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REVIEW

Intraoperative individualization of positive-end-expiratory pressure through electrical impedance tomography or esophageal pressure assessment: a systematic review and meta-analysis of randomized controlled trials

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Abstract

Purpose This systematic review of randomized-controlled trials (RCTs) with meta-analyses aimed to compare the effects on intraoperative arterial oxygen tension to inspired oxygen fraction ratio (PaO_2/FiO_2), exerted by positive end-expiratory pressure (PEEP) individualized trough electrical impedance tomography (EIT) or esophageal pressure (Pes) assessment (intervention) vs. PEEP not tailored on EIT or Pes (control), in patients undergoing abdominal or pelvic surgery with an open or laparoscopic/robotic approach.

Methods PUBMED®, EMBASE®, and Cochrane Controlled Clinical trials register were searched for observational studies and RCTs from inception to the end of August 2022. Inclusion criteria were: RCTs comparing PEEP titrated on EIT/Pes assessment vs. PEEP not individualized on EIT/Pes and reporting intraoperative PaO_2/FiO_2. Two authors independently extracted data from the enrolled investigations. Data are reported as mean difference and 95% confidence interval (CI).

Results Six RCTs were included for a total of 240 patients undergoing general anesthesia for surgery, of whom 117 subjects in the intervention group and 123 subjects in the control group. The intraoperative mean PaO_2/FiO_2 was 69.6 (95%CI 32.-106.4) mmHg higher in the intervention group as compared with the control group with 81.4% between-study heterogeneity ($p < 0.01$). However, at meta-regression, the between-study heterogeneity diminished to 44.96% when data were moderated for body mass index (estimate 3.45, 95%CI 0.78–6.11, $p = 0.011$).

Conclusions In patients undergoing abdominal or pelvic surgery with an open or laparoscopic/robotic approach, PEEP personalized by EIT or Pes allowed the achievement of a better intraoperative oxygenation compared to PEEP not individualized through EIT or Pes.

Prospero registration number CRD 42021218306, 30/01/2023

Keywords Intraoperative oxygenation · Esophageal pressure · Electrical impedance tomography · Intraoperative mechanical ventilation · Pulmonary complications

List of abbreviations

ABGs	Arterial blood gases
ARDS	Acute respiratory distress syndrome
CI	Confidence interval
EIT	Electrical impedance tomography
FiO2	Inspiratory oxygen fraction
IMV	Invasive mechanical ventilation
PaO2/FiO2	Partial arterial oxygen tension on inspired oxygen fraction

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PaO2	Arterial oxygen tension
PEEP	Positive end-expiratory pressure
Pes	Esophageal pressure
RCTs	Randomized controlled trials

1 Introduction

The achievement of lung-protection in delivering invasive mechanical ventilation (IMV) is a cornerstone for the prevention of postoperative pulmonary complications in patients undergoing general anesthesia for surgery [1, 2]. In particular, high driving pressure is associated with an increased incidence of postoperative pulmonary complications [3]. In keeping with the findings from a large prospective observational study [4], the combination of high tidal volume and low positive end-expiratory pressure (PEEP) in mechanically ventilated patients undergoing surgery is an independent risk factor for postoperative pulmonary complications. However, whereas there is widespread agreement on the need to avoid high driving pressure and tidal volume, the strategy for optimizing PEEP during general anesthesia for surgery is still under debate. According to recent findings [5], titrating PEEP on the basis of maximal compliance-minimal driving pressure is effective in ameliorating the intraoperative oxygenation and reducing the incidence of postoperative pulmonary complications compared to a fixed PEEP. However, despite these encouraging results in favor of PEEP chosen on the best respiratory system compliance-driving pressure compromise, it is worth to consider the drawbacks of setting PEEP using maximal compliance-minimal driving pressure method. In fact, the aforementioned practice is based on the assumption of a proportionality between aerated lung volume and compliance of the respiratory system. Also, the maximization of compliance and minimization of driving pressure do not take into account of the tidal recruitment phenomenon, characterized by the cyclic opening and closing of the alveoli units during respiratory phases [6]. Finally, this approach of PEEP titration is strictly dependent on mechanical ventilator regulations, such as tidal volume [7]. All these factors contribute to elucidate the mismatch between alveolar recruitment and reduced respiratory system compliance-increased driving pressure observed in conventional and non-conventional acute respiratory distress syndrome (ARDS) [6–8]. Thus, we hypothesized that different methods for setting PEEP in mechanically ventilated patients under surgery might be used to preserve intraoperative oxygenation and, possibly, reduce postoperative pulmonary complications incidence.

In recent years, several investigations, aimed at assessing the impact of mechanical ventilation driven by advanced respiratory monitoring tools, i.e., electrical impedance tomography (EIT) and esophageal pressure (Pes) assessment, on intraoperative oxygenation and postoperative pulmonary complications, have been conducted [9–14].

EIT allows the assessment of the tidal modifications of lung impedance as well as the changes of end-expiratory lung impedance in response to mechanical ventilation. Accordingly, EIT permits the evaluation of the homogeneity of ventilation distribution along with the identification the lung zones at risk for overdistention and collapse [15]. In invasively ventilated ARDS patients, several strategies for PEEP titration have been proposed with the aim of simultaneously minimizing the collapse and overdistention of the lung [16], stabilizing the end-expiratory lung impedance [17], and reducing global inhomogeneity of ventilation [18].

Pes assessment allows the evaluation of transpulmonary pressure, namely, the actual pressure distending the lung [19–21] and the partitioning of the total pressure applied to respiratory system into lung and chest wall portion [22]. In ARDS patients subjected to IMV, setting PEEP to render an end-expiratory transpulmonary pressure ≥ 0 cmH_2O has proven to ameliorate oxygenation [23] without a final improvement of mortality [24].

2 Methods

The present systematic review and meta-analysis was carried out in line with the Preferred Reporting Items for Systematic reviews and Meta-analysis (PRISMA) guidelines [25] and was registered on PROSPERO (CRD 42,021,218,306) on 13/01/2021 and finally recorded on 30/01/2023 after revision and modification.

The aim of the present study was to compare the effects of tailoring PEEP on the basis of EIT or Pes assessment vs. PEEP not individualized through EIT or Pes on intraoperative oxygenation (primary objective), as assessed by arterial oxygen tension on inspired oxygen fraction ratio (PaO2/FiO2), and pulmonary complications (secondary objective).

2.1 PICO (patients, intervention, comparator, outcome) questions

We sought information about the intraoperative application of EIT or Pes assessment for PEEP individualization (I) in adult patients subjected to IMV and general anesthesia for surgery (P) with comparator, namely, non-individualized PEEP through EIT or Pes, (C) and aimed to ascertain the impact on intraoperative oxygenation, as assessed by PaO_2/FiO_2 (O).

2.2 Search strategy and study selection

PUBMED®, EMBASE® and the Cochrane Controlled Clinical trials register were searched from inception to August 2022 for observational studies and randomized-controlled trials without language restrictions. The search was conducted by inserting the following terms, combined each other according to database syntax (Additional file 1): "laparoscopy", "robotic", "pneumoperitoneum", "open surgery", "abdominal", "pelvic", "elective", "positive end-expiratory pressure", "PEEP", "mechanical ventilation", "positive end expiratory pressure".

In addition, we reviewed the references of the selected papers, review articles, commentaries, and editorials on the same topic to find out other studies of interest missed during the primary search..

The titles and abstracts of the investigations retrieved from the search were independently evaluated by two authors (TE and MF) according to the following inclusion criteria: (1) randomized clinical trials regardless of sample size enrolling adult patients undergoing elective abdominal and/or pelvic surgery, (2) comparing titration of PEEP on the basis of EIT or Pes assessment vs. PEEP not individualized on EIT or Pes evaluation, and (3) reporting the intraoperative PaO_2/FiO_2. In case of potentially overlapping cohorts from multiple publications of the same research group/centre, the most recent publication was selected. The same authors separately evaluated the full-texts, and any disagreement was resolved by discussion or involving a senior review author (GC). When needed, the corresponding authors of the selected studies were contacted to obtain essential information not available in the published format.

2.3 Data extraction, study quality, and bias assessment

Once studies screening and selection were completed, two authors (TE and MF) independently extracted data from the screened investigations. Also in this case, any disagreement was resolved by discussion or involving a senior review author (GC). Extracted data included: investigation features (e.g., study design, setting), demographic characteristics (e.g., age, sex, body mass index), arterial blood gas exchange (e.g., PaO_2, arterial carbon dioxide tension, pH, serum lactate concentration), respiratory system mechanics and ventilator settings (tidal volume, respiratory rate, PEEP administrated, peak of inspiratory pressure, plateau inspiratory pressure, total PEEP, driving pressure, dynamic and static compliance, fraction of inspired oxygen), intraoperative pulmonary complications and hemodynamic status as well as pulmonary complications. For intraoperative pulmonary complications we intended desaturation (defined as peripheral oxygen saturation < 90%) and hypercapnia (defined as partial pressure of carbon dioxide > 6.7 kPa). For postoperative pulmonary complications (occurring till 28 days after surgery or hospital discharge) we intended desaturation (defined as oxygen saturation < 90% requiring oxygen), hypercapnia (defined as an end-tidal partial pressure of carbon dioxide > 6.7 kPa), atelectasis (radiological and/or ultrasonographic evidence of lung collapse), pneumonia (radiological and/or ultrasonographic evidence of lung consolidation and clinical symptoms), and pneumothorax (radiological and/or ultrasonographic evidence of pneumothorax with or without clinical symptoms).

The selected articles were evaluated for methodological quality using the Cochrane Collaboration's Risk of Bias tool (RoB-2 version 2019) [26], which provides specific criteria for appraisal of risk of bias according to the following domains: (1) risk of bias arising from the randomization process; (2) risk of bias due to deviations from the intended interventions; (3) risk of bias due to missing outcome data; (4) risk of bias in measurement of the outcome and (5) risk of bias in selection of the reported result. The overall risk-of-bias judgment was finally provided, according to the five domains of bias assessment as "low risk", "some concerns" or "high risk". Also, the certainty was evaluated through Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach regarding intraoperative oxygenation (primary outcome) and pulmonary complications (secondary outcome) by GRADEpro GDT software (McMaster University and Evidence Prime Inc.) [27]. The following criteria were taken into account with GRADE assessment: study risk of bias (methodological quality), inconsistency of results (unexplained heterogeneity), indirectness of evidence (population, intervention, comparator, or outcome), imprecision of results (wide confidence intervals), and publication bias. Accordingly, the certainty of the evidence for each outcome was categorized as 'high', 'moderate', 'low', or 'very low' [27].

2.4 Statistical analysis

The analysis was conducted on the data retrieved from peer-reviewed manuscripts. A descriptive analysis of all the selected variables considered in the included studies was performed. Continuous or non-continuous variables were reported as appropriate. Trials were stratified into two subgroups according to the individualization or not of PEEP based on EIT and Pes assessment. For those trials having more than two subgroups, the overall population was sorted in order to obtain two final subgroups. A random effect meta-analysis based on Der Simonian-Laird method was estimated on mean difference for the continuous endpoint and risk ratio for a binary outcome with a restricted maximum

likelihood estimator for the heterogeneity component. The zero count events, for the binary endpoint analysis, were handled in the estimation procedure according to Hybrid estimator method [28]. Other approaches are reported in Additional file 2.

The contour-enhanced funnel plot for the publication bias assessment were reported with 90%, 95%, and 99% confidence bounds (Additional file 2).

The heterogeneity statistics have been reported as I^2. The point estimate I^2 should be interpreted cautiously when a meta-analysis has few studies (< 7 investigations); for this reason, 95% confidence intervals supplement the I^2 point estimate. A 75% I^2 indicates a medium heterogeneity level [29].

Univariable meta-regression estimates was also reported with a 95% confidence interval estimation to assess the impact on body mass index, gender, and comorbidities on PaO_2/FiO_2 and pulmonary complications.

Analysis has been performed with R 3.4.2 and meta package.

3 Results

The search identified a total of 7765 potentially eligible records, as depicted in Fig. 1. After excluding duplicates and screening titles and abstracts, full texts were evaluated (Additional file 3) and 6 eligible randomized-controlled trials [9–14] were identified, for a total of 240 patients undergoing IMV for surgery, of whom 117 subjects received non-individualized PEEP and 123 subjects received individualized PEEP.

3.1 Characteristics of the included studies

Additional file 4 describes the main characteristics of the selected studies. As depicted in Fig. 2, the enrolled investigations presented a high risk of bias overall at the methodological quality assessment. The certainty obtained at GRADE rating in support of intraoperative individualization of PEEP for oxygenation and pulmonary complications were moderate (Table 1).

Among the enrolled studies, 1 trial (16.7%) was conducted also in open abdominal surgery and 4 trials (66.7%) individualized PEEP through EIT assessment.

3.2 Patient characteristics

The patients' demographic characteristics, namely, gender distribution, age, body mass index anesthesiologic risk assessment, anesthesia type and duration, surgery duration and comorbidities are reported in Additional file 5. The age ranged from an average value of 41.0 to 62.8 years in the arm with PEEP individualized via EIT and Pes and from

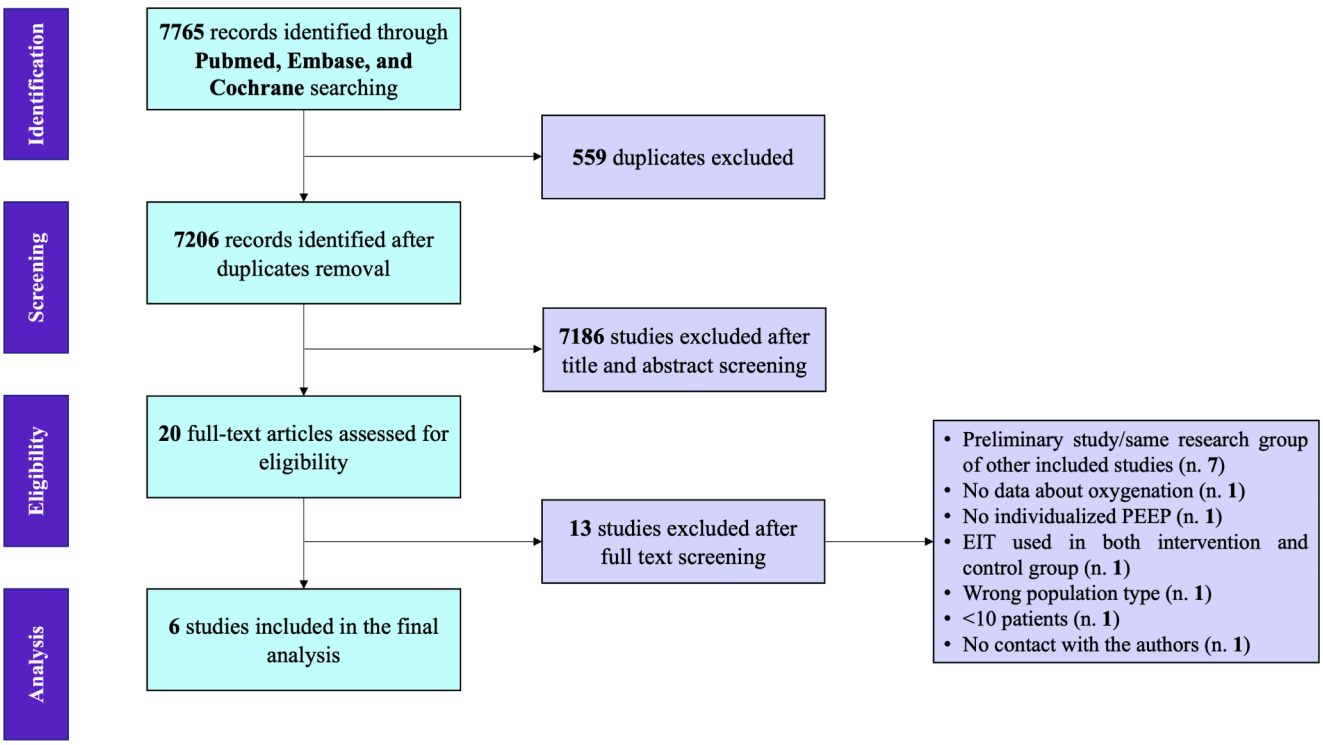

Fig. 1 Enrollment flow diagram
PEEP, positive end-expiratory pressure; EIT, electrical impedance tomography

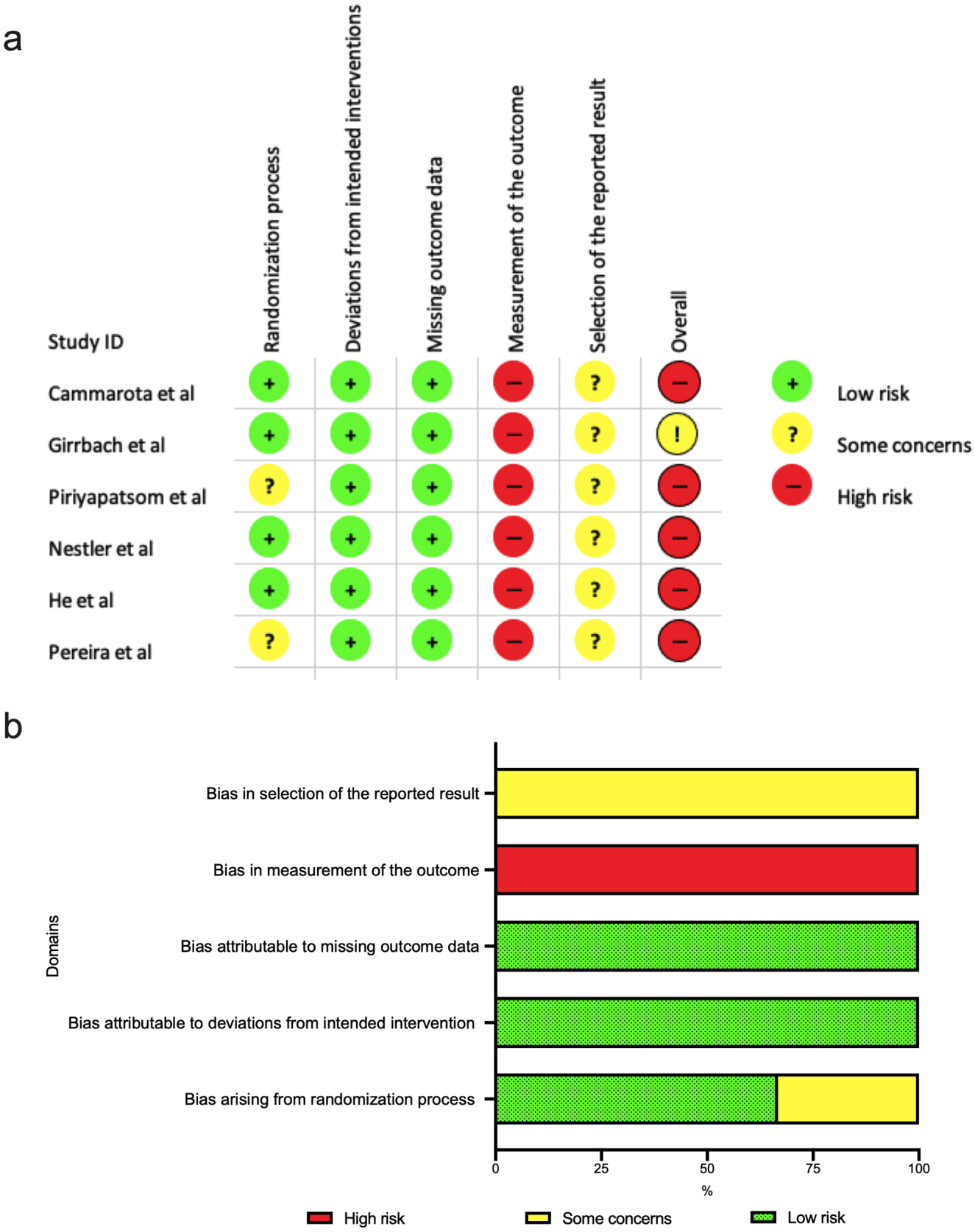

Fig. 2 Cochrane risk-of-bias (RoB 2.0) assessment tool

Table 1 Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach for intraoperative individualization of positive end-expiratory pressure

Certainty assessment								№ of patients		Effect		Certainty	Importance
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations		[Individualized PEEP]	[non-individualized PEEP]	Relative (95% CI)	Absolute (95% CI)		
Intraoperative Oxygenation (assessed as PaO_2/FiO_2 mean difference)													
6	Randomised trials	Serious[a]	Not serious	Not serious	Not serious	None		117	123		MD **69.6 mmHg higher** (32.8 higher to 106.4 higher)	⨁⨁⨁◯ Moderate	
Pulmonary complications													
4	Randomised trials	Serious[a]	Not serious	Not serious	Not serious	None		8/80 (10.0%)	10/86 (11.6%)	**RR 0.94** (0.37 to 2.42)	**7 fewer per 1.000** (from 73 fewer to 165 more)	⨁⨁⨁◯ Moderate	
									0.0%		**0 fewer per 1.000** (from 0 fewer to 0 fewer)		

PEEP, positive end-expiratory pressure; CI, confidence interval; MD, mean difference; RR, risk ratio; PaO_2/FiO_2, arterial oxygen tension to inspired oxygen fraction ratio

Explanations

a. The outcome assessors were aware of the intervention received by study participants in the major part of the enrolled investigations

41.3 to 64.2 years in the arm where PEEP was not individualized by EIT and Pes, respectively. Body mass index varied from a mean value of 22.7 to 48.3 kg/m^2 in the group where PEEP was individualized through EIT and Pes, while it ranged from a mean value of 23.9 to 53.2 kg/m^2 in the group with PEEP not individualized by EIT and Pes, respectively.

The mechanical ventilation settings and respiratory mechanics parameters, before randomization, after randomization, and at the end of surgery prior to extubation are reported in additional file 6 for overall study population. After randomization, intraoperative PEEP individualized through EIT and Pes ranged from a mean value of 8 to 18.5 cmH_2O, whereas PEEP not tailored by EIT and Pes varied from a mean value of 4 to 10 cmH_2O. After randomization and PEEP application, when reported, mean value of respiratory system compliance varied from 34.1 to 61.0 ml/cmH_2O in the interventional group and from 27.6 to 32.9 ml/cmH_2O in the control group.

3.3 Oxygenation and clinical outcomes

In additional file 7, arterial blood gas analyses obtained at baseline, before randomization, after randomization, and at the end of surgery before extubation, were described. The intraoperative mean difference in PaO_2/FiO_2 obtained after randomization between the group of patients with PEEP individualized through EIT and Pes and the group of patients without PEEP titration by EIT and Pes is depicted in Fig. 3. The mean difference in PaO_2/FiO_2 was in favor of the patients arm where PEEP was individualized through EIT and Pes with respect to the subjects group receiving non-individualized PEEP by EIT and Pes, with a 81.4% between-study heterogeneity ($p < 0.01$). However, at meta-regression, the between-study heterogeneity diminished to 44.96% when data were moderated for body mass index (estimate 2.25, 95%CI 0.01–4.49, $p = 0.049$). In Fig. 4, the pooled intraoperative mean difference in PaO2/FiO2 obtained after randomization between the group of patients with PEEP individualized through EIT and Pes and the group of patients without PEEP titration by EIT and Pes is depicted, following the elimination of He et al. study [13] due to similar PEEP levels in experimental and control arm. Also in this case, the pooled intraoperative mean difference in PaO_2/FiO_2 confirmed to be in favor of the patients' group where PEEP was individualized through EIT and Pes with respect to the subjects group receiving non-individualized PEEP by EIT and Pes, with a 41.2% between-study heterogeneity ($p = 0.15$). At meta-regression, after that data were moderated for body mass index, the between-study heterogeneity diminished to 34.8% (estimate 2.61, 95%CI 0.26–4.96, $p = 0.035$). A subgroup analysis forest plot for intraoperative oxygenation mean difference among

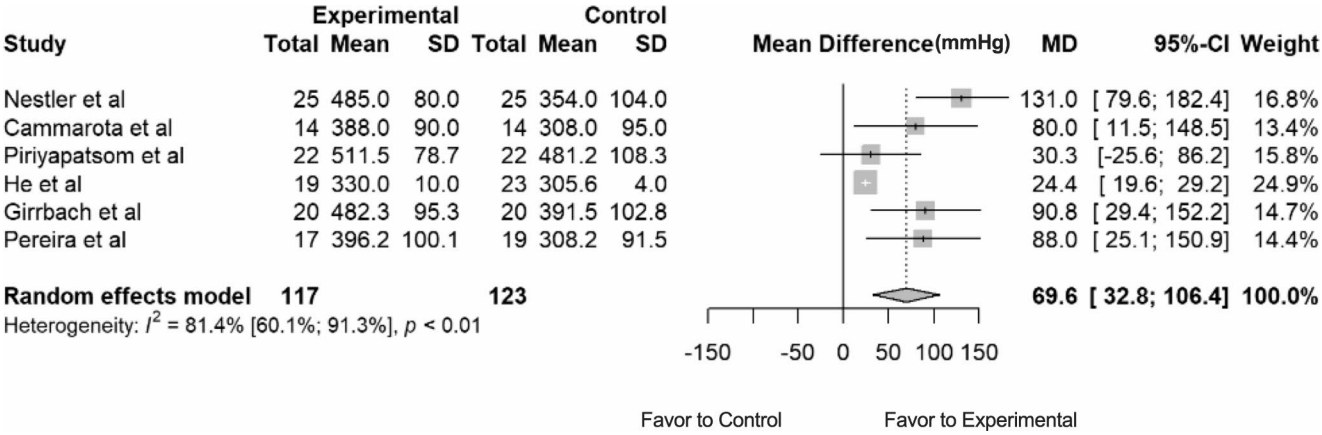

Fig. 3 Forest plot for intraoperative oxygenation after randomization in patients subjected to surgery

The vertical dotted line refers to the mean difference (mmHg) in intraoperative PaO_2/FiO_2 among patients receiving PEEP individualized through EIT or Pes vs. PEEP not individualized through EIT or Pes. Gray squares indicate the individual study mean differences whereas the black horizontal lines indicate the 95% confidence interval of single studies. The diamond refers to the to the overall mean difference (mmHg) with 95% confidence interval

PaO_2/FiO_2, arterial oxygen tension to inspired oxygen fraction; PEEP, pressure positive end-expiratory pressure; EIT, electrical impedance tomography; Pes, esophageal pressure, I^2, heterogeneity, MD, mean difference; SD, standard deviation

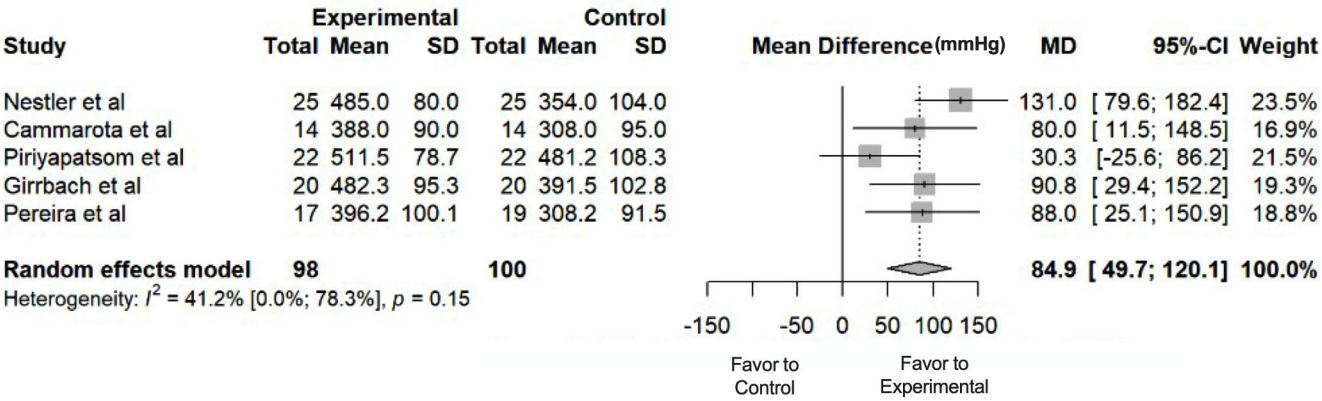

Fig. 4 Sensitivity analysis forest plot for intraoperative oxygenation for the two strategies of pressure positive end-expiratory pressure titration in patients subjected to surgery without He et al. study

The vertical dotted line refers to the mean difference (mmHg) in intraoperative PaO_2/FiO_2 among patients receiving PEEP individualized through EIT or Pes vs. PEEP not individualized through EIT or Pes. Gray squares indicate the individual study mean differences whereas the black horizontal lines indicate the 95% confidence interval of single studies. The diamond refers to the to the overall mean difference (mmHg) with 95% confidence interval

PaO_2/FiO_2, arterial oxygen tension to inspired oxygen fraction; PEEP, pressure positive end-expiratory pressure; EIT, electrical impedance tomography; Pes, esophageal pressure; I^2, heterogeneity; SD, standard deviation

experimental and control groups is represented for EIT and Pes in Fig. 5. With EIT, intraoperative oxygenation mean difference was of 107 [73.6;140.4] mmHg vs. 51 [3.0-99.1] mmHg obtained individualizing PEEP by Pes. At meta-regression, body mass index showed an estimate of 2.61 (95%CI 0.26–4.96, p = 0.03).

The pooled risk ratio for respiratory complications occurring in the time lapse between intraoperative period (day of surgery, day 0) and day 28 after surgery or day of hospital discharge for patients with individualized PEEP through EIT and Pes and patients with non-individualized PEEP by EIT and Pes is represented in additional file 2, Fig. 2. Respiratory complications risk ratio was neither in favor of PEEP individualized by EIT and Pes nor in favor of PEEP not individualized through EIT and Pes. Similar findings have been evidenced between the Hybrid adjustment method for zero count (additional file 2, Fig. 2) and the other approaches (additional file 2, Fig. 4), also with the elimination of He et al. study (additional file 2, Fig. 5).

The intraoperative hemodynamic complications with corrective therapies administration rates as well as pulmonary complication are described in Additional file 8.

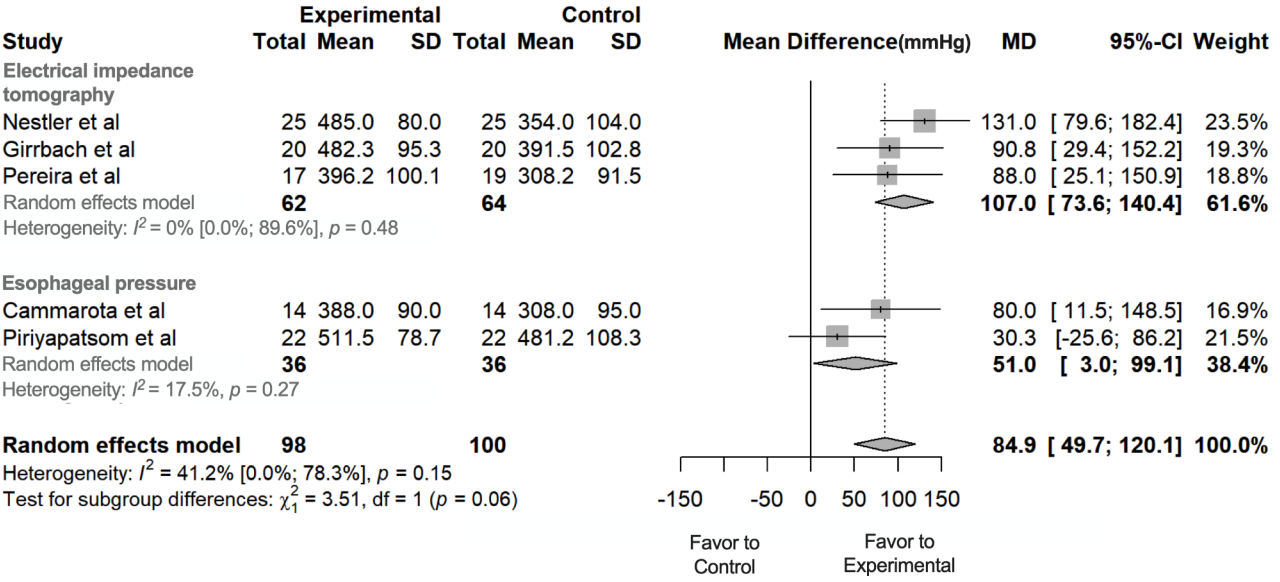

Fig. 5 Subgroup analysis forest plot for intraoperative oxygenation for the two strategies of pressure positive end-expiratory pressure titration in patients subjected to surgery

The vertical dotted line refers to the mean difference (mmHg) in intraoperative PaO_2/FiO_2 among patients receiving PEEP individualized through EIT or Pes vs. PEEP not individualized through EIT or Pes. Gray squares indicate the individual study mean differences whereas the black horizontal lines indicate the 95% confidence interval of single studies. The diamond refers to the to the overall mean difference (mmHg) with 95% confidence interval

PaO_2/FiO_2, arterial oxygen tension to inspired oxygen fraction; PEEP, pressure positive end-expiratory pressure; I^2, heterogeneity; SD, standard deviation; χ_1^2, subgroup difference

4 Discussion

In patients receiving IMV for abdominal or pelvic surgery, principally in laparoscopic or robotic technique, the application of a strategy tailoring PEEP on the basis of EIT or Pes assessment allowed to achieve a higher oxygenation compared to a ventilation strategy with non-individualized PEEP by EIT or Pes. Despite this, the individualization of PEEP through EIT or Pes did not reduce the occurrence of pulmonary complications compared to PEEP not tailored on EIT or Pes evaluation.

Advanced respiratory monitoring tools such as EIT and Pes are used to manage mechanical ventilation in patients suffering for acute respiratory failure and ARDS [15]. EIT and Pes assessment have also been employed in patients under general anesthesia to properly set the mechanical ventilation to assure lung protection and/or improve intraoperative oxygenation [30, 31]. In our surgical setting, EIT or Pes assessment were specifically adopted to individualize PEEP against the mechanical changes mainly induced by pneumoperitoneum, with or without Trendelenburg. PEEP individualized on the basis of EIT assessment was set as the best mechanical compromise at which both lung collapse and hyperdistention were minimized [12] or the PEEP valued able to assure the lowest regional ventilation delay [10, 13, 14]. On the other side, when Pes assessment was employed, the individualization of PEEP was obtained choosing a the PEEP value able to assure a mean end-expiratory transpulmonary pressure ≥ 0 cmH_2O [9, 11]. In the light of the previous considerations, the individualized PEEP via EIT and Pes ranged between a mean value of 8 cmH_2O and 19 cmH_2O in our setting, whereas the individualized PEEP set by combining maximal compliance to minimal driving pressure was between a mean value of 8 cmH_2O and14 cmH_2O, as elsewhere reported [5]. As a final consequence, in our context, individualizing PEEP by EIT and Pes yielded a mean intraoperative difference in PaO_2/FiO_2 of 69 mmHg with respect to PEEP not individualized by EIT or Pes, that reached 85 mmHg with the elimination of He et al. investigation due to similar PEEP values among study groups. Conversely, tailoring PEEP on the maximal respiratory system compliance and minimal driving pressure led to a mean intraoperative difference in PaO_2/FiO_2 of 21 mmHg compared to a fixed PEEP strategy [5]. Noteworthy, in contrast to our dataset obtained mainly in robotic/laparoscopic abdominal or pelvic surgery, data from PEEP individualized on compliance and driving pressure were acquired in both open and robotic/laparoscopic surgery [5]. Also, in that setting [5], PaO_2/FiO_2 assessment was a carried out at different time points from PEEP application compared to our context.

Interestingly, in our setting, the mean difference in intraoperative PaO_2/FiO_2 was magnified at increasing of body mass index, suggesting the necessity of application of

advanced respiratory monitoring in setting mechanical ventilation for obese patients.

In our population, it is worth to point out that, despite the increased body mass index, the individualization of PEEP by EIT allowed a higher pooled intraoperative PaO2/FiO2 difference among study arms compared to Pes assessment. EIT allows a wider assessment of ventilation distribution in real time across the ventral-to-dorsal axis. Also, the esophageal balloon calibration, an ad hoc procedure to avoid artifacts deriving from device and esophageal wall reaction [21, 32], was partially performed in the investigations titrating PEEP on Pes assessment. Indeed, conversely to Cammarota et al. [9], in Piyriapatsom et al. investigation [11], esophageal balloon calibration was not carried out, and Pes was overestimated. This could have led to the application of higher PEEP levels in Piyriapatsom et al. setting [11] study with respect to Cammarota et al. [9], with a possible detrimental effect on oxygenation.

We did not observe any modification of the risk ratio for pulmonary complications incidence, when PEEP was individualized according to EIT or Pes compared to non-individualized PEEP strategy by EIT or Pes. This data was in contrast to the reduction of postoperative pulmonary complications previously observed with the individualization of PEEP by maximizing the respiratory system compliance and minimizing respiratory system driving pressure [5]. In this perspective, in interpreting our data, it is worth considering that most of the enrolled investigations defined different times of observation of pulmonary complications occurrence compared to previous investigation [5]. Also, in our context, the major part of the enrolled trials (85.7%) were sized to evaluate the effects exerted by individualized PEEP on oxygenation and not on postoperative pulmonary complications incidence.

As a clinical implication, also in considerations of the findings obtained from previous clinical trials and meta-analysis which did not observe any difference in postoperative pulmonary complications incidence [33–36] by comparing high PEEP of 12 cmH_2O against a low PEEP of 2–5 cmH_2O, the individualization of intraoperative PEEP through EIT and Pes could find its application in obese patients undergoing laparoscopic/robotic surgery. Notwithstanding, due the numerous skills required in handling with EIT and Pes assessment and the additional equipment necessary for the application these techniques, the wide diffusion of these advanced respiratory monitoring tools could be limited. With particular regard to Pes evaluation, indeed, several factors depending on patient's characteristics and esophageal balloon could affect the reliability of Pes measurements [15, 37].

Our study has several limitations that require to be mentioned. Despite the wide search conducted, the final patients population obtained by enrolled investigations was relatively small. The study quality was affected by a high risk of bias, probably due to the high between-study heterogeneity of the enrolled population. Indeed, eliminating He et al. investigation [13] due to similar PEEP value among the study groups and moderating data by body mass index at meta-regression, the between-study heterogeneity improved considerably. Also, the high risk of bias relied on the fact that the enrolled studies were not blindly conducted because the outcome assessors were aware of the intervention received by study participants. However, at GRADE rating, our findings reached a moderate level of certainty. In our setting, end-expiratory transpulmonary pressure, calculated according to direct method, was used for the assessment of the dorsal lung collapse, as previously described [38]. Nonetheless, despite Pes has been widely employed to drive IMV in critical care and anesthesia setting [9, 11, 23, 24, 39, 40] for the purpose of recruiting the dependent lung atelectasis, the validity of the end-expiratory transpulmonary pressure as an indicator of the lung collapse remains a subject of ongoing debate [41], mainly when elevated PEEP is adopted [38]. In interpreting our data, it is worth to consider that the definitions and the time of occurrence of the pulmonary complications were taken from the studies enrolled. Thus, different results might be obtained with different clinical and temporal definition of respiratory complications. In addition, the limited sample size and low event incidence precludes conclusions drawn with regard to postoperative pulmonary complications, warranting further studies.

In conclusion, a ventilatory strategy individualizing PEEP on EIT and Pes assessment allows to achieve a better intraoperative oxygenation compared to PEEP non individualized through EIT and Pes in patients undergoing abdominal or pelvic surgery, principally carried out through laparoscopic/robotic approach. This effect seems particularly magnified in obese patients undergoing this type of surgery.

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Author contributions GC, TE, MF, and RS: conception and design of the work. GC, TE, and MF acquisition and analysis of the data for the work. GC and DA: statistical analysis. GC, PN, RS, AP, MRT, HW, PS, FDC, AM, LV, and EDR: interpretation of the data for the work. TE, MF, EB, SMM, DP, RS, and GC draft writing. All authors reviewed the manuscript.

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Data Availability Not applicable.

Declarations

Conflicts of interest No conflict of interest for TE, MF, GM, PC, CT, DA, HW, LV, EB, FDC, AP, PS, MRT, HW, and RS. GC reports speaking honoraria from Getinge and MSD outside the submitted work. RV declares honoraria for lecture from Intersurgical S.p.A. outside the submitted work. SMM disclose having received speaking fees by GE Healthcare, Masimo, and Aspen outside the present work. PN declares to have received: grants, personal fees and non-financial support from Maquet Critical Care; grants and non-financial support from Draeger and Intersurgical S.p.A; and personal fees from Oriopharma, Philips, Resmed, MSD, and Novartis, in each case for reasons that remain unrelated to the submitted work. PN also contributed to the development of the patented 'helmet Next', the royalties for which are paid to Intersurgical Spa. PN contributed to the development of a device not discussed in the present study with patent application number: EP20170199831. EDR received conference fees from MSD, Getinge, and Baxter outside the submitted work.No conflict of interest must be declared by the remaining authors.

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

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