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Spontaneous Ventilation with Halothane in Children

A Comparative Study between Endotracheal Tube and Laryngeal Mask Airway

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Background: **It has been reported that, in children breathing spontaneously *via* an endotracheal tube, halothane depresses ventilation with paradoxic 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 cardiorespiratory and 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 CO_2. They assessed paradoxic 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 $ml \cdot min^{-1} \cdot kg^{-1}$ in the LMA group *vs.* 246 ± 38 $ml \cdot min^{-1} \cdot kg^{-1}$ 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 ± 43% 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, paradoxic inspiratory movement is less when breathing through an LMA than through an endotracheal tube. (Key words: Anesthesia: halothane; pediatric. Equipment: endotracheal tube; laryngeal mask airway. Ventilation.)**

PEDIATRIC surgical operations are often peripheral and of short duration, and can be performed on patients breathing spontaneously. It is, therefore, clinically relevant to evaluate the respiratory effects of anesthetic agents and techniques. Halothane is the most commonly used agent in pediatric anesthesia. It depresses alveolar ventilation in a dose-dependent manner in adults[1] as well as in children.[2–7] This ventilatory depression is related, in part, to a preferential depression of intercostal muscle relatively to the diaphragmatic muscles.[8–10] In infants, chest wall compliance is high compared with pulmonary compliance and, during inspiration, intercostal muscles contraction prevents the rib cage from being drawn inward by diaphragmatic contraction.[11–13] By predominantly inhibiting intercostal muscles, the use of halothane in children leads to inspiratory rib cage depression.[14] Thus, this mechanical impairment of ventilation in children anesthetized with halothane may result in prolonged spontaneous ventilation being regarded with caution.

These respiratory depressant effects have been observed in children breathing through an endotracheal tube, which is known to increase respiratory work.[15] Alternatively, a laryngeal mask airway (LMA), because of its lower airflow resistance, induces less respiratory mechanical overload than does an endotracheal tube.[16] However, apart from the Sp_{O_2}, the respiratory effects of LMA in children anesthetized with halothane have never been evaluated.[17] The aim of our study was, therefore, to compare spontaneous ventilation *via* LMA and endotracheal tube in children anesthetized with halothane. Respiratory mechanics were assessed with two indices of inspiratory rib cage depression,[14] and ventilation was evaluated using standard ventilatory parameters at 1.5 minimum alveolar concentration (MAC) of halothane.

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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 cardiorespiratory 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 3.5 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% N_2O), 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[18] and the end-tidal concentration of halothane and N_2O 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 semiopen system that included a nonrebreathing low-opening-pressure valve (Digby-Leigh, LSSA, 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 (V_E; $ml \cdot min^{-1} \cdot kg^{-1}$), mean inspiratory flow (Vt/Ti; $ml \cdot kg^{-1} \cdot s^{-1}$), and effective inspiratory time (Ti/Ttot) were calculated. End-tidal carbon dioxide pressure (PET_{CO_2}; 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.[14] 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

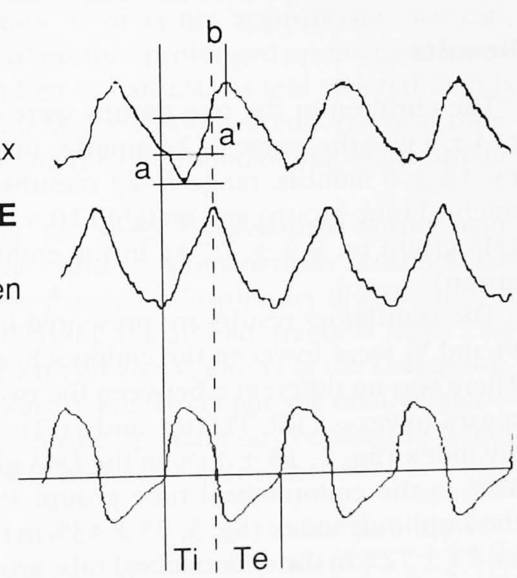

Fig. 1. Measurements of the inspiratory rib cage depression indices. Ti = inspiratory time; Te = expiratory time. (*a*) Amplitude of the rib cage depression during inspiration. (*a'*) Positive contribution of the thorax to inspiration. (*b*) Delay of the thoracic inward movement relative to that of abdomen at the end of inspiration. The amplitude index was calculated as: (a/a') × 100. The phase delay index was calculated as: (b/Ti) × 100.

Table 1. Ventilatory Measurements with Tracheal Tube and Laryngeal Mask Airway

	Tracheal Tube	Laryngeal Mask Airway
V_t	5.3 ± 1.1	7.5 ± 1.9*
RR	48 ± 11	43 ± 8
V_E	246 ± 38	325 ± 105*
$P_{ET_{CO_2}}$	41 ± 6	44 ± 10
T_i/T_{tot}	0.44 ± 0.03	0.44 ± 0.03
V_t/T_i	9.4 ± 1.4	12.3 ± 4.1

Values are mean ± SD.

V_t = tidal volume (ml · kg^{-1}); RR = respiratory rate (breaths · min^{-1}); V_E = minute ventilation (ml · min^{-1} · kg^{-1}); $P_{ET_{CO_2}}$ = carbon dioxide end-tidal pressure (mmHg); T_i = inspiratory time (s); T_{tot} = total respiratory time (s); V_t/T_i = mean inspiratory flow (ml · kg^{-1} · s^{-1}).

* $P < 0.05$ *versus* tracheal tube.

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 Ti.

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 V_E were lower in the endotracheal tube group. There was no difference between the two groups with regard to $P_{ET_{CO_2}}$, 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 *via* an LMA than *via* an endotracheal tube, during halothane anesthesia. The lesser inspiratory rib cage depression observed with the LMA was associated with greater V_E and Vt.

To avoid any side effects from medication or pain on respiration, the study was performed before surgery and regional anesthesia in children who were unpre-

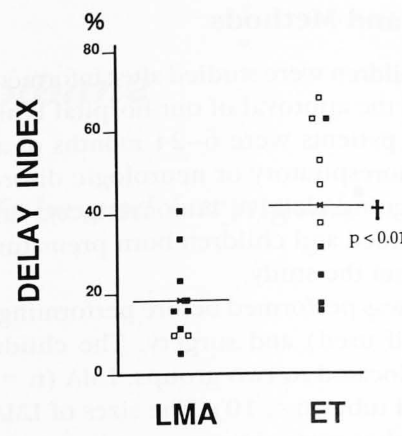

Fig. 2. Amplitude index in the laryngeal mask airway group (LMA) and in the endotracheal tube group (ET). The solid horizontal lines represent the mean value of amplitude index in each group; the points are individual values (■ = children greater than 1 yr of age; □ = children less than 1 yr of age).

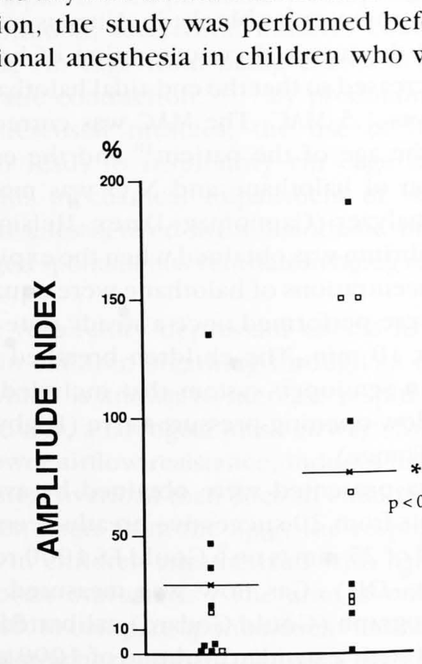

Fig. 3. Phase delay index in the laryngeal mask airway group (LMA) and in the endotracheal tube group (ET). The solid horizontal lines represent the mean value of delay index in each group; the points are individual values (■ = children greater than 1 yr of age; □ = children less than 1 yr of age).

medicated. Similarly, anesthesia was induced only with N_2O 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.[2–7] In 6–24-month-old children, the halothane MAC varies with age.[18] 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.[14] 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 V_E 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 $P_{ET_{CO_2}}$. Although the study period was very brief, we speculate that, over time, the greater paradoxic inspiratory movement with spontaneous ventilation *via* an endotracheal tube compared with an LMA could lead to diaphragmatic fatigue because of the increased contribution the diaphragm must make 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 wall muscles avoiding inspiratory rib cage depression during diaphragmatic contraction.[11–13] It has been shown using animal models[8,9] that halothane inhibits the intercostal muscles more than the diaphragmatic muscles. In human studies, a decrease in the contribution of the rib cage to ventilation has been noted during halothane anesthesia.[10] In children, dose-dependent inspiratory rib cage depression has been shown to occur during halothane anesthesia.[14] These observations 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 contribute 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[16] may limit inspiratory rib cage distortion in many children. However, the larger Vt and V_E and the associated trend toward an elevated Pa_{CO_2} with the LMA indicate increased dead space ventilation that would increase 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 determination of whether spontaneous ventilation with an endotracheal tube is or is not appropriate. We can, however, speculate that prolonged spontaneous ventilation 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 halothane anesthesia, children spontaneously breathing *via* an LMA have less paradoxic inspiratory distortion than do children breathing *via* an endotracheal tube. This was associated with greater V_E 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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