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# Humidification during low-flow anesthesia in children

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**Abstract**
*Purpose.* The aim of this study was to compare the effect of low-flow anesthesia with or without a heat and moisture exchanger with high-flow anesthesia on airway gas humidification in children.
*Methods.* One hundred twenty children were randomly assigned to one of three groups: low-flow anesthesia with 0.5 l·min$^{-1}$ of total gas flow (LFA, $n = 40$), low-flow anesthesia with 0.5 l·min$^{-1}$ using a heat and moisture exchanger (HME, $n = 40$), and high-flow anesthesia with 6 l·min$^{-1}$ (HFA, $n = 40$). The temperature and relative humidity of the inspired gas were measured throughout anesthesia.
*Results.* The relative humidity of the inspired gas in the HME group was increased compared with that of the LFA and HFA groups 20 min after induction ($p < 0.05$). The airway humidification in the LFA group was higher than that in the HFA group 10 min after induction ($p < 0.05$). The temperature of the inspired gas in the HME group was increased compared with that in the LFA and HFA groups after 70 min ($P < 0.05$).
*Conclusion.* Low-flow anesthesia is less effective in providing adequate humidification of inspired gas than low-flow anesthesia with a heat and moisture exchanger, but significantly better than high-flow anesthesia in children.

**Key words:** Anesthesia, Pediatric, Anesthetic techniques, Low-flow anesthetic techniques, Equipment, Heat and moisture exchanger, Anesthetics, Sevoflurane

## Introduction

Intraoperative airway humidification in intubated patients prevents tracheal damage from dry inspired gases, increases tracheal mucus flow, and reduces the incidence of postoperative pulmonary complications [1–3]. Humidified anesthetic gases are valuable in reducing respiratory heat loss and minimizing intraoperative hypothermia in adults [4] and children [5]. A heat and moisture exchanger (HME, artificial nose) can passively control the humidification of respiratory gases and is a handy and valuable device to protect the patient from decreasing intraoperative body temperature [6,7]. However, the HME does not attain adequate humidification immediately in infants [5,8]. Low fresh gas flows of less than 2 l·min$^{-1}$ provide sufficient humidification in adults [9,10]. In infants, reducing the fresh gas flow slowly increases the humidity of the inspired gas [11]. There are few reports concerning the humidification of anesthetic gases using an HME during low-flow anesthesia in children. The aim of this study was to compare the effect of low-flow anesthesia with or without an HME with high-flow anesthesia on airway gas humidification in children.

## Materials and methods

This study was approved by the Human Investigation Committee of Hokkaido Children's Medical Center, and informed consent was obtained from each patient's parent. One hundred twenty children between 1 month and 4 years of age with ASA physical status I or II scheduled for elective neurosurgery were studied.

A Cicero anesthesia system (Dräger, Lübeck, Germany) with a pediatric circle (diameter, 1.1 cm; length, 110 cm; compliance, 3.1 ml·mbar$^{-1}$) attached to a standard adult $CO_2$ absorbent canister was used. Fresh soda lime (1.5 l, WAKO LIME-A, Wako Pure Chemical Industries, Osaka, Japan) was used as a $CO_2$ absorbent. Patients received no premedication. Anesthesia was slowly induced via a face mask with 4 l·min$^{-1}$ nitrous oxide, 2 l·min$^{-1}$ oxygen, and 4% sevoflurane. The trachea was intubated with the tracheal tube without cuff,

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and 0.1 mg·kg$^{-1}$ of vecuronium was used if necessary. The optimal sizes of the endotracheal tube were chosen to permit an air leak between the tube and the trachea at airway pressures of 20 cm$H_2O$. After intubation, nitrogen was eliminated with 6 l·min$^{-1}$ of oxygen for 10 min.

The children were randomly assigned to one of three groups: low-flow anesthesia with 0.5 l·min$^{-1}$ of total gas flow (LFA group, $n$ = 40), low-flow anesthesia with 0.5 l·min$^{-1}$ of total gas flow using a heat and moisture exchanger (HME, Thermovent 600, Portex, Kent, UK) placed between the endotracheal tube adapter of the circle system and the endotracheal tube (HME group, $n$ = 40), and high-flow anesthesia with 6 l·min$^{-1}$ of total gas flow (HFA group, $n$ = 40). The dead space of the HME was 7.0 ml and the resistance was 0.13 cm$H_2O$ at 5 l·min$^{-1}$.

Anesthesia was maintained with a 1:1 mixture of nitrous oxide and oxygen and sevoflurane. The concentration of sevoflurane during maintenance of anesthesia ranged from 1.5% to 3.5%, depending on age and stimulation-related requirements. Minimum alveolar concentration (MAC)-hour values of sevoflurane were determined by using the mean end-tidal concentrations with the age-appropriate MAC value [12] at 5-min intervals. No barbiturates or opioids were given during anesthesia. Controlled mechanical ventilation was adjusted to maintain partial pressure of end-tidal $CO_2$ ($P_{ET}CO_2$) between 30 and 40 mmHg with vecuronium. In order to conserve body heat, the ambient temperature of the operating room was adjusted to 25°C. After the surgery was completed, the total gas flow was adjusted to 6 l·min$^{-1}$ of oxygen in all groups. The endotracheal tube was removed after spontaneous breathing was sufficient.

The relative humidity and temperature of the inspired gas were measured with a Humicap Humidity meter (Vaisala, Helsinki, Finland) and thermometer probe (temperature sensor 8405371, Dräger) placed between the endotracheal tube adapter of the circle system (or the HME) and the endotracheal tube. The response times of the humidity sensor and thermometer probe were within 2 s for a 90% relative humidity response and 1 s for a 90% temperature response. The dead space of the humidity sensor was 5.5 ml. The humidity sensor was calibrated with saturated sodium chloride and lithium chloride solutions before and after each application. The humidity of the inspired gas was recorded by a polygraph system (Nihonkohden, Tokyo, Japan) and the temperature was recorded by a PM 8020 Data manager (Dräger) throughout anesthesia. The absolute humidity was calculated from the relative humidity and temperature according to the following formula: $AH = (3.939 + 0.5019T + 0.00004615T^2 + 0.0004188T^3) \times RH/100$, where AH is absolute humidity, T is temperature, and RH is relative humidity.

The electrocardiogram, blood pressure, arterial hemoglobin oxygen saturation ($SpO_2$), fraction of inspired oxygen, inspired and expired concentration of sevoflurane and nitrous oxide, $P_{ET}CO_2$, tidal volume, respiratory rate, minute ventilation, peak airway pressure, and rectal temperature were continuously measured and recorded by a PM 8020 Data manager (Dräger) during anesthesia. A sampling tube for measuring both $P_{ET}CO_2$ and the concentrations of anesthetic gases was connected to the endotracheal tube adapter. The gas sampling flow rate was 60 ml·min$^{-1}$ and the sampling gas was returned to the expired circuit.

All values are expressed as mean ± SD. Statistical analysis of the data among the groups was performed by multiple analysis of variance with repeated measures, followed by Student's $t$-test, with Bonferroni's adjustment for multiplicity. A $P$ value of less than 0.05 was accepted as significant.

## Results

The three study groups did not differ significantly in mean age, weight, height, duration of anesthesia or surgery, MAC-hour sevoflurane, tidal volume, or respiratory rate (Table 1). There were no differences in the duration of low-flow anesthesia between the LFA and HME groups. The type of surgery also did not differ markedly.

The relative and absolute humidity of the inspired gas in the HME group was significantly increased compared with those in the LFA and HFA groups 20 min after induction (Figs. 1 and 2). The HME provided >60% of the humidity after 20 min and required over 1 h to saturate fully (approximately 80% of the humidity). The airway humidification in the LFA group (48.2 ± 16.4%) was significantly higher than that in the HFA group (5.2 ± 4.3%) 10 min after induction. The solo, low-flow anesthesia required over 1 h to provide >60% of the humidity. The absolute humidity in the LFA group was significantly higher than that in the HFA group 10 min after induction.

The temperature of the inspired gas in the HME group (32.0 ± 1.6°C) was significantly increased compared with that in the LFA (28.6 ± 1.2°C) and HFA groups (28.9 ± 1.6°C) after 70 min (Fig. 3). There were no significant differences between the LFA and HFA groups during anesthesia.

## Discussion

The relative humidity of the inspired gases differed considerably among the three groups (HME > LFA >

**Table 1.** Group characteristics and details of anesthesia

| Characteristic | LFA ($n$ = 40) | HME ($n$ = 40) | HFA ($n$ = 40) |
|---|---|---|---|
| Age (mo) | 6.2 ± 4.3 | 4.8 ± 3.7 | 4.8 ± 4.7 |
| Weight (kg) | 6.2 ± 2.3 | 6.5 ± 2.0 | 5.3 ± 2.9 |
| Height (cm) | 60.5 ± 12.7 | 59.8 ± 9.7 | 52.5 ± 22.5 |
| Duration of anesthesia (min) | 204 ± 84 | 197 ± 56 | 197 ± 92 |
| Duration of surgery (min) | 132 ± 72 | 124 ± 51 | 153 ± 73 |
| Duration of LFA (min) | 141 ± 74 | 139 ± 48 | |
| MAC-hr sevoflurane | 3.9 ± 1.9 | 3.2 ± 1.2 | 3.3 ± 1.8 |
| Tidal volume (ml·kg$^{-1}$) | 10.9 ± 0.9 | 10.5 ± 0.8 | 11.1 ± 0.8 |
| Respiratory rate (breaths·min$^{-1}$) | 18.2 ± 2.2 | 17.5 ± 2.0 | 17.1 ± 1.8 |

Values are shown as mean ± SD. LFA, Low-flow anesthesia group; HME, heat and moisture exchanger group; HFA, high-flow anesthesia group; MAC, minimum alveolar concentration.

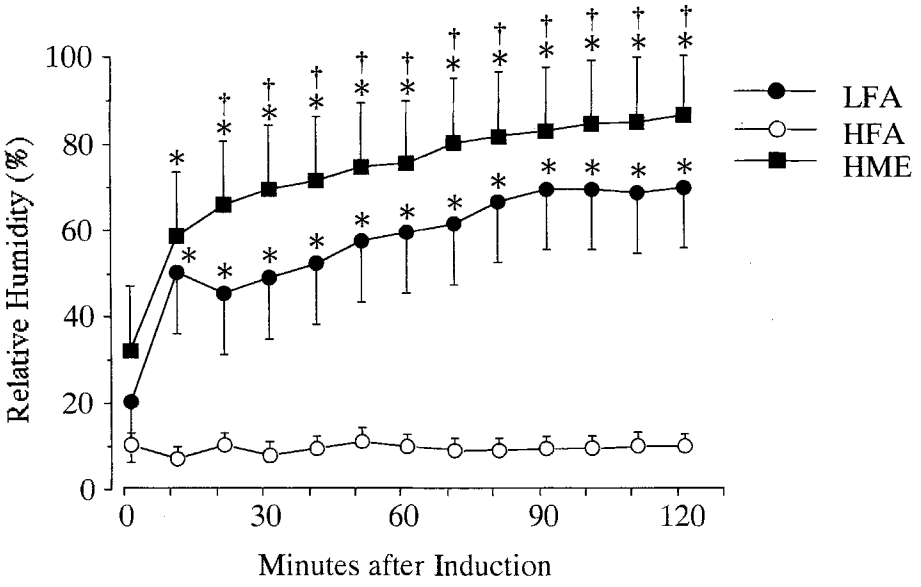


**Fig. 1.** Relative humidity of inspired gas. The relative humidity of the inspired gas in the heat and moisture exchanger (HME) group significantly increased compared with that in the low-flow anesthesia (LFA) and high-flow anesthesia (HFA) groups 20 min after induction. The humidification in the LFA group was significantly higher than that in the HFA group 10 min after induction. †$P < 0.05$ compared with the LFA group; *$P < 0.05$ compared with the HFA group. All values are expressed as mean ± SD

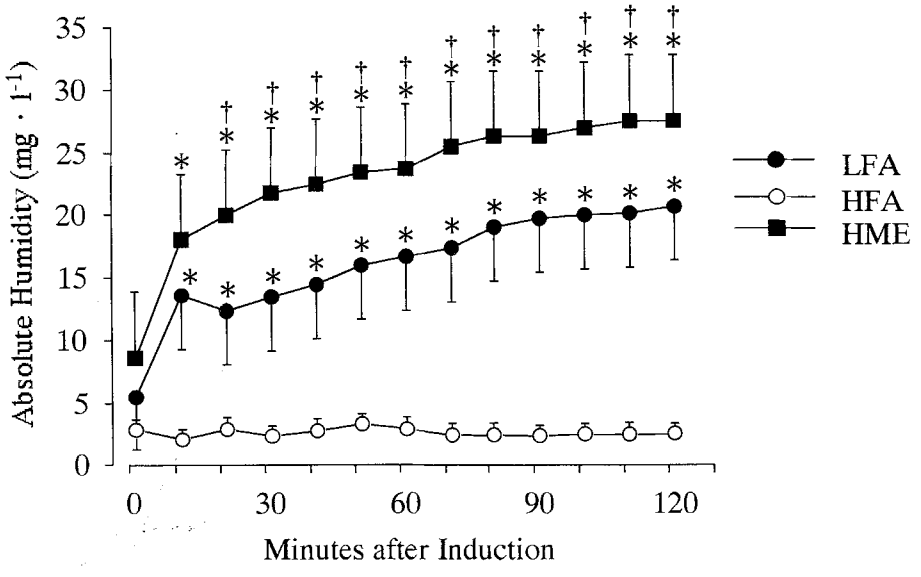


**Fig. 2.** Absolute humidity of inspired gas. The absolute humidity of inspired gas in the HME group significantly increased compared with that in the LFA and HFA groups 20 min after induction. The absolute humidity in the LFA group was significantly higher than that in the HFA group 10 min after induction. †$P < 0.05$ compared with the LFA group; *$P < 0.05$ compared with the HFA group. All values are expressed as mean ± SD

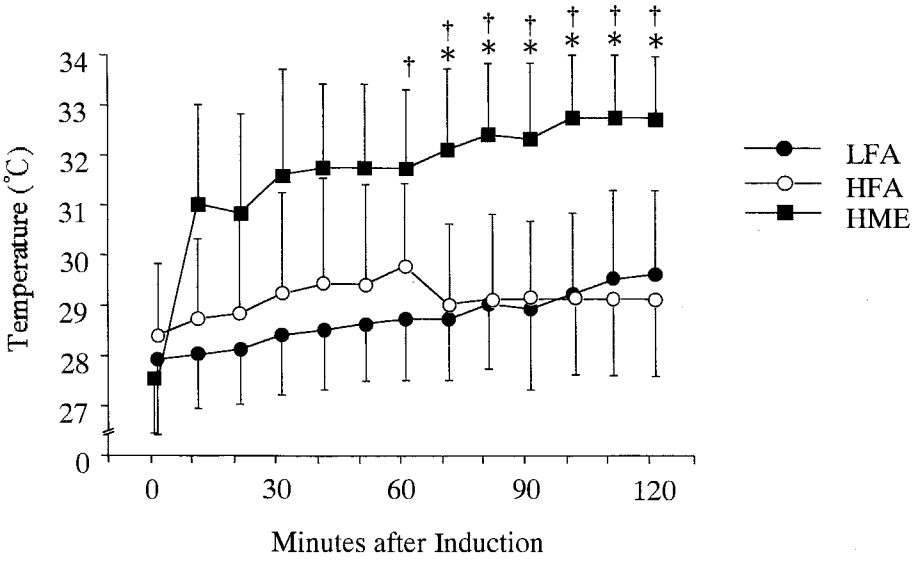


**Fig. 3.** Temperature of the inspired gas. The temperature of the inspired gas in the HME group significantly increased compared with that in the LFA and HFA groups after 70 min. †$P < 0.05$ compared with the LFA group; *$P < 0.05$ compared with the HFA group. All values are expressed as mean ± SD

HFA). Only the low-flow anesthesia required 75 min to achieve sufficient humidification. In adults, fresh gas flows less than 2 l·min$^{-1}$ provided adequate humidification even without the HME [10]. In infants and children, low fresh gas flows required over 2 h to saturate fully [11]. Bissonnette et al. reported that the use of the HME at a high fresh gas flow rate was less effective than active humidification with a heated humidifier in infants [5,8]. It required 60 and 80 min to achieve 80% of the relative humidity of the inspired gases using a circle system [8] and a Jackson-Rees modification of an Ayre's T-piece [5], respectively. Our results showed that the use of an HME under low-flow anesthesia provided >60% relative humidity of the inspired gases, the amount needed to prevent ciliary damage [1], 20 min after induction. Therefore, the application of an HME is recommended to promote airway humidification in low-flow anesthesia in children.

In our study, the temperature of inspired gas increased in the HME group 70 min after induction, but not in the LFA and HFA groups. Previous reports [2,5–8] demonstrated that intraoperative hypothermia was not prevented by humidification, either by using a heated humidifier or an HME in adults and children. To minimize convective and evaporative heat losses via the respiratory system, inspiratory gases should be heated to 35°–36°C [14]. Although the temperature of the inspired gas might not be high enough for children in the present study, hypothermia could be prevented by using a heated operating room, blankets, and warming mattresses.

In the present study, the response time of the sensor, which is in the range of a few seconds, did not affect the accuracy of the measurements of relative humidity, because most patients were ventilated at respiratory rates less than 20 breaths·min$^{-1}$. Recently, the humidity sensor, which is operated on a capacitive principle, has been widely employed because of its quick reaction [10]. Thus, the more accurate measurements would be obtained by the use of a capacitive humidity sensor.

Low-flow anesthesia has not been widely employed in children because of the potential leaks due to the use of a cuffless endotracheal tube. We adapted the cuffless endotracheal tube to allow a slight leak around the tube when 20 cm$H_2O$ positive pressure is applied to the circuit, in accordance with current practice. Because gases lost around the endotracheal tube slightly decrease the effectiveness of passive airway humidifiers [15], we maintained peak inspiratory pressures below those required to cause a leak. To minimize the loss of volume in the circuit, the gas sampling flow for measuring $P_{ET}CO_2$ was returned to the expired circuit. Furthermore, we used a lower compliance anesthetic circuit (3.1 ml·mbar$^{-1}$) compared with common pediatric circle circuits (3.5 ml·mbar$^{-1}$). Consequently, whether the low flow is being maintained can be easily determined by checking an expanded reservoir bag placed in the anesthetic circuit. The monitoring of the fraction of inspired oxygen facilitated the safe use of low-flow anesthesia in children.

It has been demonstrated that compound A produced by degradation of sevoflurane in the presence of $CO_2$ absorber may cause renal injury above a concentration of 50 ppm in animal experiments [16–18]. However, in clinical use there are few reports of renal dysfunction caused by sevoflurane in high-flow and low-flow anesthesia [19,20]. No abnormality of renal function was observed during sevoflurane anesthesia using a 2-l flow in children [21]. In the present study, we applied 0.5 l·min$^{-1}$ of total gas flow during sevoflurane anesthe-

sia within 3 h. Recently it was reported that the inspiratory concentrations of compound A were 22.7 ± 10.7 ppm during sevoflurane anesthesia within 5 h with 0.5 l·min$^{-1}$ in children [22]. Thus, it is speculated that the concentration of compound A does not exceed 50 ppm in our study. Further studies will be required to confirm the safety of low-flow anesthesia with sevoflurane in children.

In conclusion, low-flow anesthesia is less effective in providing adequate humidification of inspired gas than low-flow anesthesia with an HME, but significantly better than high-flow anesthesia in children. The use of an HME is recommended during low-flow anesthesia in children.

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