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Link to publication

The effect of heat and moisture exchanger on humidity and body temperature in a low-flow anaesthesia system

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Background: Artificial humidification of dry inspired gases seems to reduce the drop in body temperature during surgery. The aim of this study was to evaluate the humidity and temperature of anaesthetic gases with heat and moisture exchangers (HMEs). The secondary aim was to evaluate if HMEs in combination with low-flow anaesthesia could prevent a decrease in the body temperature during general anaesthesia.
Methods: Ninety patients scheduled for general surgery were randomised to receive a fresh gas flow of 1.0, 3.0 or $6.0 \, l \, min^{-1}$ with or without HMEs in a circle anaesthesia system. Relative humidity, absolute humidity, temperature of inspired gases and body temperatures were measured during 120 min of anaesthesia.
Results: The inspiratory absolute humidity levels with HMEs were 32.7 ± 3.1, 32.1 ± 1.1 and $29.2 \pm 1.9 \, mg \, H_2O \, l^{-1}$ and 26.6 ± 2.3, 22.6 ± 3.0 and $13.0 \pm 2.6 \, mg \, H_2O \, l^{-1}$ without HMEs after 120 min of anaesthesia with 1.0, 3.0, or $6.0 \, l \, min^{-1}$ fresh gas flows ($P < 0.05$, between with and without HME). The relative humidity levels with HMEs were 93.8 ± 3.3, 92.7 ± 2.2 and $90.7 \pm 3.5\%$, and without the HMEs 95.2 ± 4.5, 86.8 ± 8.0 and $52.8 \pm 9.8\%$ ($P < 0.05$, between with and without HMEs in the 3.0 and $6.0 \, l \, min^{-1}$ groups). The inspiratory gas temperatures with HMEs were 32.5 ± 2.0, 32.4 ± 0.5 and $31.0 \pm 1.9\degree C$, and 28.4 ± 1.5,

27.1 ± 0.8 and $26.1 \pm 0.6\degree C$ without HMEs after 120 min of anaesthesia ($P < 0.05$, between with and without HME). The tympanic membrane temperatures at 120 min of anaesthesia were 35.8 ± 0.6, 35.5 ± 0.6 and $35.4 \pm 0.8\degree C$ in the groups with HMEs, and 35.8 ± 0.6, 35.3 ± 0.7 and $35.3 \pm 0.9\degree C$ in the groups without the HMEs (NS).
Conclusions: The HMEs improved the inspiratory absolute humidity, relative humidity and temperature of the anaesthetic gases during different fresh gas flows. However, the HMEs were not able to prevent a body temperature drop during low-flow anaesthesia.

Tʜᴇ humidity and temperature of inspired gases in a circle system with high fresh gas flows are inadequate to maintain tracheobronchial climate (1). Ventilation with dry gases leads to considerable loss of water and heat directly from the respiratory tract as a result of the vaporisation of water (2). Inadequate humidification of inspired gases occurs most obviously when a patient is ventilated with dry, compressed gases without additional humidification (1). Therefore, heat and moisture exchangers (HMEs) are routinely used to improve airway humidification (3).

Excessive respiratory heat loss may lower body temperature, particularly in infants and young children, and artificial humidification of dry inspired gases seems to reduce the drop in body temperature during surgery (4). By means of their ability to conserve heat and moisture during expiration HMEs

are expected to prevent a body temperature drop. However, controversy still exists regarding the efficiency of the ability of HMEs to prevent intraoperative hypothermia in adults (5, 6). In a laboratory set up, Bengtsson et al. showed that the use of a circle system with a fresh gas flow of $0.5 \, l \, min^{-1}$ resulted in higher inspiratory gas temperature and humidity than a nonrebreathing system with a disposable humidifier (7). Thus it seems reasonable to hypothesise that HMEs in combination with a low-flow anaesthesia would prevent the appearance of intraoperative core hypothermia during general anaesthesia.

The aim of the present study was firstly to measure the effect of HMEs on the humidity and temperature of anaesthetic gases in the circle system using three different fresh gas flows and secondly to evaluate the ability of HMEs in combination with low-flow

anaesthesia, to improve the body temperature in adults during general anaesthesia.

Methods

The study was approved by the Ethics Committee of Lund University, Sweden, and written informed consent was obtained from all patients. We studied 90 patients, ASA physical status 1 and 2, scheduled for elective general or urology surgery with an anticipated anaesthesia duration of 2 h or longer. Patients with signs and symptoms of pulmonary or cardiovascular disease were excluded from the study. The patients were randomly assigned to receive fresh gas flows of 1.0, 3.0 or 6.0 l min^{-1} with or without a HME.

The patients were premedicated with midazolam 7.5 mg rectally 30 min prior to arriving in the operating room. Intravenous fluid therapy consisted of 0.5 ml kg^{-1}*nothing by mouth hours before anaesthesia and maintenance with 150 ml h^{-1} of 25 mg ml^{-1} buffered room temperature glucose. Anaesthesia was induced by administration of 100% oxygen for 3–4 min followed by 2 µg kg^{-1} of fentanyl, 3–4 mg kg^{-1} of thiopental, and muscle relaxation was produced with 1.0–1.5 mg kg^{-1} of succinylcholine. Ventilation of the lungs was manually assisted with 100% oxygen via a circle breathing system (Anmedic^{TM}, Sweden) until tracheal intubation was performed and a Servo 900C ventilator (Siemens-Elema^{TM}, Sweden) was connected. The ventilator delivered the set tidal volumes with oxygen into a large corrugated hose with a 2.2-l internal volume (8) (Fig. 1). The tubing system and the CO_2 absorber had an internal volume of 2.4 l. The anaesthetic system was equipped with clean and dry tubes before each anaesthesia. Fresh gas flow (60% nitrous oxide in oxygen) was supplied to the circle system with 4.5 l min^{-1} (1.5 l min^{-1} of oxygen and 3.0 l min^{-1} of nitrous oxide) during the first 5 min and then adjusted to 1.0, 3.0 or 6.0 l min^{-1} with an end-tidal isoflurane
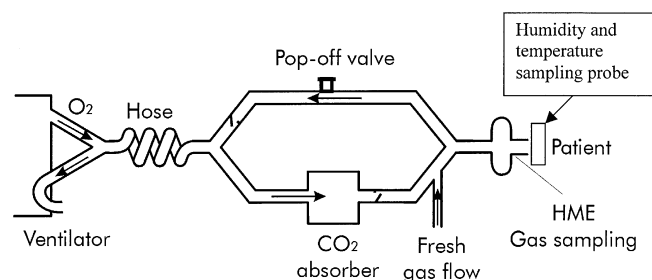

Fig. 1. The humidity sensor system was placed between the Y-piece and tracheal tube or, when used, between the heat and moisture exchanger and the tracheal tube.

concentration of 0.8–0.9%. The humidity sensor system (Gibeck Respiration) was placed between the Y-piece and the tracheal tube or, when used, between the HME (Humid Vent 2, Gibeck, Sweden, 35 ml of dead space) and the tracheal tube (Fig. 1). The humidity sensor system had a sampling rate of 21 times per second and a sampling time of 17 s. Data were measured every 10-min during the anaesthesia. The stated system accuracy was ±4% relative humidity and ±1%°C. The response times are 1.4 s for a 90% relative humidity response and <150 ms for a 90% temperature response. Data were collected into a personal computer and absolute humidity was calculated from relative humidity and temperature. The collected data were computed to numeric values and the maximum values were taken for statistical analysis. The ventilation of the lungs was adjusted to maintain an end-tidal CO_2 concentration of 4.5 kPa. The ventilatory rate was 15 per min, and the inspiratory and pause times were 33 and 10%, respectively.

During the procedure routine monitoring included electrocardiogram (lead II), heart rate, noninvasive mean arterial pressure (MAP) and haemoglobin oxygen saturation (SpO$_2$) (Merlin^{TM}, Hewlett Packard). The inspired oxygen and end- tidal concentrations of isoflurane, N$_2$O and CO_2 were monitored (Merlin^{TM}, Hewlett Packard) at 1-min intervals during the first 15 min of anaesthesia and thereafter at 5-min intervals throughout the study. Gases were sampled at the Y-piece and analyzed gas was returned to a port fitted into the CO_2 absorber. Anaesthetic gases were delivered using a isoflurane anaesthetic vaporiser (Penlon Sigma Elite^{TM}) and an AGA^{TM} (Sweden) anaesthesia machine. Prior to each anaesthetic administration, fresh soda lime (Absorber, Anmedic^{TM}, 15% water) was used.

Preoperative tympanic membrane temperatures were measured on arrival in the operating theatre. The tympanic membrane and room temperature were measured at 5-min intervals during the first 10-min of anaesthesia and thereafter at 10-min intervals during the anaesthesia using a calibrated temperature monitor (CIE 303K^{TM}, Taiwan). The accuracy of the tympanic membrane temperature was ±0.1°C. The temperature in the operating room was maintained at 23°C, and the temperatures were measured during 120 min of anaesthesia. Additional doses of 1 µg kg^{-1} of fentanyl were administered if the mean blood pressure increased more than 20% of baseline and a similar decrease in blood pressure was treated with 5–10 mg of ephedrine i.v. Neuromuscular block was achieved with 0.5 mg kg^{-1} of atracurium i.v. Incremental doses of 0.1–0.2 mg kg^{-1} of atracurium were given at two twitches achieved with a train-of-four stimulus (Microstim^{TM}, Glaxo Wellcome).

Residual muscle paralysis was reversed with i.v. glycopyrrolate and neostigmine. At termination of the procedure, the oxygen flow rate was increased to $6 l min^{-1}$ and spontaneous ventilation allowed returning. Following eye opening to command, the tracheas were extubated.

All data are reported as mean values with variability expressed as SD. The relative humidity, absolute humidity, temperatures of inspired gases, tympanic membrane and room temperature were compared with repeated measures ANOVA where appropriate and Student's t-test. Demographic data were compared using the χ^2-test. P-values less than 0.05 were considered statistically significant.

Results

There were no significant differences between the groups with and without HMEs regarding preoperative tympanic temperatures or demographic data (Table 1).

The inspiratory absolute humidity values measured after 120 min of anaesthesia of 1.0, 3.0 or $6.0 l min^{-1}$ of fresh gas flow with HMEs were 32.7 ± 3.1, 32.1 ± 1.1 and 29.2 ± 1.9 mg $H_2O l^{-1}$. The corresponding figures without HMEs were 26.6 ± 2.3, 22.6 ± 3.0 and 13.0 ± 2.6 mg $H_2O l^{-1}$. There were significant differences between the groups with and without HMEs at all three fresh gas levels ($P < 0.05$) (Table 2).

The relative humidity with the HMEs were 93.8 ± 3.3, 92.7 ± 2.2 and 90.7 ± 3.5%, and without the HMEs 95.2 ± 4.5, 86.8 ± 8.0 and 52.8 ± 9.8% after 120 min of anaesthesia with 1.0, 3.0 or $6.0 l min^{-1}$ of fresh gas flow. The relative humidity was significantly higher when the HMEs were used (3.0 and $6.0 l min^{-1}$ of fresh gas flow) compared to the situation when the HMEs were not connected (Table 2).

The tympanic membrane temperatures at 120 min of anaesthesia were 35.8 ± 0.6, 35.5 ± 0.6 and 35.4 ± 0.8°C in the groups with HMEs, and 35.8 ± 0.6, 35.3 ± 0.7 and 35.3 ± 0.9°C in the groups without the HMEs (NS). The time course of the inspiratory and tympanic membrane temperatures with and without HMEs are shown in Figs 2 and 3.

No patient was excluded from the study and all anaesthesia lasted for more than 120 min. There were no intraoperative problems noted during the study and no patient needed rescue medication or blood transfusion. The operating room temperature was maintained at 23°C in all cases during the study. The patients recovered well from the anaesthesia and surgery and were discharged from the hospital in accordance with normal routines for the particular surgical procedure.

Discussion

Appropriate humidification is a prerequisite for a normal function of the ciliated epithelium of the respiratory tract (1). Lung ventilation with dry gases leads to considerable loss of water and heat directly from the respiratory tract as a result of the vaporisation of water (2). Patients who are tracheal intubated are particularly exposed, because their normal humidification and heat-conserving mechanisms in the nose and upper airway are bypassed. Therefore, the use of heat and moisture exchangers has become increasingly popular in anaesthesia practice (3).

During anaesthesia, the absolute humidity of the inspired gases is recommended preferably to be >23 mg l^{-1} of H_2O to reduce the risk of dehydration of the respiratory tract (9). In this study, after 120 min of anaesthesia, the inspiratory absolute humidity with the HMEs connected were 32.7 ± 3.1, 32.1 ± 1.1 and 29.2 ± 1.9 mg l^{-1} of H_2O with 1.0, 3.0 or $6.0 l min^{-1}$ of fresh gas flows, respectively. Although, the absolute humidity of the inspiratory gases was significantly higher with low than high gas flows, even during a gas flow as high as $6.0 l min^{-1}$, the use of a HME seemed to be efficient in protecting the respiratory

Table 1

Demographic data and preoperative tympanic membrane temperatures in the groups studied (mean $\pm$ SD).

	With HME 1.0 l min^{-1} (n = 15)	With HME 3.0 l min^{-1} (n = 15)	With HME 6.0 l min^{-1} (n = 15)	Without HME 1.0 l min^{-1} (n = 15)	Without HME 3.0 l min^{-1} (n = 15)	Without HME 6.0 l min^{-1} (n = 15)
Weight (kg)	77 ± 11	73 ± 14	75 ± 13	73 ± 14	72 ± 16	75 ± 12
Age (year)	52 ± 7	58 ± 9	54 ± 11	55 ± 6	54 ± 8	57 ± 6
Sex (female/male)	5/10	4/11	7/8	4/11	4/11	3/12
Preop temp.* (C°)	36.9 ± 0.1	36.9 ± 0.1	36.9 ± 0.1	36.9 ± 0.1	36.9 ± 0.1	36.9 ± 0.1

*Preoperative tympanic membrane temperature.
No significant differences were found.
HME = heat and moisture exchangers.

Table 2

Absolute and relative humidity of the inspired gases in the groups studied at 120 min of anaesthesia with different fresh gas flows (mean ± SD).

Fresh gas flow (l min^{-1})	1.0	3.0	6.0
Absolute humidity mg H_2O L^{-1}			
With HME	32.7 ± 3.1*	32.1 ± 1.1*	29.2 ± 1.9*
Without HME	26.6 ± 2.3	22.6 ± 3.0	13.0 ± 2.6
Relative humidity (%)			
With HME	93.8 ± 3.3	92.7 ± 2.2*	90.7 ± 3.5*
Without HME	95.2 ± 4.5	86.8 ± 8.0	52.8 ± 9.8

*$P < 0.05$ within the absolute humidity groups, with and without heat and moisture exchangers HMEs.
*$P < 0.05$ within the 3 and 6 l min^{-1} relative humidity groups, with and without HMEs.

tract (Table 2). The results from the present study thus suggest that the properties of the used HMEs seem to guarantee a satisfactory absolute inspiratory gas humidity during clinical procedures of at least 120 min, regardless of the level of fresh gas flow up to 6.0 l min^{-1}.

In this paper humidity is defined in two ways. First, as the absolute humidity, which is the mass of water held in a given volume of gas. Second, as the relative humidity, which is the amount of water expressed as a percentage of the amount that a volume of gas could hold at a same temperature and pressure if fully saturated. Therefore, in order to interpret absolute humidity, it is necessary to know the temperature. This fact probably explains the determined values presented in Table 2. The relationship between the presented temperatures (Fig. 2) and the absolute and relative humidity values (Table 2) suggests that a saturated vapour at a higher temperature holds a higher absolute humidity value. The results in the groups without

HMEs demonstrated a comparably greater washout of water than a decrease in temperature, since the relative humidity values decreased with increasing fresh gas flows. Reasonably these findings are due to that a continues fresh gas flow, temporarily at higher flow rates, is washing out a greater quantity of heat and moisture through the hose and ventilator than is offered to the circle system.

In the present study we used the Humid-Vent 2 filter (Gibeck). In an experimental set-up this HME had been shown to have a satisfactory humidity output at low-flow rates (10). The relative humidity values that we recorded in our clinical setting using the HME indicate sufficient water vapour content for a satisfactory saturation at all present inspiratory temperatures. Notably, at a low fresh gas flow (1.0 l min^{-1}), the values of the group without HMEs represent similar relative humidity values as with HMEs (Table 2). These findings are in accordance with those of Bengtsson et al. (7).
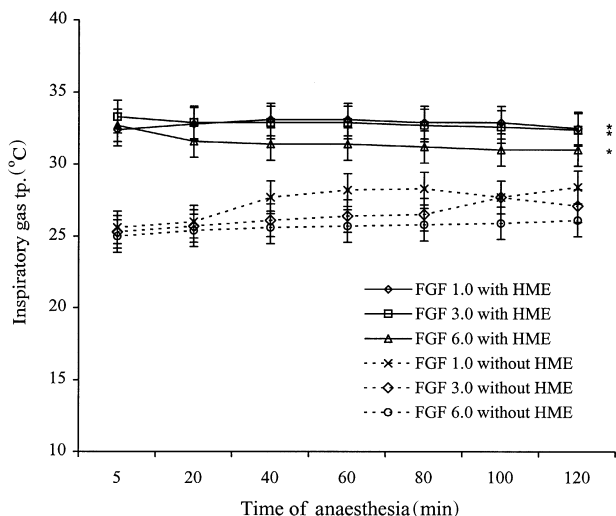

Fig. 2. The inspiratory gas temperatures at different fresh gas flows (FGF) with and without heat and moisture exchangers (HMEs) after 5, 20, 40, 60, 80, 100 and 120 min of anaesthesia. P < 0.05 between and without HMEs.
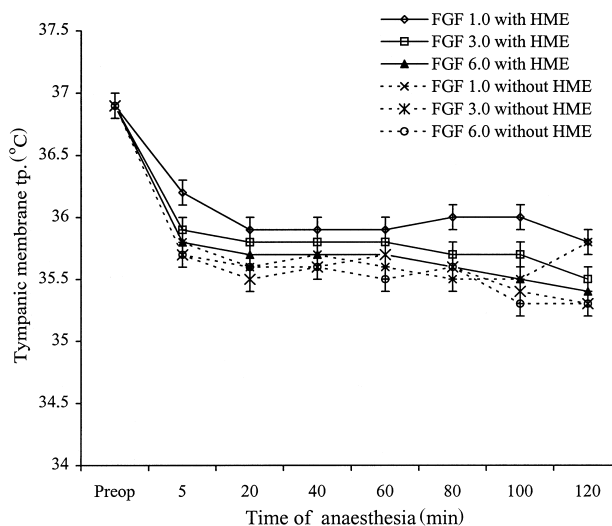

Fig. 3. The tympanic membrane temperatures at different fresh gas flows (FGF) with and without heat and moisture exchangers (HMEs) preoperatively (preop) and after 5, 20, 40, 60, 80, 100 and 120 min of anaesthesia. No significant differences were found between the tympanic membrane temperature groups, with and without HMEs.

Core hypothermia is a common problem in the operating period and is associated with a number of different factors (11). It has been demonstrated that various anaesthetic induction techniques cause significantly different reduction in core temperature (12). Several anaesthetic agents (e.g. volatile anaesthetics and narcotics) increase the heat loss because of their sympatolytic and vasodilatory properties. Ikeda et al. demonstrated that anaesthetic induction with propofol caused significantly lower core hypothermia than with sevoflurane (12). Our findings show that the present induction technique with thiopental and maintenance anaesthesia with isoflurane also caused hypothermia, which persisted throughout surgery regardless of the use of HMEs and different fresh gas flows (Fig. 2). Thus, it seems reasonable that a depression of the global thermal regulation during the general anaesthesia is the main reason for the heat loss. Neither the used HMEs or the present low-flow technique were able to eliminate this threat to the patients even though there was a difference in the inspiratory temperature of as much as 6.3°C between the $1.01\,\mathrm{min}^{-1}$ group with HMEs and the high-flow group of $6.01\,\mathrm{min}^{-1}$ without HMEs.

It has been shown that core hypothermia after induction of general anaesthesia results from an internal core-to-peripheral redistribution of heat, resulting in a loss of heat to the environment via conduction and convection (13, 14). These studies also demonstrate that the core temperatures prevailing after the induction did not change significantly during the first hour of anaesthesia. This is congruent with our findings that the core temperature initially rapidly decreased (14, 15). In accordance with the findings of Stoneham et al. the temperature decrease in our study correlated with the time interval between the induction of the general anaesthesia and the surgical incision, while the subsequent decrease in temperature during anaesthesia was insignificant (14). Therefore, our findings favour the view that an early redistribution of body heat is the major reason for the intraoperative core temperature drop.

We conclude that the HMEs improved the absolute and relative humidity of the anaesthetic gases during different fresh gas flows. However, HMEs, even in combination with low-flow anaesthesia, confer no measurable benefit regarding hypothermia over a standardized 2-h low-flow anaesthesia during elective general or urology surgery.

Acknowledgements

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