Comparison of the tidal volume of the recruitment maneuver followed by PEEP for mechanically ventilated children

Maho Goto  
Kyushu University

Masanori Tsukamoto (✉ tsukamoto@dent.kyushu-u.ac.jp)  
Kyushu University Hospital

Takashi Hitosugi  
Kyushu University

Kazuya Matsuo  
Kyushu Institute of Technology

Takeshi Yokoyama  
Kyushu University

Michi Eto  
Kyushu University

Research Article

Keywords: children, ventilation volume, recruitment maneuver, general anesthesia.

Posted Date: February 7th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2508674/v1

License: ☑️ This work is licensed under a Creative Commons Attribution 4.0 International License.  
Read Full License
Abstract

Background

Atelectasis occurs in most children during the induction of general anesthesia. In clinical practice, the recruitment maneuver (RM) followed by positive end-expiratory pressure (PEEP) to prevent atelectasis have beneficial effects. It has been shown to improve oxygenation and restore lung volume and may reduce the heterogeneity of the distribution of tidal volume (V\textsubscript{T}). However, the change in VT due to RM followed by PEEP in pediatric patients during the induction of general anesthesia is unknown. Therefore, we assessed the effects of RM followed by PEEP on V\textsubscript{T}, respiratory function, and hemodynamics in pediatric patients.

Methods

Pediatric patients (ASA-PS: 1-2; aged 3 months to 10 years) who underwent general anesthesia for elective dental or oral surgery were divided into three groups: infants (<1 year), preschool children (1-6 years), and school children (6 > years). Following tracheal intubation, mechanical ventilation of the lungs was initiated with controlled ventilation of 15 cmH\textsubscript{2}O and a PEEP of 4 cmH\textsubscript{2}O. The RM followed by PEEP was increased progressively in steps of 5 cmH\textsubscript{2}O every three breaths up to the target level of 35 cmH\textsubscript{2}O. V\textsubscript{T}, heart rate (HR), blood pressure (BP), and SpO\textsubscript{2} were monitored before and after RM followed by PEEP. The differences in these parameters were analyzed statistically using a paired t-test.

Results

Sixty patients were included (20 in each group). V\textsubscript{T} before vs. after RM followed by PEEP were 61.8 ± 9.7 vs 80.1 ± 13.9 mL (p < 0.05) in the infant group, 135.8 ± 28.5 vs 164.0 ± 36.9 mL (p < 0.05) in the preschool children group, 217.7 ± 49.7 vs 246.9 ± 50.1 mL (p < 0.05) in the school children group, respectively. HR and BP before and after RM followed by PEEP increased by 2-3% and decreased by 4-7% in all groups. None of the patients had clinically respiratory (desaturation, barotrauma) or hemodynamic (hypotension) complications.

Conclusion

RM combined with 4 cmH\textsubscript{2}O of PEEP resulted in a significant increase in V\textsubscript{T} (12-18%; 19-29 mL) without respiratory or hemodynamic complications. Therefore, this RM method might improve the lung function in pediatric patients.

Trial registration

This prospective observational study was conducted after receiving approval from the Ethics Review Board of Kyushu University Hospital (Approval No.30-446).
Background

General anesthesia with tracheal intubation and mechanical ventilation is widely used in patients undergoing a variety of surgical procedures. [1–3] However, alveolar collapse is multifactorial in origin and begins quickly after tracheal intubation. [4, 5] Reduced lung compliance [6–8] and pulmonary gas exchange impairment may result in decreased oxygenation of arterial blood. [9–11] Absorption atelectasis occurs when the flux of oxygen from the alveoli into the capillaries exceeds that of the waste gas returning to the alveoli. [5, 12, 13] The atelectasis might increase the risk of volutrauma as a constant volume is imparted to a dwindling alveolar volume. [1, 6] This frequently occurs during induction of general anesthesia when the fraction of inspired oxygen (FiO₂) is increased to 100%. [1] The atelectasis, which cannot be seen on conventional chest radiography, is demonstrated on computed tomography (CT) scans of the chest. [1, 8, 14, 15]

Atelectasis occurs in children and adults during the induction of general anesthesia. [4, 13, 16] Younger children and infants are especially vulnerable to hypoxemia due to their smaller functional residual capacity (FRC). [4, 8, 9, 12, 13] Desaturation can subsequently occur by intubation or mask ventilation. Manual ventilation with increased FiO₂ and a large tidal volume (V₉) is then required to recover oxygen saturation (SpO₂) levels.

Various ventilatory strategies have been proposed to improve gas exchange during general anesthesia [6, 7, 14–17] by lowering V₉ and increasing the partial pressure of oxygen (PaO₂). Positive end-expiratory pressure (PEEP) is the pressure applied by the ventilator at the end of each expiration to ensure that the alveoli do not collapse. PEEP induces only a modest increase in PaO₂. [1, 18–20] Clinical data have demonstrated that a mechanical ventilation system using lower V₉ and PEEP decreases the risks of pulmonary complications by minimizing the alveolar stretching at the end of expiration and avoiding possible inflammation or alveolar collapse. [18–20]

Recently, a strategy of reopening the atelectatic lung areas during anesthesia with a recruitment maneuver (RM) followed by PEEP has been recommended. [1, 4–6] It has been shown to improve oxygenation and restore lung volume and may reduce the heterogeneity of V₉ distribution. [1, 4–6, 21–23]

However, the change in V₉ due to RM followed by PEEP during induction of general anesthesia remains unknown. Therefore, we assessed the effects of RM followed by PEEP on V₉ and hemodynamics and respiratory function in pediatric patients.

Methods

Study Design

This prospective observational study was approved by the Ethics Review Board of Kyushu University Hospital (Approval No.30–446). The study was conducted from January 2019 to May 2022. The subjects
included patients who underwent dental treatment and oral maxillofacial surgery at Kyushu University Hospital under general anesthesia. Patients with upper respiratory tract or preoperative lung disease were excluded from the study. Written informed consent was obtained from the legal guardians of the eligible children before general anesthesia. Pediatric patients (American Society of Anesthesiologists – physical status (ASA-PS): 1–2; aged 3 months to 10 years) who underwent general anesthesia for elective dental treatment or oral surgery were divided into three groups: infants (<1 year), preschool children (1–6 years), and school children (6 > years).

Participants

Patients were transferred to the operating room without premedication. Anesthesia was then induced by the inhalation of 1–8% sevoflurane after beginning non-invasive monitoring of SpO$_2$ by pulse oximetry, electrocardiography (ECG), and non-invasive blood pressure (BP) and heart rate (HR) checks. FiO$_2$ was maintained at 100% throughout the study period. After loss of consciousness, the sevoflurane concentration was adjusted according to each patient’s hemodynamic condition.

In cases of airway obstruction, airway and jaw thrusts were applied to relieve the obstruction, and ventilation was gently assisted, as necessary. Atropine, fentanyl, and remifentanil were administered after peripheral intravenous access was achieved. Intubation was facilitated with rocuronium, using a Mackintosh laryngoscope (Smiths Medical Japan, Tokyo, Japan). The size of the endotracheal tube (ETT) was judged to be appropriate when air leakage was observed at an airway pressure of 10–30 cmH$_2$O. When air leakage was either not observed at 30 cmH$_2$O or observed below 10 cmH$_2$O, the ETT was replaced by another one size above or below. \[24, 25\] The choice of anesthetic maintenance was determined by each anesthesiologist. Mechanical ventilation was performed using a Datex-Ohmeda Aestiva (GE Healthcare, Madison, WI, USA). Anesthesia was maintained using inhalational anesthetics such as sevoflurane, isoﬂurane, and desflurane, with the administration of fentanyl and remifentanil with end-tidal carbon dioxide maintained at 35–45 mmHg for analgesia to all patients.

Interventions

Following tracheal intubation, mechanical ventilation of the lungs was initiated in a controlled ventilation with 15 cmH$_2$O and a PEEP of 4 cmH$_2$O, inspiratory: expiratory ratio of 1:2, and initial ventilatory rate of 15 breaths/min. FiO$_2$ was maintained at 100% throughout the study period (Figure.1). After 2 min, the RM followed by PEEP increased progressively in steps of 5 cmH$_2$O every three breaths up to the target level of 40 cmH$_2$O. It took approximately 1 min to perform this RM with an anesthesia ventilator. V$_T$, HR, BP and SpO$_2$ were recorded by an independent observer before and after RM followed PEEP. The positions of the patients remained unchanged during the measurement period.

**Data Analysis**
An a priori power analysis was performed using 10 data points based on the clinical experiences resulting from our preliminary study. The sample size of 18 patients was calculated based on $\alpha = 0.05$, 2.0 standard deviation (SD), and a power of 80% using JMP® 15 (SAS Institute Inc., Cary, NC, USA). Factoring in an estimated dropout rate of approximately 10%, the total sample size for this study was set to 60 patients. The paired t-test was used to compare groups for nonparametric data using MATLAB (version 2015a; MathWorks, Inc., Natick, MA, USA). All values are expressed as the mean $\pm$ SD or number (n). The significance level was set at $p < 0.05$.

**Results**

In total, 60 patients were included, with 20 in each group (Table 1). RM followed by PEEP was performed according to the planned protocol in all patients randomized to the recruitment group, with no patient exceeding 40 cmH$_2$O of inspiratory pressure. $V_T$ before and after RM followed by PEEP were 61.8 $\pm$ 9.7 and 80.1 $\pm$ 13.9 mL ($p < 0.05$) in the infant group, 135.8 $\pm$ 28.5 and 164.0 $\pm$ 36.9 mL ($p < 0.05$) in the preschool children group, and 217.7 $\pm$ 49.7 and 246.9 $\pm$ 50.1 mL ($p < 0.05$) in the school children group, respectively (Table 2). The HR increased by 2–3% and the BP decreased by 4–7% after RM followed by PEEP in all groups. None of the patients had clinically respiratory (desaturation, barotrauma) or hemodynamic (hypotension) complications.

**Discussion**

In prospective observational study, we compared $V_T$ before and after RM followed by PEEP in mechanically ventilated pediatric patients. $V_T$ after RM followed by PEEP significantly increased (19–29 mL) in each group. However, no hemodynamic or respiratory complications were observed.

Anesthesia-induced atelectasis occurred frequently and immediately (within a few minutes) after the induction of general anesthesia. [5, 6, 7, 13] Children, most particularly infants, are at an increased risk of developing atelectasis, because of the proximity of the residual volume to the closing volume of the lung and the absence of pathways for collateral ventilation before 3–4 years [12, 13, 22, 23]. They have a relatively lower FRC because the highly compliant nature of their chest wall has a reduced ability to counteract the inward elastic recoil of the lung tissue. [4, 7] Therefore, early and active management after intubation is benefited by RM followed by PEEP. [1, 5, 6, 8]

PEEP might be associated with alveolar collapse related to local compression atelectasis caused by overdistended upper lobes. [6, 12, 20] However, PEEP alone is insufficient in improving oxygenation. [5, 7, 13] Indeed, PEEP might increase the normally aerated lung fraction along with a reduction in the proportion of poorly aerated lung tissue, although the extent of atelectasis may remain unchanged. [8] In contrast, PEEP increases FRC, intracranial pressure, intraocular pressure (IOP), and central venous pressure, which might subsequently inhibit blood efflux from the intraocular vessels and thereby increase IOP. [9, 21, 26]
RM followed by PEEP might be an important component of a lung-protective ventilation strategy to re-expand the atelectatic lungs and improve lung compliance. [4, 7] High inspiratory pressures are required to re-open collapsed alveoli, and these must be maintained for a sufficient period of time to allow lung units with slow time constants to re-expand. The RM method restores FRC and has been shown to reduce shunts and improve the perfusion of poorly ventilated lung units.

The method of using RM followed by PEEP in this study sustained inflation of the lungs to a specific peak inspiratory pressure of 30–50 cmH₂O for 20–40 s with a stepwise increase in PEEP. [1, 6, 9, 14, 21, 22] It was effective for a marked increase in oxygenation for a few hours, associated with improved respiratory system elastance and dead space. [23] This may reduce the amount of pulmonary shunt, despite a concomitant increase in perfusion to poorly ventilated lung units (low VA/Q), which might result in a small but significant reduction in PAO₂-PaO₂ for at least 40 min after 7–8 seconds of RM followed by PEEP. [1, 6, 18]

However, optimal pressure, duration, and frequency are yet to be determined in children. There is no consensus on the optimal performance of RM followed by PEEP. Compared with adults, data on the influence of RM in children undergoing general anesthesia are relatively limited. [4, 5, 12, 13]

Despite the advantages of RM followed by PEEP, some side effects have been reported, including hypotension, bradycardia, barotrauma, oxygen desaturation, and ventilator-induced lung injury. [9, 19, 20] Sustained inflation of the lung often gives rise to a decrease in venous return and cardiac output (CO). Increasing airway pressure leads to decreased venous return, CO, and HR by increasing pulmonary vascular resistance. [26] However, such effects are expected to be transient, with BP and CO returning to the baseline within several minutes, and serious complications may not be common; in this study, significant differences were observed in some parameters, but no respiratory and hemodynamic abnormalities were observed.

Our study had several limitations. First, the use of 100% FiO₂ may have contributed to an increase in the amount of reabsorption atelectasis. However, the use of high FiO₂ in pediatric anesthetic practice is common; pediatric patients can desaturate rapidly, and respiratory adverse events associated with airway obstruction are frequent. Second, our patients were graded ASA PS 1–2. The use of RM followed by PEEP in more unstable patients such as acute lung injury was not tested and could increase the side effects.

**Conclusion**

RM followed by PEEP following tracheal intubation significantly increased Vₜ by 12–18% (19–29 mL) without respiratory or hemodynamic complications. Therefore, RM followed by PEEP may improve the lung function in pediatric patients.

**Declarations**
Ethics approval and consent to participate; This prospective observational study protocol was approved by Ethics Review Board of Kyushu University Hospital (Approval No.30-446). Confirming informed consent was obtained from all study participants. Moreover, all methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication; Not applicable.

Availability of data and materials; The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests; The authors declare that they have no competing interests.

Funding; This research did not receive any specific grant from funding agencies in the public, commercial.

Authors’ contributions;

Study conception/design: M. Tsukamoto, T. Hitosugi, T. Yokoyama

Data acquisition: M. Goto, M. Eto, K. Hano.


Final approval of the manuscript: all authors.

Accuracy and integrity of the manuscript: all authors.

Acknowledgements; Not applicable

Declarations of interest; The authors declare that they have no conflicts of interest.

References


18. Ahn S, Byun SH, Chang H, Koo YB, Kim JC. Effect of recruitment maneuver on arterial oxygenation in patients undergoing robot-assisted laparoscopic prostatectomy with intraoperative 15 cmH2O


**Tables**

Table 1

All values are expressed as mean ± standard deviation (SD) or number (n).

<table>
<thead>
<tr>
<th></th>
<th>Infant group (n=20)</th>
<th>Preschool children group (n=20)</th>
<th>School children group (n=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (M/F)</td>
<td>11/9</td>
<td>12/8</td>
<td>14/6</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>0.4 ± 0.2</td>
<td>3.3 ± 1.3</td>
<td>7.8 ± 1.3</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>60.9 ± 13.9</td>
<td>92.8 ± 11.0</td>
<td>122.9 ± 9.0</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>6.4 ± 0.7</td>
<td>14.0 ± 3.0</td>
<td>23.6 ± 3.9</td>
</tr>
</tbody>
</table>
Table 2: A paired t-test was used to compare the groups for nonparametric data.

<table>
<thead>
<tr>
<th></th>
<th>Infant group (n=20)</th>
<th>Prevalence children group (n=20)</th>
<th>School children group (n=20)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before followed by PEEP</td>
<td>After followed by PEEP</td>
<td>P value</td>
</tr>
<tr>
<td>VT (mL)</td>
<td>61.8 ± 9.7</td>
<td>80.1 ± 13.9</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>HR (bpm)</td>
<td>142.3 ± 13.5</td>
<td>144.7 ± 13.3</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>BP (mmHg)</td>
<td>78.2 ± 12.1 / 41.7 ± 7.0</td>
<td>75.3 ± 10.9 / 38.9 ± 5.1</td>
<td>&lt;0.05/0.12</td>
</tr>
</tbody>
</table>

All values are expressed as mean ± standard deviation (SD).

Statistical significance was set at p < 0.05.

Figures
Mechanical ventilation of the lungs was initiated in a controlled ventilation with 15 cmH$_2$O and a PEEP of 4 cmH$_2$O, inspiratory: expiratory ratio of 1:2, and initial ventilatory rate of 15 breaths/min.

The RM followed by PEEP increased progressively in steps of 5 cmH$_2$O every three breaths up to the target level of 40 cmH$_2$O.

**Supplementary Files**

This is a list of supplementary files associated with this preprint. Click to download.

- recruitmentdatafinal.xlsx