Intraoperative mechanical ventilation strategies for obese patients: a systematic review and network meta-analysis

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Summary
Several intraoperative ventilation strategies are available for obese patients. However, the same ventilation interventions have exhibited different effects on PaO2/FIO2 concerning obese patients in different trials, and the issue remains controversial. Therefore, we conducted a network meta-analysis to identify the optimal mechanical ventilation strategy. We searched the Cochrane Central Register of Controlled Trials (CENTRAL) in the Cochrane Library, Embase, MEDLINE, CINAHL and Web of Science for studies published up to June 2014, and the PaO2/FIO2 in obese patients given different mechanical ventilation strategies was assessed. We assessed the studies for eligibility and extracted data and then pooled the data and used a Bayesian fixed-effect model to combine direct comparisons with indirect evidence. Eligible studies evaluated different ventilation strategies for obese patients and reported the intraoperative PaO2/FIO2 ratio, atelectasis and pulmonary compliance. Thirteen randomized controlled trials were included for network meta-analysis, including 476 patients who received 1 of 12 ventilation strategies. Volume-controlled ventilation with higher PEEP plus single recruitment manoeuvres (VCV + higher PEEP + single RM) was associated with the highest PaO2/FIO2 ratio, improving intraoperative pulmonary compliance and reducing the incidence of intraoperative atelectasis.

Keywords: Intraoperative ventilation strategies, network meta-analysis, obese, PaO2/FIO2 ratio.
evaluation of ventilation strategies such as pressure-controlled ventilation (PCV), volume-controlled ventilation (VCV), positive expiratory end pressure (PEEP) and PEEP plus recruitment manoeuvres (RM) using traditional pairwise meta-analysis. Their conclusions were as follows: (i) PEEP plus RM can increase the intraoperative oxygenation and lung compliance of obese patients and (ii) there was no significant difference between PCV and VCV in terms of improving intraoperative oxygenation. However, traditional pairwise meta-analysis does not classify the magnitude of the PEEP and RM method; thus, the grouping is approximate because the PEEP magnitude and RM method may both vary. It has been reported that in terms of improving the oxygenation in obese patients undergoing surgery, using 10 cmH2O PEEP was better than using 5 cmH2O PEEP (6), and using single RM was better than using single-progressive RM (7); moreover, there are many other types of intraoperative ventilation strategies for obese patients, such as VCV + PEEP and VCV + PEEP + single RM. Based on the earlier two points, the results obtained from the traditional pairwise meta-analysis have significant limitations. Network meta-analysis permits evaluating the comparative effectiveness of multiple interventions, even when some pairs may not have been directly compared, and has the potential to reduce the uncertainty in treatment effect estimates (8,9). Based on the advantages of network meta-analysis, the parameters of various intraoperative ventilation strategies for obese patients were refined in this study; subsequently, the effectiveness and safety of various intraoperative ventilation strategies were compared to identify an optimal ventilation strategy for obese patients.

Materials and methods

We conducted our systematic review in accordance with the methods recommended by the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines (10).

Literature search

Relevant trials were identified via electronic and manual searches. We searched the Cochrane Central Register of Controlled Trials (CENTRAL) in the Cochrane Library, Embase, MEDLINE, CINAHL and Web of Science using a combination of MeSH and text words (Appendix 1). We did not restrict our search by language or year of publication. The final search update was performed in June 2014. We reviewed the reference lists of the published meta-analyses. In addition, we manually searched the Index Medicus for randomized controlled trials (RCTs), meta-analyses and systematic reviews to add studies that the initial electronic search missed.

Inclusion and exclusion

The literature screening was conducted in two separate groups. Meetings were held to discuss and decide whether to include an article when there was disagreement between the two groups. We first used EndNote X6 (Thomson Reuters, New York, America) to identify duplicate publications. Subsequently, we excluded reviews, retrospective studies, observational studies, case reports, animal studies, experiments on children, pure physiological mechanism studies, repeated reports, repeated experiments (evaluation of a study or the second analysis of experimental data), non-invasive mechanical ventilation studies and non-randomized trials. Finally, randomized controlled intraoperative mechanical ventilation trials on obese adult patients with a BMI no less than 30 kg m\(^{-2}\) were selected for the analysis. All trials were of high quality with a low risk of bias. No paper was excluded for quality reasons.

Outcome measures and data extraction

The extracted information includes basic information on the study (e.g. experimental design, experimental time and country in which the study is conducted), basic information about the included patients (e.g. age, gender and BMI), detailed information on the specific process of the trial and mechanical ventilation parameters, and the patient’s clinical outcomes and safety outcomes. The primary outcome of this study was the PaO\(_2\)/FIO\(_2\) ratio of obese patients. If multiple PaO\(_2\)/FIO\(_2\) ratios were present in a trial, then the last intraoperative arterial blood gas result was used. The secondary outcome consisted of the results regarding atelectasis rate, lung compliance and lung function. Data were extracted by the two groups independently and then compared against each other for validation. When necessary, the data extraction table was sent to the original authors or reporters to request them to complete and correct the data. In cases of missing data, we also contacted the authors for assistance.

Statistical analysis

Network meta-analysis combines the direct and indirect evidence for all relative treatment effects and provides estimates with maximum power (11–14). Network meta-analysis was performed using the GeMTC package in R (i386 3.0.2) (15). In this analysis, the mean difference (MD) and 95% confidence interval were used as the parameters to measure the effect of the mechanical ventilation strategy on the intraoperative PaO\(_2\)/FIO\(_2\) ratio and lung compliance of obese patients to achieve the maximum accuracy and effectiveness (16). The difference was considered statistically significant when the confidence interval did not
include 0. The odds ratio (OR) and 95% confidence interval were used to measure the incidence of atelectasis in obese patients. The confidence interval was calculated using the Bayesian statistical method. The difference was considered statistically significant when the confidence interval did not include 1.0.

Model selection was based on the Dias guidelines for evaluating linear models (17). Dbar indicates the posterior mean of the residual deviance, pD indicates the effective number of parameters (leverage) and DIC indicates the ‘deviance information criterion’. A smaller Dbar value indicates a better model fit. However, the model with the lowest DIC is generally chosen to aid interpretation because it accounts for model complexity. A lower DIC value indicates a better model fit. Differences between the models of less than 3–5 were not considered significant (17,18). The models were run for 150,000 iterations, and convergence was assessed using the Brooks–Gelman–Rubin diagnostic (19). We used a technique known as ‘back calculation’ (20) to evaluate the consistency in the findings of the network meta-analysis based on direct vs. indirect evidence. During this process, three types of model are estimated: unrelated study effects, unrelated mean effects and consistency.

The output of the summary function can be plotted for a visual representation. We investigated the possibility of statistical heterogeneity and inconsistency between direct and indirect effect estimates by visual inspection of the forest plots and the I² statistic using the Higgins–Thompson method (low heterogeneity, 25%; moderate, 50%; and high, 75%) (21). We also ranked the different interventions in terms of their likelihood of leading to an association with the best results for each outcome (11). In the Markov chain Monte Carlo cycle, each ventilation strategy is ranked based on the estimated effect size. These probabilities sum to 1 for each treatment and each rank. X% means that the strategy achieves x% effectiveness. Thus, a larger percentage denotes more effective interventions, which, however, only represents one of the possibilities and not certainty (22).

Sensitivity analysis

Among the articles included in our study that report the PaO₂/FIO₂ ratio (6,7,23–28), all surgeries except the laparoscopic surgery in the study by De Baerdemaeker et al. (23) were laparotomy. We excluded the study by De Baerdemaeker et al. and conducted a sensitivity analysis.

Results

We identified 352 studies by reviewing titles and abstracts (Fig. 1). After this initial screening, we retrieved the full text of potentially eligible articles for detailed assessment. Finally, we excluded 10 irrelevant articles (Appendix 2) and 13 RCTs were included for the network meta-analysis (Table 1) (6,7,23–33), with a total of 476 patients randomly receiving one of 12 ventilation strategies (Table 2) labelled A (VCV + lower PEEP), B (VCV + lower PEEP + single-progressive RM), C (VCV + lower PEEP + single sudden RM), D (PCV + lower PEEP), E (VCV + higher PEEP + single-progressive RM), F (VCV + lower PEEP + single RM), G (VCV), H (PCV), I (VCV + higher PEEP), J (VCV + higher PEEP + single RM), K (VCV + single RM) and L (PSV + lower PEEP). Compared with the previous conventional meta-analysis, in our study, the ventilation strategies were refined and divided into 12 ventilation strategies depending on different ventilation modes, different parameters of the same ventilation mode, different ventilation levels of the same mode with the same parameters and different setting methods of the same ventilation mode with the same parameters (Table 2).

Heterogeneity

Among all of the included studies, nine reported information on the PaO₂/FIO₂ ratio and were included for meta-analysis. Three of these studies were three-arm trials, and the rest were two-arm trials. In trials using combined ventilation strategies A and D, for the end point of the PaO₂/FIO₂ ratio, the I² value exceeded 75% (I² = 91.8%), indicating high heterogeneity. The data analysis showed that the results of Cadi et al. (29) exhibited large errors, which may be the source of heterogeneity (Appendix 7). Upon excluding this study, the remaining eight articles (6,7,23–28) showed no heterogeneity. Comparing the PaO₂/FIO₂ ratio results (Fig. 2) from a traditional pairwise meta-analysis and a network meta-analysis did not suggest inconsistency between the direct and indirect evidence (Appendix 3).

Intraoperative PaO₂/FIO₂ ratio

We chose a fixed-effect model (Appendix 4a) with MD to merge the remaining eight articles. Ventilation strategies A, B, D, G, H, I, K and J were all able to improve the intraoperative PaO₂/FIO₂ ratio, and the respective MD values and 95% confidence intervals were 130 (40,230), 130 (17,230), 230 (130,350), 190 (99,290), 190 (80,290) and 130 (38,220) (Appendix 8a). Compared with strategy D, strategies A, B, C, E, F and I were able to improve the intraoperative PaO₂/FIO₂ ratio, and their MD values and 95% confidence intervals were 93 (12, 170), 100 (5.3, 200), 140 (42, 240), 220 (120, 320), 200 (100, 290), 97 (14, 180) and 230 (100, 350) (Appendix 8b), respectively. Comparison between the results of other ventilation strategies see Appendix 8c. The PaO₂/FIO₂ ratios, MD values and 95% confidence intervals of various ventilation strategies are shown in Appendix 5a. The sensitivity analysis
that excluded the study by De Baerdemaeker LE et al. showed no change in the results of the network meta-analysis on the obese patients’ PaO₂/FIO₂ ratio.

Intraoperative atelectasis rate

Two articles reported the secondary outcomes of the intraoperative atelectasis rate (28,32) involving four types of ventilation strategies (Appendix 6a). We chose a fixed-effect model (Appendix 4b) with ORs for the combined effect size. Compared with ventilation strategy I, strategy J showed a lower atelectasis rate, and its OR and 95% confidence interval were 0.072 (0.0084, 0.46). The ORs and 95% confidence intervals of atelectasis rates for the various ventilation strategies are shown in Appendix 5b. No inconsistencies were found between the direct and indirect comparisons, and none of the comparisons exhibited heterogeneity.

Intraoperative pulmonary compliance

Intraoperative pulmonary compliance was reported in three articles (23,28,31); however, the ventilation strategy used in the study by De Baerdemaeker et al. was unrelated to the ventilation strategies in other studies, and thus, we only used the results of the remaining two papers in the network meta-analysis, involving three types of ventilation strategies (Appendix 6b). We chose a fixed-effect model (Appendix 4c) with MD for combined effect size. Compared with ventilation strategy I, strategy J was able to improve patients’ lung compliance, and its MD and 95% confidence interval were 12.8 (6.44,19.1), while strategy K reduced patients’ lung compliance, and its MD and 95% confidence interval were −12.3 (−17, −7.53) (Appendix 5b). The comparison between the results showed no heterogeneity, and the results of direct comparison were consistent with the results of indirect comparison (Appendix 9).

Sensitivity analysis

The sensitivity analyses regarding the laparoscopic surgery in the study by De Baerdemaeker et al. (23) did not affect the results from the meta-analyses of the PaO₂/FIO₂ ratio. After the exclusion of this study (23), ventilation strategy J was still associated with the highest PaO₂/FIO₂ ratio (compared with strategies A, B, G, H, I and K) and still had statistical significance.
<table>
<thead>
<tr>
<th>Study</th>
<th>Ventilation strategies</th>
<th>No. of patients (n)</th>
<th>Surgery</th>
<th>BMI (kg·m⁻²)</th>
<th>Details of recruitment manoeuvres (all pressures in cm H₂O)</th>
<th>Result</th>
<th>Lung compliance (mL·cm⁻¹·H₂O)</th>
<th>Atelectasis (n)</th>
<th>Lung function FEV₁ (L)</th>
<th>Pulmonary complications (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tusman (6)</td>
<td>B VS E</td>
<td>20</td>
<td>Open colectomy</td>
<td>33 ± 2/35 ± 4</td>
<td>Progressive increase in PEEP from 5 to 10-15-20, each over three cycles. PIP 40 + PEEP 30 for 10 cycles</td>
<td>216 ± 48/28 ± 44</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>de Souza (7)</td>
<td>A VS B VS C</td>
<td>47</td>
<td>Open bariatric surgery</td>
<td>49.2 ± 6.3/50.3 ± 7.2/46.3 ± 5.0</td>
<td>Progressive: increase in PEEP from 5 to 10-15-20 for 2 min each Sudden: increase in PEEP from 5 to 30 for 2 min Gradual reduction in PEEP to the initial level of 5 cmH₂O every 5 s</td>
<td>266 ± 11 ± 82 ± 2.07/291.88 ± 97 ± 0.7/323.4 ± 91 ± 3</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>De Baerdemaeker</td>
<td>A VS D</td>
<td>24</td>
<td>Laparoscopic gastric banding</td>
<td>41.4 ± 4.5/50.8 ± 3.6</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chalhoub (24)</td>
<td>A VS F</td>
<td>52</td>
<td>Open bariatric</td>
<td>45.5 ± 5.3/44.4 ± 3.7</td>
<td>Positive inspiratory pressure of 40 for 15 s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>De Cadi (29)</td>
<td>D VS A</td>
<td>36</td>
<td>Laparoscopic obesity surgery</td>
<td>44 ± 5/44 ± 5</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sprung (25)</td>
<td>A VS E</td>
<td>17</td>
<td>Open bariatric surgery</td>
<td>51 ± 5/56 ± 11</td>
<td>Increasing PEEP from 4 cm H₂O (baseline) to 10 cm H₂O (three breaths), 15 cm H₂O (three breaths) and 20 cm H₂O PEEP. RM was repeated at 30 and 60 min after first recruitment and hourly afterward</td>
<td>303 ± 103/34 ± 61</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Hans (36)</td>
<td>G VS H</td>
<td>40</td>
<td>Laparoscopic and open Roux-en-Y bypass</td>
<td>41.7 ± 5 ± 8</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xiaochun (27)</td>
<td>A VS I VS G</td>
<td>30</td>
<td>Open nephrectomy</td>
<td>33.4 ± 1/3.7/33.9 ± 1.6</td>
<td>No</td>
<td></td>
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<tr>
<td>Reinius (28)</td>
<td>J VS K VS I</td>
<td>30</td>
<td>Open gastric bypass surgery</td>
<td>45 ± 5/45 ± 4/44 ± 3</td>
<td>Inspiratory pressure was increased to 55 cm H₂O, and an inspiratory hold was kept for 10 s</td>
<td>283 ± 3 ± 108 ± 3/291.7 ± 105</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Whalen (30)</td>
<td>E VS A</td>
<td>20</td>
<td>Laparoscopic bariatric Roux-en-Y operations</td>
<td>48 ± 6/53 ± 11</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tafer (31)</td>
<td>J VS I</td>
<td>26</td>
<td>Laparoscopic bariatric surgery</td>
<td>44 ± 7/45 ± 5</td>
<td>Inspiratory pressure 40 with PEEP 20, respiratory frequency 0.7 bpm for 3 min</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Taib (32)</td>
<td>F VS J VS K</td>
<td>66</td>
<td>Laparoscopic bariatric surgery</td>
<td>44.3 ± 6.90/83.3 ± 6.85/41.8 ± 7.9</td>
<td>Inspiratory pressure 40 for 7-8 s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zoremba (33)</td>
<td>D VS L</td>
<td>68</td>
<td>Different non-bariatric</td>
<td>32 ± 2/32 ± 2</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*No* refers to no result. Ventilation strategies are described in Table 2.

BMI, body mass index; FEV₁, forced expiratory volume in 1 s; PEEP, positive expiratory end pressure; PIP, peak inspiratory pressure; RM, recruitment manoeuvres.
In Fig. 3, we summarize the rankings of the different competing ventilation strategies in terms of the PaO$_2$/FIO$_2$ ratio and atelectasis rate. Ventilation strategy J had the greatest potential to improve the patient’s intraoperative PaO$_2$/FIO$_2$ ratio, and the possibility of it receiving the first ranking was 51.9%, followed by strategy E, whose probability was 41.6% (Appendix 10a). Strategy D was likely to be associated with the lowest in terms of the PaO$_2$/FIO$_2$ ratio. Strategy J showed the greatest potential to reduce the atelectasis rate, with a possibility of 61.0%, while strategy I was the most likely to cause atelectasis (Appendix 10b).

**Table 2** 12 ventilation strategies for obese patients

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Volume-controlled ventilation with lower PEEP (VCV + lower PEEP)</td>
</tr>
<tr>
<td>B</td>
<td>Volume-controlled ventilation with lower PEEP and single-progressive recruitment manoeuvres (VCV + lower PEEP + single-progressive RM)</td>
</tr>
<tr>
<td>C</td>
<td>Volume-controlled ventilation with lower PEEP and single sudden recruitment manoeuvres (VCV + lower PEEP + single sudden RM)</td>
</tr>
<tr>
<td>D</td>
<td>Pressure-controlled ventilation with lower PEEP (PCV + lower PEEP)</td>
</tr>
<tr>
<td>E</td>
<td>Volume-controlled ventilation with higher PEEP and single-progressive recruitment manoeuvres (VCV + higher PEEP + single-progressive RM)</td>
</tr>
<tr>
<td>F</td>
<td>Volume-controlled ventilation with lower PEEP and single recruitment manoeuvres (VCV + lower PEEP + single RM)</td>
</tr>
<tr>
<td>G</td>
<td>Volume-controlled ventilation (VCV)</td>
</tr>
<tr>
<td>H</td>
<td>Pressure-controlled ventilation (PCV)</td>
</tr>
<tr>
<td>I</td>
<td>Volume-controlled ventilation with higher PEEP (VCV + higher PEEP)</td>
</tr>
<tr>
<td>J</td>
<td>Volume-controlled ventilation with higher PEEP and single recruitment manoeuvres (VCV + higher PEEP + single RM)</td>
</tr>
<tr>
<td>K</td>
<td>Volume-controlled ventilation and single recruitment manoeuvres (VCV + single RM)</td>
</tr>
<tr>
<td>L</td>
<td>Pressure support ventilation with lower PEEP (PSV + lower PEEP)</td>
</tr>
</tbody>
</table>

Lower PEEP ≤ 10 mmHg, higher >10 mmHg.

PEEP, positive expiratory end pressure.

**Discussion**

There have been many clinical trials on the application of different ventilation strategies on obese patients under general anaesthesia. However, as indicated by the results of these clinical trials, which type of ventilation strategy is associated with the best fit for obese patients remains controversial. The meta-analysis in the present study showed that among strategies that consider improving the PaO$_2$/FIO$_2$ ratio as the primary outcome, strategy J was associated with the highest PaO$_2$/FIO$_2$ ratio compared with strategies A, B, D, G, H, I and K, and the difference was statistically significant. Moreover, strategy J was associated...
with the highest intraoperative pulmonary compliance of obese patients under general anaesthesia compared with strategies I and K. In addition, compared with strategies F, I and K, strategy J was associated with the highest prevention of intraoperative atelectasis. Therefore, we speculate that strategy J may be associated with the optimal ventilation strategy for obese patients.

The superiority of strategy J may be related to the following reasons: (i) high PEEP can significantly increase the functional residual capacity of obese patients, alleviate focal atelectasis, increase the alveolar–arterial oxygen difference, improve lung compliance and alveolar ventilation, and prevent atrophic alveolar collapse, thereby effectively reducing the incidence of pulmonary shunts and improving arterial oxygen. Coussa et al. (34) and Duggan and Kavanagh (35) also demonstrated that using high PEEP could reduce the incidence of atelectasis in obese patients under general anaesthesia more effectively than low PEEP. (ii) During lung expansion, the volume of pulmonary ventilation increases, and small airways are expanded; consequently, the previously collapsed alveoli are expanded. Expanding the lung for a certain period can help the gas to evenly distribute among the alveoli, fully open the alveoli, increase the stability of the re-expanded alveoli and improve lung compliance. The ventilation/perfusion ratio increases as the number of alveoli involved in gas exchange increases, resulting in an increased PaO2/FIO2 ratio (36–38). These phenomena may be the underlying mechanisms by which strategy J improves lung function, the PaO2/FIO2 ratio, and lung compliance and reduces the incidence of atelectasis. Through direct and indirect comparison, we found that compared with strategies A, B, C, E, F, I and J, strategy D was associated with the lowest increase in oxygenation, with statistical significance.

Strategy D was associated with the lowest PaO2/FIO2 ratio, possibly for the following reasons (i) the tidal volume of the PCV ventilation mode changes with pressure and lung compliance (39). The lung compliance of obese patients under general anaesthesia decreases, which might cause decreased tidal volume and inadequate ventilation, resulting in decreased oxygen content in the alveoli and reduced oxygenation. (ii) PCV can decrease ventilation in the dorsal lung region close to the diaphragm in normal weight patients (40), and this pathophysiological change can be exacerbated in obese patients due to the increased thoracic and abdominal pressure, resulting in a more significant ventilation–perfusion imbalance (41). (iii) However, studies have noted that extending I/E (inspiration/expiration) in PCV can produce high mean airway pressure and increase inspiratory time; therefore, more collapsed distal pulmonary alveoli can be expanded to improve oxygenation (42–44). In the articles included in our analysis, the patient’s I/E ratio was usually 1:2, which may cause the insufflation time to be too short to allow the pulmonary pressure in the lung to reach an equilibrium or to effectively increase the mean airway pressure to affect oxygenation (42,44,45).

For the endpoint of the PaO2/FIO2 ratio in trials using ventilation strategies A and D, there was significant heterogeneity and inconsistency between the results of direct and indirect comparison. Upon carefully comparing the PaO2/FIO2 ratio in articles 23 and 25, we found that the PaO2/FIO2 ratios of strategy A in article 25 was 199 (74) mmHg, which was much lower than the PaO2/FIO2 ratio of the other ventilation strategies. A careful comparison of the respiratory parameters in the original articles included in our study showed that the actual ranges of the respiratory rate and tidal volume in article 25 were higher than in other trials that used VCV and PCV. Therefore, we speculated that the excessively high respiratory rate and tidal volume caused a certain degree of ventilator-induced lung injury (VILI) in obese patients, resulting in large difference in the PaO2/FIO2 ratio between different clinical trials that used the same ventilation strategies. In fact, the authors of article 25 offered the same speculation. Unfortunately, there was no data-supported detailed analysis of the VILI in that article.

Limitations
This study had certain limitations: (i) only a small number of trials were included for ventilation strategies such as B,
D and G; the sample size was relatively small; and a head-to-head direct comparison of treatment measures was lacking. Therefore, the results are prone to bias. A parallel comparative and multicentre study with a large sample size will be necessary to validate our results. (ii) In addition to oxygenation, we are also concerned about short- and long-term post-operative pulmonary complications from these strategies, such as barotraumas, atelectasis and pneumonia. Additionally, we are also concerned about post-operative pulmonary function and hospital stay duration. However, except for the PaO$_2$/FIO$_2$ ratio, we extracted only three articles regarding short-term post-operative pulmonary complications and only one article regarding post-operative lung function. Additionally, the inclusion criteria for post-operative pulmonary complications were not exactly the same in our included studies. Because of the limited original research and because the original experimental results are not complete, the rare abovementioned related results were included in our study. Therefore, the results of this study are relatively simple and lack a comprehensive conclusion. A further parallel comparative and multicentre study with a large sample size will be necessary to confirm our results. (iii) Different PEEP magnitudes and different RM methods will affect the outcome indicators; the size of tidal volumes and pneumoperitoneum will also affect the outcomes. However, in our included articles, the magnitude of the tidal volumes cannot be subdivided.

Conclusions

The results of this meta-analysis show that strategy J (VCV + higher PEEP + single RM) was superior to other strategies in improving oxygenation, intraoperative pulmonary compliance and preventing atelectasis in obese patients under anaesthesia, whereas strategy D (PCV + lower PEEP) was the lowest in improving oxygenation for obese patients.

Conflict of interest statement

No conflict of interest was declared.

Authors’ contributions

CW and NZ searched the scientific literature; LG, CC, XP and YC performed the statistical analyses; WW, LG, CW and XW participated in the data interpretation and drafted the report; CW conceived the study and contributed data; and EL made important revisions to the draft report.

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Supporting information

Additional Supporting Information may be found in the online version of this article, http://dx.doi.org/10.1111/obr.12274

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Appendix S10a Rankings based on simulations in terms of PaO$_2$/FIO$_2$ ratio
Appendix S10b Rankings based on simulations in terms of atelectasis

References


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