Spontaneous Ventilation with Halothane in Children

A Comparative Study between Endotracheal Tube and Laryngeal Mask Airway

Jean Reignier, M.D.,* Mondher Ben Ameur, M.D.,* Claude Ecoffey, M.D.†

Background: It has been reported that, in children breathing spontaneously via an endotracheal tube, halothane depresses ventilation with paradoxical inspiratory movement. Endotracheal tubes have a higher airflow resistance than do laryngeal mask airways (LMAs). Therefore, the aim of this study was to compare spontaneous ventilation via the LMA with that via the endotracheal tube in children anesthetized with halothane.

Methods: The authors studied two groups of 6–24-month-old children with no cardiopulmonary or neurologic disorders, undergoing elective minor surgery with halothane anesthesia: one group breathing via LMA (n = 10) and one group breathing via endotracheal tube (n = 10). They measured tidal volume, respiratory rate, minute ventilation, and end-tidal CO₂. They assessed paradoxical inspiratory movement using amplitude index and phase delay index.

Results: Age and weight were similar in both groups. Mean ± SD tidal volume (7.5 ± 1.9 ml/kg in the LMA group vs. 5.3 ± 1.1 ml/kg in the endotracheal tube group; P < 0.05) and minute ventilation (325 ± 105 ml min⁻¹ kg⁻¹ in the LMA group vs. 246 ± 88 ml min⁻¹ kg⁻¹ in the endotracheal tube group; P < 0.05) were lower in the endotracheal tube group. The phase delay index (18 ± 11% in the LMA group vs. 41 ± 19% in the endotracheal tube group; P < 0.05) and the amplitude index (25 ± 45% in the LMA group vs. 74 ± 72% in the endotracheal tube group; P < 0.05) were significantly smaller with the LMA than with the endotracheal tube.

Conclusions: In 6–24-month-old children anesthetized with halothane, paradoxical inspiratory movement is less when breathing through an LMA than through an endotracheal tube.

Keywords: Anesthesia; halothane; pediatric; equipment; endotracheal tube; laryngeal mask airway. Ventilation.

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VENTILATION AND LARYNGEAL MASK AIRWAY

Materials and Methods

Twenty children were studied with the consent and the approval of our institutional review board. The patients were 6–24 months old and were undergoing elective minor surgery that was avoided and children less than 6 months were excluded from the study.

The study was performed before induction of anesthesia (i.e., used only and surgically randomized to two groups: endotracheal tube [n = 10] and LMA [n = 10]). The endotracheal tube was chosen at the discretion of the child. We used LMA size 1 (range: 8.5–12 kg), size 2 (3.5–7 kg), size 3 for children (weight ≥ 7 kg), size 4 for children (weight ≥ 10, 2, 8, and 10.3 kg), and size 5 for children (weight ≥ 19 kg). The cuff was inflated to just permit intubation of the endotracheal tube when using neumoumoculcular blockers and the inspired concentration of halothane was then decreased so that the concentration was 1.5 MAC. The inspired concentration of halothane was adjusted to permit intubation of the endotracheal tube when using neumoumoculcular blockers and the inspired concentration was then decreased so that the concentration was 1.5 MAC. The inspired concentration of halothane was adjusted to permit intubation of the endotracheal tube when using neumoumoculcular blockers and the inspired concentration was then decreased so that the concentration was 1.5 MAC.

All the data presented were obtained from measurements from 20 seconds at a chart speed of 25 mm/s on a Valley View, OH). Gas flow pneumotachograph (Gould) was used and analyzed with a standard pneumotachograph head was used and the tracheal or LMA of the gas delivery system was obtained from the airflow signal. Inspiratory tidal volume was obtained from the airflow signal.
Materials and Methods

Twenty children were studied after informed parental consent and the approval of our hospital Ethical Committee. The patients were 6–24 months of age, were free of cardiopulmonary or neurologic disorders, and were undergoing elective minor surgery. Premedication was avoided and children born prematurely were excluded from the study.

The study was performed before performing regional anesthesia (if used) and surgery. The children were randomly allocated to two groups: LMA (n = 10) and endotracheal tube (n = 10). The sizes of LMA and endotracheal tubes were chosen according to the weight of the child. We used LMA size 2 in all children (weight range 8.5–12 kg) and cuffed endotracheal tube size 5.5 for three children (weighing, respectively, 7.1, 6.2, and 7 kg), size 4 for three children (weighing, respectively, 10.2, 8, and 9.3 kg), and size 4.5 for four children (weighing, respectively, 12, 12.7, 14, and 12.1 kg). The cuff was inflated only during the duration of the study. Anesthesia was induced with a mixture of oxygen, nitrous oxide (50% N₂O), and halothane. The inspired concentration of halothane was initially adjusted to permit intubation or LMA introduction without using neuromuscular blockade. Nitrous oxide was stopped and the inspired concentration of halothane was then decreased so that the end-tidal halothane concentration was 1.5 MAC. The MAC was corrected according to the age of the patient and the end-tidal concentration of halothane and N₂O was monitored with a gas analyzer (Capnomag, Datex, Helsinki, Finland). Equilibrium was obtained when the expired and inspired concentrations of halothane were equal. Measurements were performed once a steady state was established for 10 min. The children breathed spontaneously via a semi-open system that included a non-rebreathing low-opening-pressure valve (Digby-Leigh, ISSA, Paris, France).

All the data presented were obtained by averaging measurements from 20 successive breaths recorded at a chart speed of 25 mm/s on a Gould ES 1000 recorder (Valley View, OH). Gas flow was measured with a pneumotachograph (Gould Godard) calibrated before each analysis with a standard volume of 1000 ml. The pneumotachograph head was inserted between the valve and the tracheal or LMA tubes. The dead space of the gas delivery system was 7 ml. Tidal volume (Vt; ml/kg) was obtained from integration of the inspiratory airflow signal. Inspiratory time (Ti), total respiratory time (Ttot), and respiratory rate (RR) were measured. Minute ventilation (Vt/min·kg⁻¹), mean inspiratory flow (VTi/ml·kg⁻¹·s⁻¹), and effective inspiratory time (Ti/Ttot) were calculated. End-tidal carbon dioxide pressure (PETCO₂; mmHg) was measured using a capnograph (MARK III, Gould Godard) calibrated before each study. The thoracic and abdominal movements during ventilation were measured with a Respitrace (model 150, Studley Instruments, Ardsley, NY). Bands were placed at the nipple level on the rib cage and at the level of the umbilicus on the abdomen. Abdominal movements and gas flow were synchronous in all instances, and the onset of inspiration was defined by simultaneous outward movement of the abdomen and increase in inspiratory gas flow. Inspiratory rib cage depression was defined when a thoracic inward movement was present at the onset of inspiration. Inspiratory rib cage depression was assessed by two indices, as shown in figure 1. The thoracic amplitude index was the amplitude of the rib cage depression during inspiration, expressed as a percentage of the positive contribution of the thorax to inspiration. The thoracic delay index was measured at the onset of expiration. This point was defined by simultaneous inward movement of the abdomen and increase in expiratory gas flow. At the end of expiration, when inspiratory rib cage...
Table 1. Ventilatory Measurements with Tracheal Tube and Laryngeal Mask Airway

<table>
<thead>
<tr>
<th></th>
<th>Tracheal Tube</th>
<th>Laryngeal Mask Airway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vt</td>
<td>5.3 ± 1.1</td>
<td>7.5 ± 1.9*</td>
</tr>
<tr>
<td>RR</td>
<td>48 ± 11</td>
<td>43 ± 8</td>
</tr>
<tr>
<td>Vd</td>
<td>246 ± 38</td>
<td>325 ± 105*</td>
</tr>
<tr>
<td>PCO₂</td>
<td>41 ± 6</td>
<td>44 ± 10</td>
</tr>
<tr>
<td>T / Ttot</td>
<td>0.44 ± 0.03</td>
<td>0.44 ± 0.03</td>
</tr>
<tr>
<td>Vt / Ti</td>
<td>9.4 ± 1.4</td>
<td>12.3 ± 4.1</td>
</tr>
</tbody>
</table>

Values are mean ± SD.

Vt = tidal volume (ml·kg^-1); RR = respiratory rate (breaths·min^-1); Vd = minute ventilation (ml·min^-1·kg^-1); PCO₂ = carbon dioxide end-tidal pressure (mmHg); T = inspiratory time (s); Ttot = total inspiratory time (s); Vt/Ti = mean inspiratory flow (ml·kg^-1·s^-1).

* P < 0.05 versus tracheal tube.

Fig. 2. Amplitude index in the laryngeal mask airway group (LMA) and in the endotracheal tube group (ET). The solid horizontal lines represent the mean value of amplitude index in each group; the points are individual values (● = children greater than 1 yr of age; □ = children less than 1 yr of age).

Depression occurred, the thoracic outward movement continued, although lung volume began to decrease. Consequently, the delay of the thoracic inward movement relative to that of the abdomen at the onset of expiration could be measured and was expressed as a percentage of Tt.

Comparisons were done using the Mann–Whitney U test for inspiratory rib cage depression indices and Student’s t test for other variables. A P value of less than 0.05 was required to consider differences as significant. The values are expressed as mean ± SD.

Results

The children in the two groups were of similar age (14 ± 5 months, range 7–24 months, in the LMA group vs. 12 ± 6 months, range 6–23 months, in the endotracheal tube group) and weight (10.4 ± 1.2 kg in the LMA group vs. 9.9 ± 2.7 kg in the endotracheal tube group).

The ventilatory results are presented in table 1. The Vt and Vd were lower in the endotracheal tube group. There was no difference between the two groups with regard to PCO₂, RR, Ti/Ttot, and Vt/Ti. The phase delay index (fig. 2; 18 ± 11% in the LMA group vs. 41 ± 19% in the endotracheal tube group; P < 0.05) and the amplitude index (fig. 3; 25 ± 43% in the LMA group vs. 74 ± 72% in the endotracheal tube group; P < 0.05) were significantly smaller in the LMA group compared with the endotracheal tube group.

Discussion

In the current study, paradoxic inspiratory movement, as assessed with two inspiratory rib cage depression indices, was smaller in children breathing through an LMA than through an endotracheal tube, during halothane anesthesia. The lesser inspiratory rib cage depression observed with the LMA was associated with greater Vt and Vd.

To avoid any side effects from medication or pain on respiration, the study was performed before surgery and regional anesthesia in children who were unpremedicated. Similarly, anesthesia with 15% N₂O and halothane without N₂O and halothane at 1.5 MAC was used. This concentration is in the range of clinical practice and experimental conditions in which 24-month-old children, half the age of the children in the study, were studied. The length of the study was limited to anesthesia, but was sufficient to maintain the steady state. With these conditions, ventilation could be considered to be controlled by factors such as halothane and the airway of the endotracheal tube. Thus, it is possible that the effects of the LMA and the endotracheal tube on ventilation of children anesthetized with halothane in the absence of any other parameters requires noninvasive and invasive techniques relative to lung volume change.

The main result was that the amplitude indices were smaller in the LMA group than in the endotracheal tube group. The inspiratory rib cage depression index was greater in the LMA group than in the endotracheal tube group. Furthermore, the amplitude index was less than 5%, i.e., the depression and only one group, the LMA group, had an amplitude index less than 5% and the depression was greater than 50%, i.e., severe depression. Thus, the inspiratory rib cage distortion was significantly smaller in an endotracheal tube. Therefore, the hypothesis that an LMA, as an endotracheal tube, produces a lesser inspiratory rib cage distortion in children anesthetized with halothane and maintaining similar PCO₂, RR, and tidal volume was very brief, we speculate that the greater paradoxic inspiratory rib cage depression observed with an endotracheal tube could reduce the increased contribution of the increased tidal volume to the wall muscles avoiding inspiratory chest wall compliance.

Fig. 3. Phase delay index in the laryngeal mask airway group (LMA) and in the endotracheal tube group (ET). The solid horizontal lines represent the mean value of delay index in each group; the points are individual values (● = children greater than 1 yr of age; □ = children less than 1 yr of age).
medicated. Similarly, anesthesia was induced only with 
N₂O and halothane without neuromuscular blockade. 
Halothane at 1.5 MAC was used in this study because 
this concentration is in the range commonly used in 
clinical practice and experimental designs. In 6- 
24-month-old children, the halothane MAC varies with 
age. The concentration of halothane was, therefore, 
normalized according to the age of each patient. The 
length of the study was limited to minimize exposure 
to halothane, but was sufficient to obtain a stable 
ventilatory steady state. With these standardized anesthetic 
conditions, ventilation could be affected by only two 
factors: halothane and the airway device, i.e., LMA or 
endotracheal tube. Thus, it was possible to compare 
the effects of the LMA and the endotracheal tube on the 
ventilation of children anesthetized with halothane. 
The inspiratory rib cage depression indices used in this 
study have been described in a previous study. These 
parameters require noninvasive measurements of thoracic 
and abdominal movements without calibration 
relative to lung volume change.

Our main result was that the phase delay and amplitude 
indices were smaller in the LMA group than in the 
endotracheal tube group. This improvement of inspiratory 
rib cage depression indices was associated with 
greater Vt and Vc in the LMA group than in the 
endotracheal tube group. Furthermore, we should note (fig. 
3) that, in the LMA group, five children had an amplitude 
index less than 5%, i.e., no inspiratory rib cage 
depression and only one greater than 50%. Conversely, 
in the endotracheal tube group, only one child had an 
amplitude index less than 5%; however, in five children, 
it was greater than 50%, i.e., high inspiratory rib cage 
depression. Thus, significantly fewer children exhibited 
inspiratory rib cage distortion with an LMA than with 
an endotracheal tube. Therefore, our data support the hypothesis that an LMA, as compared with an endotracheal 
tube, produces a lesser degree of inspiratory rib 
cage distortion in children anesthetized with halothane 
and maintaining similar PETCO₂. Although the study pe-
riod was very brief, we speculate that, over time, the 
greater paradoxical inspiratory movement with sponta-
neous ventilation via an endotracheal tube compared 
with an LMA could lead to diaphragmatic fatigue be-
cause of the increased contribution the diaphragm must 
made for a constant minute ventilation.

In infants, chest wall compliance is high compared 
with pulmonary compliance. During inspiration, the 
rib cage is actively stabilized by the contraction of chest 
walls muscles avoiding inspiratory rib cage depression 
during diaphragmatic contraction. It has been 
shown using animal models that halothane inhibits 
the intercostal muscles more than the diaphragmatic 
muscles. In human studies, a decrease in the contribu-
tion of the rib cage to ventilation has been noted 
during halothane anesthesia. In children, dose-de-
pendent inspiratory rib cage depression has been shown 
to occur during halothane anesthesia. These observa-
tions support the notion that halothane, by itself, is 
able to induce inspiratory rib cage depression in infants.

Our study shows that the endotracheal tube may con-
tribute to the halothane-induced depression of rib cage 
muscle activity. The mechanical load imposed on the 
intercostal muscles by the endotracheal tube results in 
increased degrees of paradoxic inspiratory chest wall 
motion. In contrast, an LMA with a lower resistance to 
gas flow may limit inspiratory rib cage distortion in 
many children. However, the larger Vt and Vc and the 
associated trend toward an elevated PaCO₂ with the LMA 
indicate increased dead space ventilation that would 
reduce the total workload imposed on the respiratory 
muscles. Therefore, at the very least, it can be argued that 
the LMA does not appear to be worse than the 
endotracheal tube, trading increased dead space (volume 
work) for reduced airway resistance (resistive work). 
The brevity of the study period does not allow deter-
mination of whether spontaneous ventilation with an 
endotracheal tube is or is not appropriate. We can, 
however, speculate that prolonged spontaneous ven-
tilation in children via an LMA is less affected than is 
ventilation via a higher-resistance endotracheal tube, 
thereby decreasing the likelihood of diaphragmatic 
fatigue.

In conclusion, our study showed that, during hal-
mothane anesthesia, children spontaneously breathing via 
an LMA have less paradoxical inspiratory distortion than 
do children breathing via an endotracheal tube. This 
was associated with greater Vc and Vt in the LMA group. 
Further studies are needed to define the relative merits 
of each airway during spontaneous ventilation under 
specific clinically relevant conditions.

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