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Efficacy of a heat and moisture exchanger in inhalation anesthesia at two different flow rates

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Abstract
In general anesthesia with endotracheal intubation, a circle system with a heat and moisture exchanger (HME) and a low total flow is often used to prevent hypothermia and to maintain inspired gas humidity. The purpose of the present study was to compare the inspired gas humidity and body temperature, in general anesthesia with or without an HME at two different total flow rates. Eighty patients (American Society of Anesthesiologists [ASA] I or II) scheduled to undergo either orthopedic or head and neck surgery were studied. They were divided into four groups, of 20 patients each: total flow of 2 l·min^{-1} with (group HME2L) or without (group 2L) HME, and a total flow of 4 l·min^{-1} with (group HME4L) or without (group 4L) HME. The relative and absolute humidity and pharyngeal and inspired gas temperatures were measured for 2 h after endotracheal intubation. The relative humidity was not significantly different among groups 2L, HME2L, and HME4L. Group 4L had significantly lower absolute humidity than group 2L. The pharyngeal temperature did not decrease significantly for 2 h in any of the groups. During general anesthesia with a total flow of 2 l·min^{-1} in 2 h, HME might not be necessary, while with a total flow of 4 l·min^{-1}, HME could be useful to maintain inspired gas humidity.

Key words Heat and moisture exchanger · Relative humidity · Circle system · Humidification

Introduction

The upper airway plays important roles as a heater and a humidifier of inhaled air. In normal respiration, the inhaled air reaches the alveoli saturated with water vapor at the core temperature. However, during intubation, the upper airway is bypassed. Without humidification and heating, the dry, cold inspired gas may cause respiratory mucosal dysfunction and hypothermia [1,2]. A circle system in combination with a heat and moisture exchanger (HME) and/or low fresh gas flow is a simple method for maintaining the humidity and temperature of the inspired gas [3–8].

Low-flow anesthesia has been used to maintain airway humidity and temperature during general anesthesia. However, a total flow of less than 1 l·min^{-1} is not recommended for sevoflurane anesthesia because of the risk of inducing renal damage by compound A [9]. Therefore, when low-flow is used in sevoflurane anesthesia, 2 l·min^{-1} is recommended [9]. However, no reports have shown any changes in the inspired gas humidity or body temperature during sevoflurane anesthesia at a total flow of 2 l·min^{-1}. The aim of the present study was to compare the inspired gas humidity and body temperature in general anesthesia with or without HME at two different total flows: 2 l·min^{-1} and 4 l·min^{-1}.

Patients and methods

After obtaining written informed consent from the patients and the approval of the hospital's ethics committee we randomly divided 80 patients (American Society of Anesthesiologists [ASA] I or II), undergoing general anesthesia for orthopedic or head and neck surgery, into four groups by the envelope method (20 patients in each group): group 2L, total flow of 2 l·min^{-1} without HME; group 4L, total flow of 4 l·min^{-1} without HME; group HME2L, total flow of 2 l·min^{-1} with HME; and group HME4L, total flow of 4 l·min^{-1} with HME. Any patients with pulmonary or cardiac disease were excluded from the study.

Anesthesia was induced with sevoflurane and the concentration was gradually increased to 5% in 4 l·min^{-1} oxygen; anesthesia was maintained with 2%–3% sevoflurane (endtidal concentration) in 2 (group 2L, Group HME2L) or 4 l·min^{-1} (group 4L, group HME4L) of oxygen. Tracheal intubation was performed. A

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pharyngeal temperature probe was inserted in the upper pharyngeal cavity to measure the core temperature. After the location of the probe was checked by laryngofiberscopy, the probe was fixed with adhesive tape. The pharyngeal temperature was measured by a calibrated patient monitor (Life Scope9; Nihon Kohden, Tokyo, Japan). The accuracy of the pharyngeal temperature measurement was ±0.1°C. The temperature in the operating room was maintained at 22°C–23°C. The crystalloid solutions, warmed at 37°C, were infused at a rate of 3–5 ml·kg^{-1}·h^{-1}. All patients were anesthetized using an anesthesia machine (Model CT-7FII; Acoma, Tokyo, Japan; Breathing circuit, Cat. No 353901, Hudson Respiratory Care, Temecula, CA, USA) with a CO_2 absorber (Dräger sorb; Dräger, Lübeck, Germany). In the HME groups, a hydrophobic HME with 45 ml of dead space (Hygrobac "S"; Mallinkrodt DAR, Mirandola, Italy) was used on the oral side of a two-way breathing circuit with a one-way valve (Fig. 1). The anesthesia apparatus, including the CO_2 absorber and breathing circuit, has an internal volume of 2.5 l. The tidal volume of the ventilator was set to 8–10 ml·kg^{-1}. The respiratory rate was adjusted to keep endtidal CO_2 between 35 and 40 mmHg (Ohmeda 5250 RGM; Ohmeda, Louisville, CO, USA). The temperature of the circulating-water mattress used (RK-2000K; Thermia; Baxter Health Care, Valereia, Dearfield, IL, USA) was set at 38°C. All patients were anesthetized by one senior anesthesiologist.

The inspiratory airway humidity and temperature were measured by the Moiscope (Senko Medical, Tokyo, Japan), at 5, 10, 15, 20, 25, 30, 60, and 120 min after endotracheal intubation. The sampling time for the relative humidity and temperature was 50 ms. The response time was 3 s to detect changes in relative humidity from 40% to 100%. The accuracy of the measuring device was ±3% for relative humidity and ±0.2°C for temperature. The absolute humidity was calculated from the relative humidity and temperature according to the following formula:

$$AH = RH \times Psat/(0.945 \times [1 + T/273])$$

where AH is absolute humidity, RH is relative humidity, Psat is saturated water vapor, and T is the inspiratory air temperature.

All data values are shown as means ± SD. Statistical analysis according to sex was performed using the χ^2 test. All other data were analyzed by repeated-measures analysis of variance with Bonferroni correction. A P value of less than 0.05 was considered to be statistically significant. A post-hoc power analysis was done using the G Power ver. 2.1.2 (University of Trier, Trier, Germany).

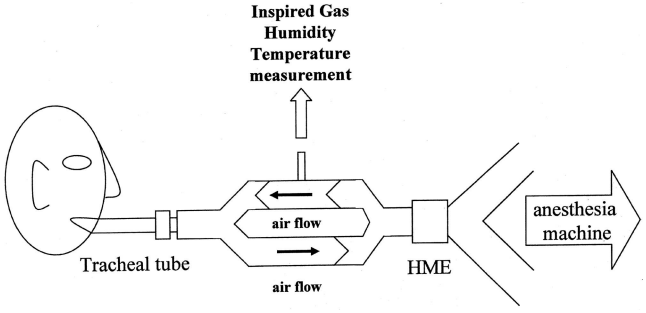

Fig. 1. Anesthesia circuit with one-way value to measure the humidity and the temperature of inspired gas with a heat and moisture exchanger (HME)

Results

The power of this study was 0.4204. There were no significant differences in the backgrounds of the patients among the four groups (Table 1). The absolute humidity values in group HME2L and group HME4L were significantly higher than those in group 2L and group 4L (Table 2). The relative humidity was not different among group 2L, group HME2L, and group HME4L at 30, 60, and 120 min after endotrachal intubation (Table 2). Groups 2L and 4L showed significantly lower inspired gas temperatures than groups HME2L and HME4L. However, there were no significant differences among the four groups regarding the pharyngeal temperature (Fig. 2).

Discussion

The absolute humidity was more than 22 mg H_2O·l^{-1} in group 2L. The relative humidity in group 2L was not significantly different from that in groups HME2L and

Table 1. Patient characteristics

	Group 2L (n = 20)	Group 4L (n = 20)	Group HME2L (n = 20)	Group HME4L (n = 20)
Age (years)	56 ± 17	58 ± 21	64 ± 16	64 ± 16
Sex (M/F)	9/11	6/9	14/6	14/6
Weight (kg)	57 ± 10	57 ± 9	57 ± 9	57 ± 9
Height (cm)	156 ± 7	156 ± 10	158 ± 9	158 ± 9

Values are means ± SD or numbers of patients

Table 2. Relative humidity (RH) and absolute humidity (AH) of inspired gas

	5 Min	10 Min	15 Min	20 Min	25 Min	30 Min	60 Min	120 Min
RH (%)								
Group 2L (n = 20)	91.7 ± 11.5	93.7 ± 7.5	96.0 ± 6.1	97.1 ± 4.5	97.5 ± 3.9	98.8 ± 2.7	99.7 ± 1.5	99.5 ± 2.3
Group 4L (n = 20)	73.1 ± 14.0	75.2 ± 13.6	73.5 ± 16.4	72.3 ± 15.0	77.3 ± 15.0	76.8 ± 15.3	69.1 ± 15.6	71.0 ± 18.2
Group HME2L (n = 20)	100 ± 0*,**	100 ± 0*,**	100 ± 0*,**	100 ± 0*,**	100 ± 0*,**	100 ± 0**	100 ± 0**	100 ± 0**
Group HME4L (n = 20)	100 ± 0*,**	100 ± 0*,**	100 ± 0*,**	100 ± 0*,**	100 ± 0*,**	100 ± 0**	100 ± 0**	100 ± 0**
AH (mg·l^{-1})								
Group 2L (n = 20)	22.5 ± 2.8	23.4 ± 2.4	23.8 ± 2.4	24.1 ± 2.1	24.1 ± 2.0	24.4 ± 1.8	24.6 ± 2.7	25.2 ± 2.6
Group 4L (n = 20)	17.4 ± 4.0	18.2 ± 3.2	17.3 ± 3.3	17.6 ± 2.7	18.4 ± 2.9	18.0 ± 3.3	16.9 ± 3.5	17.7 ± 5.0
Group HME2L (n = 20)	28.2 ± 2.5*,**	29.0 ± 2.9*,**	29.9 ± 1.8*,**	30.0 ± 1.8*,**	30.1 ± 1.9*,**	30.2 ± 2.0*,**	30.0 ± 2.3*,**	29.5 ± 3.2*,**
Group HME4L (n = 20)	28.0 ± 3.8*,**	29.2 ± 3.3*,**	30.4 ± 2.9*,**	30.5 ± 2.9*,**	30.8 ± 3.1*,**	30.8 ± 3.2*,**	30.5 ± 3.7*,**	30.6 ± 3.8*,**

* $P < 0.05$ vs group 2L; ** $P < 0.05$ vs group 4L
Values are means ± SD

Fig. 2. a The pharyngeal temperature and **b** inspired gas temperature at different total gas flows with or without the heat and moisture exchanger (HME). *Bars* indicate SD. * $P <$ 0.05 vs group 2L. *Diamonds*, group 2L, with total flow of 2 l·min^{-1} without HME; *triangles*, group 4L, with total flow of 4 l·min^{-1} without HME; *dots*, group HME2L, with total flow of 2 l·min^{-1} with HME; *squares*, group HME4L, with total flow of 4 l·min^{-1} with HME

HME4L. The pharyngeal temperature did not change significantly in any of the four groups.

The humidity and temperature of the inspired gas were influenced by the fresh gas flow and the volume of the circle system. Recently, low-flow anesthesia has often been used to decrease the consumption of anesthetics. During low-flow anesthesia (<1 l·min^{-1}), it has been considered that recycled exhaled gases are sufficient and that HME is not necessary. Johansson and colleagues [8] reported that an HME improved both the absolute and relative humidity with total flows of 1.0, 3.0, and 6.0 l·min^{-1}. However, they studied the humidity at only one point. We measured the humidity more frequently than in their study to clarify the time course using different total flows (2.0 and 4.0 l·min^{-1}).

In this study, we investigated the changes in pharyngeal temperature as the core temperature. Matsukawa and colleagues [10] reported that the pharyngeal temperature did not differ from the tympanic membrane

temperature in mechanically ventilated patients under general anesthesia. Therefore, it seems that the pharyngeal temperature would have been a reliable core temperature in our study.

The most appropriate humidity of inspired gas during mechanical ventilation is still unknown. The lowest recommended absolute humidity of inspired gas is $20\,mgH_2O\cdot l^{-1}$ [5]. Williams and colleagues [1] reported an apparent correlation between the absolute humidity of the inspired gas and the exposure time in relation to respiratory mucocilliary function (e.g., mucus thickness, mucocilliary transport, cell morphology). In our study, the absolute humidity in group 2L was gradually increased from 22 to $25\,mgH_2O\cdot l^{-1}$ in 2 h. This might be sufficient to maintain the respiratory mucocilliary function, as judged by Williams and colleagues [1]. However, the absolute humidity in group 4L was 17 to $18\,mgH_2O\cdot l^{-1}$, which might be too low to maintain respiratory mucocilliary function.

The relative humidity is also important. Miyao and colleagues [11] reported that, even if the absolute humidity was sufficient, a low relative humidity of about 50% dried the secretions and the condensed secretions might stick in the endotracheal tube. In the present study, the relative humidity values in group 2L, group HME2L, and group HME4L were more than 90%. Therefore, the relative humidity in group 2L, group HME2L, and group HME4L seemed to be sufficient, although it was not sufficient in group 4L.

Recently, Kurz and colleagues [12] reported that perioperative hypothermia increased the incidence of surgical-wound infection. Therefore, it is important to prevent perioperative hypothermia. During surgery under general anesthesia, hypothermia results from an impairment of thermoregulation by the anesthetics, exposure to a cold environment, and altered distribution of body heat [11]. Therefore, we usually use an apparatus such as a circulating-water mattress or a forced-air warming device, in combination with the HME. In the present study, we used a circulating-water mattress for all patients.

In the present study, the pharyngeal temperature did not decrease in any of the four groups. However, Johansson and colleagues [8] reported that an HME did not prevent an early redistribution of body heat, and it also did not maintain the body temperature in the absence of concomitant heating methods. Eckerbom and Lindholm [13] also reported that the heat conserved with an HME was rather low. Therefore, when a circulating-water mattress is used, HME may have no more additive effects to help in maintaining the body temperature, although there were no control data for the absence of a circulating-water mattress in the present study.

In conclusion, in sevoflurane anesthesia with a total flow of $4\,l\cdot min^{-1}$, an HME could be useful for maintaining appropriate humidity, while with a total flow of $2\,l\cdot min^{-1}$, an HME might not be necessary.

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