REVIEW ARTICLE

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Pressure-Controlled Versus Volume-Controlled Ventilation for Surgical Patients: A Systematic Review and Meta-analysis

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ALMOST ALL SURGERIES with general anesthesia require mechanical ventilation, which may trigger ventilator-induced lung injury through various mechanisms.[1–3] Large tidal volume and high airway pressure may cause overextension of the alveoli, which will result in barotrauma and volutrauma.[2] Factors such as reduced functional residual capacity, raised diaphragm, alternate permeability of the alveolar capillaries, high inspired oxygen concentration, and no positive end-expiratory pressure (PEEP) may lead to a low tidal volume pulmonary injury (ie, atelectrauma).[2] It has been reported that "atelectasis occurred in nearly all anesthetized patients and might lead to life-threatening postoperative pulmonary complications (PPCs) such as hypoxemia, pneumonia, and ventilator-induced lung injury."[4] Any aforementioned injuries cause a massive release of inflammatory cytokines and inflammatory mediators, which subsequently will result in biotrauma.[2] The effects would be more significant under situations such as obesity,[5] one-lung ventilation (OLV),[6,7] laparoscopic surgery,[8] or surgeries using specific positions[9]

In 2010, a large retrospective study demonstrated that the incidence of PPCs could reach 5%. Once they occur, the hospital length of stay (LOS) and the mortality would increase significantly ($p < 0.0001$).[10] Considering the increasing number of surgeries worldwide and the high morbidity (25%) and mortality (3.5%-7%) in surgical patients,[11,12] it would be of great significance if any protective methods had an effect on the reduction of PPCs.[13] For mechanical ventilation, researchers have proposed many lung-protective strategies, which commonly refer to low tidal volume, application of PEEP, or implementation of a recruitment maneuver.[14–16] Previous studies have confirmed that these strategies could lead to a better clinical outcome in patients with acute respiratory distress syndrome (ARDS).[17] In recent years, these strategies have been applied to surgical patients. Several meta-analyses demonstrated that the use of low tidal volume, PEEP, continuous positive airway pressure, or a recruitment maneuver improved intraoperative oxygenation and reduced the incidence of postoperative pulmonary injury, pulmonary infection, and atelectasis.[18,19] A meta-analysis in the obese first compared pressure-controlled ventilation (PCV) and volume-controlled ventilation (VCV) on intraoperative oxygenation. However, no meaningful conclusion could be drawn because limited studies were included, which decreased the power.[20]

Unlike the constant flow commonly used in VCV, PCV with its initial high-speed flow allows the pressure gradient between the proximal airway and the alveoli to reach its peak at the beginning of inspiration. This facilitates the delivery of the tidal volume early during the inspiratory phase and the recruitment of unstable alveoli. The following decelerating flow keeps the inspiratory pressure constant, thus reducing inhomogeneity by allowing redistribution of the tidal volume among the alveoli with different time constants and allows a more even distribution of the tidal volume.[21] Additionally, PCV has been demonstrated to provide a lower peak airway pressure (Ppk) and a higher mean airway pressure.[22] Finally, PCV can reduce intrathoracic pressure and pulmonary vascular resistance, which thereby improves right ventricular function.[23] All of the advantages just mentioned theoretically can improve the ventilation-to-perfusion (V/Q) ratio and oxygenation.[24–26] In 2000, a study found that compared with VCV, PCV reduced the mortality (about 30%) and morbidity (eg, renal failure) in patients with ARDS,[27] although some results of clinical trials and experimental studies on PCV were inconsistent. Some authors proposed that PCV reduced the Ppk by decreasing the pressure in the breathing circuit rather than the pressure inside the bronchi. Therefore, the effect of PCV and VCV on alveolar expansion may be similar.[28] An animal study demonstrated that the V/Q distribution was more even and a greater improvement in oxygenation was identified in the VCV mode.[29] Another animal study proved that the initial high-speed flow generated by PCV could trigger shearing of the airway and alveoli, which led to alveoli closure in the collapsed region of the lung and resulted in atelectasis and severe pulmonary injury.[30] Thus, it has remained controversial whether PCV has lung-protective effects for surgical patients under general anesthesia. The authors, therefore, decided to conduct this systematic review and meta-analysis to determine whether PCV could improve intraoperative oxygenation, and ventilation parameters, and reduce the incidence of PPCs by comparing PCV with VCV in all adult surgical patients.

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MATERIALS AND METHODS

Search Strategy

Two of the authors (JJ and KN) independently searched PubMed, EMBASE, Cochrane Central Register of Controlled Trials (CENTRAL), ScienceDirect (Elsevier), Web of Science, CINAHL (EBSCO), and several Chinese databases including CNKI, WanFang, VIP, and SinoMed from their dates of inception to December 2014. To identify all studies, the authors combined the following terms: *pressure-controlled ventilation, volume-controlled ventilation, protective ventilation*, or other related words as either free words, key words or Mesh words with the Cochrane highly sensitive strategies for identifying randomized controlled trials (RCTs) of the Cochrane Handbook for Systematic Reviews of Interventions (version 5.1.0).[31] The authors screened references of all eligible trials to identify any potentially relevant studies. For literature without full text, they manually searched in the relevant journals.

Selection Criteria

RCTs and randomized crossover trials with full text of any languages that evaluated the effect of PCV and VCV on intraoperative oxygenation, ventilation parameters, and PPCs in adult patients ($\geq$18 years) undergoing any kind of surgery with general anesthesia were included. One group used PCV and the other used VCV. The preset pressure of the PCV group was required to allow a tidal volume equal to the level of that in the VCV group, then adjusted to an acceptable range of end-tidal carbon dioxide ($EtCO_2$). As to the other parameters (PEEP, recruitment maneuver, inhaled oxygen concentration, etc.), 2 groups should adopt the same level or same criteria. In this case, if any significant difference was identified, the authors could deduce that the reason was due mainly to different ventilation modes. The primary outcomes were intraoperative and postoperative oxygenation indices (OIs). The secondary outcomes obtained intraoperatively included oxygen saturation (SaO_2), alveolar-arterial oxygen gradient (A-aDO_2), pulmonary shunt fraction (Qs/Ot), deadspace-to-tidal volume ratio (Vd/Vt), Ppk, plateau airway pressure (Ppl), mean airway pressure (Pm), static compliance (Csta), dynamic compliance (Cdyn), and $PaCO_2$. Other postoperative secondary outcomes included mortality, incidence of acute pulmonary injury, atelectasis, pneumonia, and hospital LOS. The definitions of the outcomes are summarized in Appendix A. For RCTs, if there was only one time point, the results at this time point were selected; if there was more than one time point with a specific background (eg, OLV, laparoscopy, and surgery with specific positions), the results at the last time point in this specific background were selected; if not with a specific background, the results at the last time point before the end of the 2 ventilation modes were selected. For the crossover studies, 30 minutes' observational time interval was required, which might avoid a "carry-over effect"[23]; and if the first ventilation mode lasted only 30 minutes, and the second one was used until the end of the surgery, the authors supposed that the postoperative outcomes were affected mainly by the second one.

Two authors (JJ and NK) independently screened the list of all titles and abstracts and selected any potential studies. After further assessment of full texts, studies that met the inclusion criteria were retrieved. Any disagreements between 2 reviewers were resolved by discussion with a third reviewer (YY) for specialized aspects and a fourth reviewer (BL) for methodologic aspects. Studies were included when consensus was reached.

Data Extraction and Management

Two authors (JJ and NK) independently extracted and recorded data on a data extraction form. The form included first author's name, type of study, type of surgery, endotracheal ventilation or laryngeal mask airway, preoperative respiratory function of the included patients, preset tidal volume (Vt), inspired oxygen fraction (F_IO_2), ratio of the inspiratory time to expiratory time (I:E), application of PEEP, and all the primary and secondary outcomes. The authors resolved any disagreements on data extraction by discussion between the 2 authors, and if necessary, with a third reviewer (YY). For continuous data, the authors extracted mean, SD, and sample size; for dichotomous variables, they extracted number of events that occurred and sample size. If median and interquartile range (IQR) were given for the symmetrical data, the median was considered as similar to mean and the IQR was approximately 1.35 SDs.[31]

Risk for Bias Assessment of the Included Studies

Two reviewers (JJ and KN) independently assessed the risk of bias for each eligible study by using the risk of bias assessment tool provided in the Cochrane Handbook (version 5.1.0), including 7 domains (ie, sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective outcome reporting, and other bias).[31] According to this 2-part tool, the authors first described what was reported in the study and entered relative information in the risk of bias table; then assigned a judgment of "low risk" of bias, "high risk" of bias, or "unclear risk" of bias; finally, a risk of bias summary figure was generated using Review Manager Software (RevMan5.3).[31] Any disagreements on this assessment were resolved by discussion with a third author (YY). If all 7 domains were assigned to low risk of bias, a study was classified as low risk; if $\geq$1 domains were assigned to unclear risk of bias, it was classified as unclear risk; if $\geq$1 domains were assigned to high risk of bias, it was classified as high risk.[31] Based on the primary outcomes ($>$10 included studies), a funnel plot was drawn to qualitatively assess the existence of publication bias.[32]

Data Analysis and Synthesis

Weighted mean difference (WMD) and 95% confidence interval (CI) were used for continuous data. In the case of different units of continuous data, standard mean difference was used. Relative risk (RR) and 95% CI were used for dichotomous data, $p < 0.05$ was considered statistically significant.

Review Manager software was used to perform pooled analysis for the outcomes from $>$1 study. The authors planned to assess the statistical heterogeneity by using Cochran Q test