to 2 cm until the changes in pressure were in synchrony with the breathing), aiming to maintain a corresponding PEEP at a transpulmonary pressure (P$_L$) between -1 and 1 cmH$_2$O at end expiration. The ARM was with PEEP of 20 cmH$_2$O and peak pressure of 50 cmH$_2$O with sustained inflation of 10 seconds. It was initiated with 10 cmH$_2$O, with PEEP being increased by 5 cmH$_2$O every 3 minutes until a P$_L$ value of 0 ± 1 was reached. Pneumoperitoneum between 16 and 18 cmH$_2$O was subsequently installed. The consecutive decrease in P$_L$ was responded by another gradual increase of PEEP until the P$_L$ reached 0 ± 1 cmH$_2$O again. For the experimental group, a mean PEEP of 23.8 cm H$_2$O (95% [Confidence Interval-CI] 19.6 to 40.4) was required to establish a P$_L$ of 0 cmH$_2$O at end expiration. In Stankiewicz-Rudnicki et al. (2016), it is not clear how the ARM protocol was performed, and only that two sustained inflation were made for 10 seconds, each with a peak pressure of 40 cmH$_2$O. The experimental group subsequently maintained a PEEP of 10 cmH$_2$O.

For the control groups, the three studies (Eichler et al., 2017, Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016) showed distinct PEEP values, and two (Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016) of the three authors did not perform ARM in their protocol. For Nestler et al. (2017), PEEP was fixed at 5 cmH$_2$O and ARM was not performed for its control group. For Stankiewicz-Rudnicki et al. (2016), the PEEP was maintained at 0 cmH$_2$O, without ARM. The control group was only submitted to ARM and PEEP determined at 10 cmH$_2$O in the study by Eichler et al. (2017).

3.6 Outcome Measures

The impedance variation variable (Δz) and/or impedance ratio (IR) was measured in two studies (Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016) through EIT. One study (Eichler et al., 2017) measured the end-expiratory lung impedance (EELI) through the EIT, but did not present its data in absolute values. End-expiratory lung volume (EELV) was measured in one study (Nestler et al., 2017) through EIT. The distribution of ventilation by regions of interest (ROIs) was measured in one study (Stankiewicz-Rudnicki et al., 2016) through EIT and the data were supplied by e-mail by the author. The three studies (Eichler et al., 2017, Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016) measured the variable drive pressure (Δp) through mechanical ventilation. However, in two of the three studies (Eichler eta al., 2017, Stankiewicz-Rudnicki et al., 2016), the variable Δp was adjusted to maintain a tidal volume close to 8 ml/kg of predicted weight, and therefore its data were not given in mean and standard deviation. Respiratory compliance was measured in the three studies (Eichler et al., 2017, Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016) through mechanical ventilation. All three studies (Eichler et al., 2017, Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016) measured the positive end-expiratory pressure (PEEP) variable through mechanical ventilation (Eichler et al., 2017, Stankiewicz-Rudnicki et al., 2016) and EIT (Nestler et al., 2017). Two of the three studies (Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016) measured the plateau pressure variable (P$_{plat}$) through mechanical ventilation. For one of the three studies (Stankiewicz-Rudnicki et al., 2016) the blood pressure and heart rate variables were provided by e-mail by the study author.

3.7 Metanalysis

3.7.1 Plateau pressure

Two studies (Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016) reported the plateau pressure used in mechanical ventilation, with a combined sample of 99 patients. When compared to the control (control: Plat = 18.7 cmH$_2$O without ARM and Plat = 21.5 cmH$_2$O without ARM, respectively), the plateau pressure did not differ significantly, with mean difference of 4.45 cmH$_2$O (95% CI -0.26 to 9.15), as shown in Figure 3. Still, by analyzing the protocol data of the two studies in more detail (Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016), we observed a heterogeneity classified as high in relation to the plateau pressure variable (P = 0.0009; I^2 = 91%).

Figure 3: Plateau pressure outcome between the intervention group and the control group.
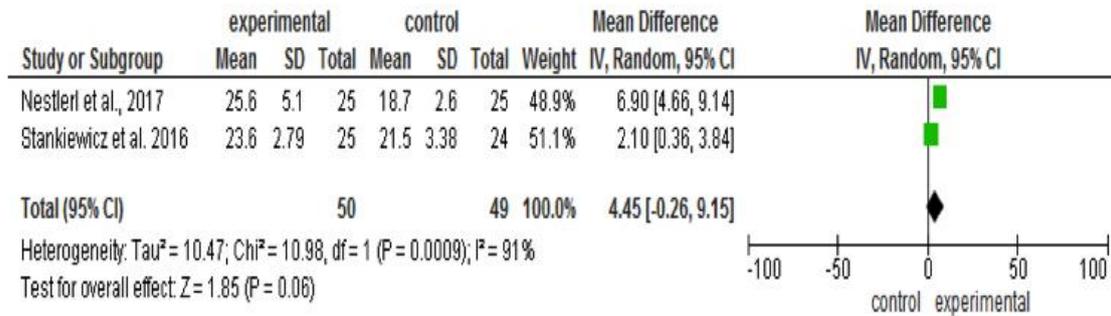
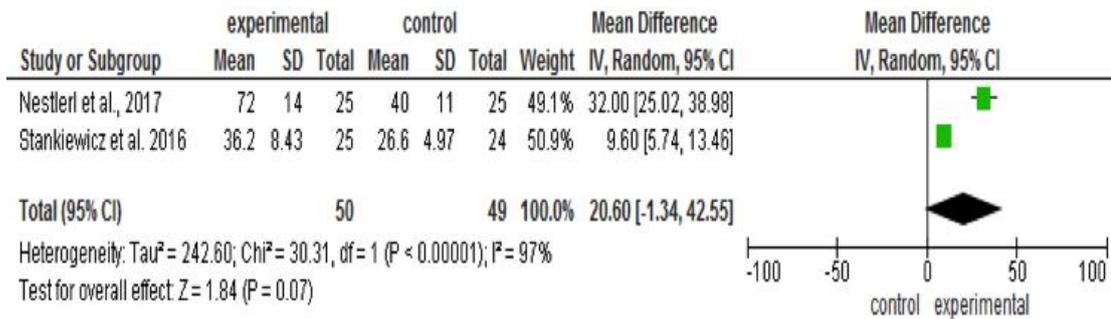Source: Review Manager (RevMan) version 5.3 software.

One study (Nestler et al., 2017) reported the effect of plateau pressure for the PEEP$_{IND}$ group, providing data on 50 patients. The plateau pressure for the PEEP$_{IND}$ group was on average 6.90 cmH$_2$O (CI 95% 4.66 to 9.14) higher than the PEEP$_5$ group which was frequently related by causing pulmonary hyperdistension, especially in the non-dependent lung.

In the study by Stankiewicz-Rudnicki et al. (2016), a reduction in respiratory compliance and increased plateau pressure was observed for the two analyzed groups (PEEP 0 and PEEP 10) at the time of 15 mmHg influx of pneumoperitoneum (T3), and it was reestablished after defibrillation of the pneumoperitoneum with normalization of intra-abdominal pressure.

3.7.2 Respiratory compliance

Two studies (Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016), reported respiratory system compliance prior to extubation with a combined sample of 99 patients. When compared to the control group (control: Compl = 40.0 ml/cmH$_2$O without ARM and Compl = 26.6 ml/cmH$_2$O without ARM, respectively), respiratory system compliance did not present a significant difference, with a mean difference of 20.60 (95% -1.34 to 42.55), as shown in Figure 4. In addition, we observed heterogeneity classified as high in relation to the respiratory compliance variable (P < 0.00001; I^2 = 97%).

Figure 4: Respiratory compliance outcome between the experimental group and the control group.

Source: Review Manager (RevMan) version 5.3 software.

One study (Nestler et al., 2017) reported the effect of respiratory system compliance on the $PEEP_{IND}$ group, providing data on 50 patients. The compliance of the respiratory system for the $PEEP_{IND}$ group was on average 32.00 (CI 95% 25.02 to 38.98) ml cmH$_2$O^{-1} higher than the PEEP$_5$ group at the end of follow-up, and this effect was associated with ARM.

In the study by Stankiewicz-Rudnicki et al. (2016) in obese patients with a PEEP level of 10 cmH$_2$O preceded by ARM, it was shown to improve respiratory compliance well with pulmonary oxygenation, but did not eliminate the appearance of atelectasis induced by general anesthesia.

3.8 GRADE evaluation

According to the GRADE evaluation, the plateau pressure and respiratory system compliance results showed very low quality evidence due to limitations in studies and lack of directionality (Table 2).

Table 2: Quality of evidence using the GRADE approach (plateau pressure versus respiratory compliance). [1] No allocation and blinding of participants, in addition to incomplete data. [2] High heterogeneity. [3] Sample sizes below that expected for the studies.

No of studies	Design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	Recruitment maneuvers (RM) and mechanical ventilation with positive end-expiratory pressure (PEEP)	RM and without PEEP, without RM and with PEEP or without RM and without PEEP	Relative (95% CI)	Absolute	Quality	Importance
Quality assessment						No of patients		Effect				
plateau pressure (assessed with: mechanical ventilator)												
2	randomised trials	serious[1]	serious[2]	serious[2]	serious[3]	none	50/0 (0%)	49/0 (0%)	not pooled	not pooled	⊕○○○ VERY LOW	IMPORTANT
								0%		not pooled		
Respiratory compliance (assessed with: mechanical ventilator)												
2	randomised trials	serious[1]	serious[2]	serious[2]	serious[3]	none	50/0 (0%)	46/0 (0%)	-	-	⊕○○○ VERY LOW	IMPORTANT
								0%		-		

Source: Grading of Recommendations Assessment, Development and Evaluation (GRADE) software.

3.8.1 Plateau Pressure inconsistency

We observed an inconsistency for the plateau pressure variable due to a high heterogeneity with P = 0.0009 and I^2 = 91%, since similarity of the estimates of its effect for the intervention group was presented and there was no overlap of confidence intervals from 4.66 - 9.14 for the study of Nestler et al. (2017), and of 0.36 - 3.84 for the study by Stankiewicz-Rudnicki et al. (2016).

3.8.2 Respiratory Compliance inconsistency

We observed an inconsistency for the respiratory compliance variable due to a high heterogeneity with P <0.00001 and I^2 = 97%, since similarity of the estimates of its effect in the experimental group was presented and there was no overlap between the confidence intervals 25.02 - 38.98 for the study of Nestler et al. (2017) and of 5.74 - 13,46 for the study by Stankiewicz-Rudnicki et al. (2016).

3.8.3 Indirect evidence

For confidence in the effect estimates, meaning the quality of evidence was considered reduced or indirect, since there were no direct comparisons between the interventions, which in fact does not answer our research question. Some reasons led to this conclusion such as: differences in ventilation modes, fixation of the EIT electrode strap in different regions, not all patients were evaluated by EIT, different protocols for ARM, different peak pressure and different PEEP.

3.8.4 Inaccuracy

To determine if the estimation of the quality of the evidence was accurate, the calculation of the optimal size of the information was used. For this, we assume an α value of 0.05 and a β value of 0.2, with a power of 0.80 (https://www.stat.ubc.ca/~rollin/stats/ssize/b2.html) and a total number of events of 76 was established. Therefore, as the sample size for the three studies (Eichler et al., 2017, Nestler et al., 2017, Stankiewicz-Rudnicki et al., 2016) was lower than expected, a classification of inaccuracy would be more appropriate.

4. Discussion

This review identified that ARM followed by mechanical ventilation with PEEP guided by EIT in obese patients submitted to laparoscopic bariatric surgery does not clarify the impact of changes in plateau pressure and respiratory system compliance, and evidences the scarcity of studies with more methodological rigor.

The three included studies showed important limitations and great heterogeneity in a small number of randomized trials such as different alveolar recruitment protocols, mechanical ventilation modes, positive end-expiratory pressure levels, and EIT electrode fixation positions on the patient's chest.

In fact, a gold standard in terms of intraoperative ARM protocol followed by PEEP for obese patients does not exist, although the poor quality found in the studies through GRADE corroborates this statement. However, this is the first systematic review to evaluate ARM followed by mechanical ventilation with PEEP guided by EIT in this population, and there is evidence that PEEP improves intraoperative respiratory function (Karsten et al., 2014, Maracajá-Neto et al., 2009, Meininger et al., 2005), especially when combined with ARM (Karsten et al., 2014, Maisch et al., 2008, Tusman et al., 2004).

In laparoscopic bariatric surgery, PEEP is an easy-to-use intraoperative intervention 9Karsten et al., 2011), and may be associated with ARM (Karsten et al., 2011, Maisch et al., 2008, Tusman et al., 2004). The loss of intraoperative alveolar units is due to the effects caused by general anesthesia and pneumoperitoneum insufflation, decreasing the EELV (Duggan et al., 2005). Similar results were found in the study by Nestler et al. (2017), where anesthetic induction and tracheal intubation in

obese patients with low levels of PEEP (5 cmH$_2$O) resulted in reducing EELV by more than 50% and a deviation of pulmonary ventilation to a non-dependent region. Although using PEEP to prevent alveolar collapse during expiration may be effective, PEEP with low levels may not be sufficient to keep the airways open (Eichler et al., 2017), causing patients to experience hypoxemia during surgery and pulmonary and non-pulmonary complications after surgery (Aldenkortt et al., 2012, Eichler et al., 2017, Reinius et al., 2009, Lellouche et al., 2012).

Intraoperative use of PEEP can be dynamically monitored and quantified through real-time EIT, which enables a refined assessment of atelectasis formation during laparoscopic video surgery (Karsten et al., 2011; Simon et al., 2021). However, little is known through the EIT about the influence of ARM in this population on pulmonary phenomena such as perfusion, aeration and distribution of pulmonary ventilation.

Patients with morbid obesity submitted to general anesthesia have characteristic differences in respiratory mechanics when compared to adults with normal weight (Eichler et al., 2017), which may hamper the mechanical ventilation strategy in this population. ARM with high levels of PEEP may be a very useful intraoperative alternative (Aldenkortt et al., 2012), as it prevents atelectasis, keeps the alveoli open (Stankiewicz-Rudnicki et al., 2016) and delays complications induced by the effect of anestesia.

On the other hand, evidence showed that patients undergoing elective abdominal surgery with high tidal volumes (10 to 12 ml/kg of predicted weight) without PEEP and PEEP between 6-8 cmH$_2$O resulted in an increase in pulmonary and extrapulmonary complications (Futier & Pereira, 1863), and should therefore be avoided (Eichler et al., 2017). Thus, high tidal volumes with insufficient PEEP are harmful and outdated for this population (Eichler et al., 2017), and so it is recommended that ARM in the presence of high levels of PEEP can improve intraoperative oxygenation and respiratory system compliance without adverse hemodynamic effects in obese patients undergoing surgery (Aldenkortt et al., 2012, Stankiewicz-Rudnicki et al., 2016).

Another important and not very established point is the definition of a protocol for ARM which could avoid or minimize all the pulmonary complications expected in the intraoperative period. The three studies presented in this review applied different models for ARM, varying from different inspiratory pressure levels, different strategies to calculate ideal PEEP, and unusual equipment in clinical practice, such as the esophageal balloon. However, the problem in question is not knowing what better equipment to calculate the ideal PEEP, but whether ARM with PEEP guided by EIT is effective in preventing pulmonary complications in obese patients, regardless of protocol.

Given this, Stankiewicz-Rudnicki et al. (2016) found their ARM protocol with PEEP of 10 cmH$_2$O and peak inspiratory pressure (PIP) of 40 cmH$_2$O to be insufficient to prevent atelectasis in the dependent lung regions in obese patients. Similarly, Eichler et al. (2017), after ARM with PEEP between 10 and 20 cmH$_2$O and peak of 50 cmH$_2$O showed no improvement in respiratory system compliance and no improvement in postoperative oxygenation. Otherwise, the results presented by Nestles et al. (2017), where MRA with PEEP$_{IND}$ was able to restore EELV, improve oxygenation, prevent atelectasis in dependent lung areas, and redistribute pulmonary ventilation to similar levels to pre-intubation and maintain them during the entire surgery. In this study, ARM was achieved with a peak of 50 cmH$_2$O and PEEP of 30 cmH$_2$O, being adjusted to 26 cmH$_2$O and gradually reduced by 2 cmH$_2$O.

From a practical point of view, it would be expected that the ideal PEEP preceded by ARM guided by EIT during the intraoperative period would result in preventing atelectasis formation, leading to an improvement in oxygenation and respiratory mechanics. However, what has been observed is a very low effect to improve clinical outcomes and care to obese patients. Therefore, it seems that ARM with variations in Peak between 40 and 50 cmH$_2$O and PEEP between 10 and 20 cmH$_2$O has no potential effect for the prevention of pulmonary complications in obese patients.

Another relevant aspect that has been evidenced is the formation of atelectasis and distribution of pulmonary ventilation through the effects caused by pneumoperitoneum (He et al., 2016, Bordes et al., 2015), which is in accordance with the results in the study by Eichler et al. (2017). The authors found a reduction in respiratory system compliance, reduction in oxygenation, and atelectasis during insufflation, and pneumoperitoneum between 16 and 18 cmH$_2$O with PEEP of 10 cmH$_2$O. However, the authors also showed an improvement in compliance and oxygenation after an increase in PEEP between 20 and 25 cmH$_2$O during the pneumoperitoneum period, with higher intra-abdominal pressures (2017). In addition, in the study by Stankiewicz-Rudnicki et al. (2016), the distribution of pulmonary ventilation did not change with pneumoperitoneum insufflation of 15 mmHg; on the contrary, this suggests a more homogeneous distribution by investigating the EIT.

5. Conclusion

According to the randomized clinical trials in the literature, low evidence was found that obese patients undergoing laparoscopic bariatric surgery under ARM with PEEP guided by EIT did not achieve improvement in regional intraoperative pulmonary ventilation. In addition, these findings are based on limited randomized trials in quantity and quality, thus requiring more adequate studies with a larger sample size and more rigorous control of bias risk. A consensus is needed on how to analyze the EIT data in obese patients submitted to laparoscopic bariatric surgery and how to present its efficacy or damage. More adequate future randomized clinical trials with larger sample sizes and tighter control for bias are needed.

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