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Temperature and humidity of the Dräger Cato anesthetic machine circuit

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Abstract
Purpose. The Dräger Cato anesthetic machine (Dräger, Lübeck, Germany) effectively humidifies and warms anesthetic gases, because it has a built-in hotplate to heat the breathing system, and expired gas passes through the CO_2 absorbent three times during one breath. In the present study, we measured the temperature and absolute humidity (AH) of the anesthetic circuit in the Dräger Cato machine with and without heat moisture exchangers (HME), and compared them with those in another anesthetic machine, the Aestiva/5 (Datex-Ohmeda, Helsinki, Finland).
Methods. Forty-eight adult patients were randomly assigned to one of eight groups according to the anesthetic machine, fresh gas flow (FGF), and the use of HME ($n = 6$ each): Cato 0.5 l·min^{-1} without HME (group 1), Cato 1.0 l·min^{-1} without HME (group 2), Cato 0.5 l·min^{-1} with HME (group 3), Cato 1.0 l·min^{-1} with HME (group 4), Aestiva 0.5 l·min^{-1} without HME (group 5), Aestiva 1.0 l·min^{-1} without HME (group 6), Aestiva 0.5 l·min^{-1} with HME (group 7), and Aestiva 1.0 l·min^{-1} with HME (group 8). The temperature and AH of the anesthetic gases were measured with a Moiscope (S.K.I. Net, Tokyo, Japan), which was placed between the endotracheal tube and the Y-piece of the anesthetic circuit. The HME was placed between the Moiscope and the Y-piece of the anesthetic circuit. The temperature and AH of the anesthetic gases were measured at 5, 10, and 15 min and then every 15 min up to 150 min after tracheal intubation.
Results. Among the groups without HME (groups 1, 2, 5, and 6), the inspired temperatures and AH in groups 1 and 2 were significantly higher than those in groups 5 and 6 at all times during the study period ($P < 0.01$–0.001). The inspired temperatures and AH of the groups with HME (groups 3, 4, 7, and 8), were significantly higher than those in groups 2, 5, and 6 ($P < 0.01$–0.001). Among the groups with HME, the AH in group 3 was significantly higher than that in group 8 until the final study period.
Conclusion. The present study indicates that the Dräger Cato machine was more effective in warming and humidifying respiratory gas than the Aestiva/5, and that Aestiva/5 without HME does not reach the optimal temperature and humidity ranges, even if minimal flow anesthesia (0.5 l·min^{-1}) is performed.

Key words Heat and moisture exchanger · Anesthetic machines · Dräger Cato · Humidification · Temperature

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Introduction

Maintenance of airway humidity and temperature during anesthesia is important for preventing pulmonary damage [1–5]. To address this concern, apparatuses such as heat moisture exchangers (HME) are used to humidify anesthetic circuits in clinical situations [1,6]. Some anesthetic machines inherently humidify and warm anesthetic gases. The Dräger Cato anesthetic machine (Dräger, Lübeck, Germany) has a built-in hotplate to heat the breathing system [7]. In addition, the Dräger Cato machine has a unique mechanism such that expired gas passes through the CO_2 absorbent three times during a breath. Accordingly, one would expect that the inspired gases were warmer and more humidified in this machine than in other ones. Because the temperature and humidity of anesthetic gases in this machine have not yet been investigated, we aimed to compare temperature and humidity, with and without an HME, with those of the Aestiva/5 (Datex-Ohmeda, Helsinki, Finland).

Methods

The study was approved by the hospital ethics committee. An informed consent form was signed by each patient prior to participation in the study. The subjects were 48 patients undergoing general anesthesia for various surgeries expected to last at least 2.5 h. Patients were excluded if they were heavy smokers (>40 ciga-

Table 1. Patient demographics (mean ± SD; $n = 6$)

Group	Anesthetic machine	Total flow ($l \cdot min^{-1}$)	HME	Sex (M/F)	Age (yr)	Height (cm)	Weight (kg)
1	Cato	0.5	−	6/0	37.0 ± 15.9	165.0 ± 5.2	72.7 ± 7.0
2	Cato	1.0	−	6/0	44.2 ± 9.2	172.2 ± 5.6	65.8 ± 6.2
3	Cato	0.5	+	6/0	45.5 ± 13.7	166.3 ± 6.2	64.2 ± 8.6
4	Cato	1.0	+	5/1	37.8 ± 10.8	171.0 ± 6.7	68.7 ± 13.5
5	Aestiva	0.5	−	5/1	49.8 ± 11.9	163.0 ± 7.0	60.3 ± 9.7
6	Aestiva	1.0	−	6/0	43.7 ± 15.7	168.2 ± 3.1	70.5 ± 13.8
7	Aestiva	0.5	+	6/0	43.5 ± 9.9	168.3 ± 6.5	63.8 ± 6.3
8	Aestiva	1.0	+	5/1	34.0 ± 11.9	171.3 ± 6.9	68.5 ± 12.1

Cato, Dräger Cato anesthetic machine (Dräger, Lübeck, Germany); Aestiva, Aestiva 3000 (Datex-Ohmeda, Helsinki, Finland); HME, heat moisture exchanger

rettes per day), had respiratory tract disorders, or had significant obesity (body mass index >35). The anesthesia machine used in the present study was either the Dräger Cato anesthetic machine or an Aestiva/5. Patients were randomly assigned to one of eight groups according to anesthetic machine, fresh gas flow (FGF), and use of HME (Humid-Vent 1 port, Gibeck, Germany) ($n = 6$ each; Table 1): Cato $0.5 l \cdot min^{-1}$ without HME (group 1), Cato $1.0 l \cdot min^{-1}$ without HME (group 2), Cato $0.5 l \cdot min^{-1}$ with HME (group 3), Cato $1.0 l \cdot min^{-1}$ with HME (group 4), Aestiva $0.5 l \cdot min^{-1}$ without HME (group 5), Aestiva $1.0 l \cdot min^{-1}$ without HME (group 6), Aestiva $0.5 l \cdot min^{-1}$ with HME (group 7), and Aestiva $1.0 l \cdot min^{-1}$ with HME (group 8).

Thirty minutes after receiving an i.m. injection of atropine (0.5 mg) and midazolam ($0.08 mg \cdot kg^{-1}$), each patient was given an i.v. injection of fentanyl (100–200 mg), propofol (2–2.5 $mg \cdot kg^{-1}$), and vecuronium ($0.1 mg \cdot kg^{-1}$) to facilitate tracheal intubation. Before tracheal intubation, the patient received oxygen ($5 l \cdot min^{-1}$) via a face mask. After tracheal intubation, anesthesia was maintained with sevoflurane, N_2O ($3 l \cdot min^{-1}$), and O_2 ($2 l \cdot min^{-1}$). After 10 min, FGF was reduced to 0.5 or $1 l \cdot min^{-1}$. The flow rates of N_2O and O_2 were adjusted to maintain an inspiratory O_2 concentration of approximately 40%. Ventilation was controlled at a rate of $10 l \cdot min^{-1}$, and the tidal volume was adjusted to maintain an end-tidal P_{CO_2} of 35–40 mmHg. End-tidal concentrations of sevoflurane and CO_2 were analyzed using a Capnomac Ultima gas analyzer (Capnomac, Datex, Finland). Amsorb (Armstrong Medical, Coleraine, Northern Ireland) was used as the CO_2 absorbent, which was changed before the administration of anesthetics to each patient. Body temperature was maintained at 36° to 37°C using a forced-air warming blanket (Snuggle Warm; Smiths Industries, Irvine, CA, USA). Room temperature was maintained at 23°–26°C.

The temperature and absolute humidity (AH) of anesthetic gases were measured with a Moiscope (S.K.I. Net., Tokyo, Japan), which was placed between the endotracheal tube and the Y-piece of the anesthetic circuit. This device can measure the temperature and relative humidity, and it displays the temperature and calculated AH every 1 s. The accuracy of this device is ±3% AH and ±0.2°C. The HME was placed between the Moiscope and the Y-piece of the anesthetic circuit. The temperature and AH of anesthetic gases were measured before the mask was attached to the patient, at 5, 10, and 15 min, and then every 15 min up to 150 min after tracheal intubation. Because the temperature and AH at the Y-pieces fluctuated with the phases of the respiratory cycle [9], we recorded the minimal readings of these values.

Values are expressed as means ± SD. The data were statistically analyzed with two-way repeated-measures analysis of variance (ANOVA) and with Fisher's post hoc test for multiple comparisions. The patients' demographic data were also analyzed in the same way. A P value less than 0.05 was considered to indicate statistically significance.

Results

There were no differences between the groups in age, height, and body weight (Table 1). There were also no differences between the groups in the preanesthetic ambient temperature and AH of the operating room (Tables 2 and 3).

There were significant differences in temperature between groups 1 and 5, groups 1 and 6, groups 2 and 5, and groups 2 and 6 at all times during the study period ($P < 0.05$) (Table 2). The temperatures of the groups with HME were significantly higher than those of groups 2, 5, and 6 ($P < 0.05$) (Table 2).

AH in groups 1 and 2 was significantly higher than in groups 5 and 6 at all times during the study period ($P < 0.05$). There were significant differences in AH between groups 1 and 2 from 30 to 105 min ($P < 0.05$) and

Table 2. Inspiratory temperature (°C) of anesthetic circuit (mean ± SD; $n = 6$)

Group	Anesthetic machine	Total flow ($l \cdot min^{-1}$)[a]	HME	Time (min)				
				Pre	5	10	15	30
1	Cato	0.5	−	24.4 ± 0.9	27.8 ± 1.8[1,2]	28.3 ± 1.5[1,2]	30.6 ± 1.5[1,2]	31.3 ± 2.1[1,2]
2	Cato	1.0	−	23.2 ± 3.4	28.1 ± 3.0[1,2]	28.4 ± 3.1[1,2]	29.4 ± 3.1[1,2]	29.0 ± 3.0[1,3]
3	Cato	0.5	+	24.8 ± 1.0	30.9 ± 1.0[1–6]	31.7 ± 0.8[1–5]	32.5 ± 0.8[1,2,4–6]	33.0 ± 0.8[1,2,4–6]
4	Cato	1.0	+	24.3 ± 1.6	30.1 ± 2.0[1–3]	30.9 ± 1.8[1–4]	32.0 ± 1.8[1,2,4]	32.3 ± 2.1[1,2,4]
5	Aestiva	0.5	−	23.4 ± 0.7	23.5 ± 2.0	24.2 ± 1.9	25.1 ± 1.9	25.7 ± 2.5
6	Aestiva	1.0	−	23.5 ± 1.7	23.3 ± 1.7	23.6 ± 1.7	24.0 ± 1.7	24.3 ± 1.8
7	Aestiva	0.5	+	24.5 ± 0.5	28.2 ± 1.6[1,2]	29.5 ± 1.3[1,2]	29.9 ± 1.3[1,2]	30.3 ± 1.1[1,2]
8	Aestiva	1.0	+	24.0 ± 3.2	28.5 ± 1.4[1,2]	29.6 ± 1.6[1,2]	30.2 ± 1.6[1,2]	30.4 ± 0.8[1,2]

Time (min)							
45	60	75	90	105	120	135	150
31.5 ± 2.4[1,2]	32.0 ± 2.6[1,2]	32.6 ± 2.6[1,2]	32.4 ± 2.9[1,2]	32.7 ± 2.5[1,2]	32.8 ± 2.6[1,2]	32.6 ± 2.3[1,2]	32.7 ± 2.3[1,2]
29.9 ± 2.1[1,2]	30.3 ± 2.8[1,2]	30.4 ± 2.7[1,2]	30.9 ± 2.4[1,2]	31.3 ± 2.3[1,2]	31.5 ± 2.3[1,2]	31.2 ± 2.2[1,2]	31.4 ± 2.1[1,2]
33.0 ± 0.8[1,2,4]	33.1 ± 0.7[1,2,4]	33.1 ± 0.8[1,2,4]	33.6 ± 0.7[1,2,4]	33.6 ± 0.8[1,2]	33.7 ± 0.8[1,2]	33.6 ± 0.9[1,2,4]	33.6 ± 0.9[1,2,4]
32.6 ± 2.1[1,2,4]	33.1 ± 1.3[1,2,4]	33.2 ± 1.2[1,2,4]	33.6 ± 1.1[1,2,4]	33.1 ± 2.0[1,2]	33.7 ± 0.9[1,2,4]	33.8 ± 0.9[1,2,4]	33.8 ± 0.9[1,2,4]
26.2 ± 2.5	26.4 ± 2.7	26.8 ± 2.7	27.4 ± 2.5	27.2 ± 2.8	27.7 ± 2.5	27.5 ± 2.6	27.7 ± 2.6
24.4 ± 1.9	24.4 ± 1.9	24.5 ± 2.1	24.8 ± 2.3[1]	24.8 ± 2.3[1]	25.3 ± 2.5[1]	25.1 ± 2.3[1]	25.4 ± 2.4[1]
31.3 ± 0.7[1,2]	31.6 ± 0.7[1,2]	32.0 ± 1.3[1,2]	31.8 ± 0.8[1,2]	31.9 ± 0.8[1,2]	31.8 ± 0.9[1,2]	32.2 ± 0.9[1,2]	32.2 ± 0.9[1,2]
30.9 ± 1.2[1,2]	31.2 ± 1.3[1,2]	31.4 ± 1.5[1,2]	31.4 ± 1.8[1,2]	31.8 ± 1.6[1,2]	31.8 ± 1.5[1,2]	31.8 ± 1.3[1,2]	31.8 ± 1.3[1,2]

Cato, Dräger Cato anesthetic machine; Aestiva, Aestiva 3000

[a] Total flow was 5 $l \cdot min^{-1}$ during first 10 min; thereafter the flow was reduced to 0.5 or 1 $l \cdot min^{-1}$

[1] $P < 0.05$ vs group 5; [2] $P < 0.05$ vs group 6; [3] $P < 0.05$ vs group 1; [4] $P < 0.05$ vs group 2; [5] $P < 0.05$ vs group 7; [6] $P < 0.05$ vs group 8

Table 3. Inspiratory absolute humidity (mg $H_2O \cdot l^{-1}$) of anesthetic circuit (mean ± SD; $n = 6$)

Group	Anesthetic machine	Total flow ($l \cdot min^{-1}$)[a]	HME	Time (min)				
				Pre	5	10	15	30
1	Cato	0.5	−	10.7 ± 2.4	15.1 ± 2.1[1,2,5,6]	16.7 ± 1.8[1,2,5,6]	27.2 ± 4.9[1,2]	30.1 ± 4.5[1,2]
2	Cato	1.0	−	10.7 ± 0.7	15.5 ± 6.0[1,2,5,6]	17.7 ± 6.5[1,2,5,6]	22.7 ± 5.9[1,2,5,6]	24.6 ± 5.7[1–3,5,6]
3	Cato	0.5	+	10.5 ± 2.1	30.2 ± 2.7[1–6]	30.5 ± 3.1[1–4]	33.6 ± 1.9[1–4,6]	35.1 ± 1.8[1–6]
4	Cato	1.0	+	11.1 ± 3.2	29.0 ± 3.3[1–4]	29.7 ± 3.1[1–4]	32.4 ± 2.9[1,2,4]	32.8 ± 3.1[1,2,4]
5	Aestiva	0.5	−	10.1 ± 0.9	4.8 ± 3.7	5.5 ± 3.6	14.0 ± 6.5	15.8 ± 5.1
6	Aestiva	1.0	−	10.5 ± 1.6	4.2 ± 3.2	4.9 ± 3.0	10.2 ± 4.8	14.2 ± 2.6
7	Aestiva	0.5	+	10.5 ± 1.7	25.7 ± 3.1[1,2]	27.6 ± 4.0[1,2]	28.3 ± 4.4[1,2]	30.0 ± 2.6[1,2]
8	Aestiva	1.0	+	10.4 ± 1.5	25.2 ± 2.6[1,2]	26.5 ± 2.2[1,2]	28.2 ± 2.7[1,2]	29.4 ± 1.7[1,2]

Time (min)							
45	60	75	90	105	120	135	150
31.1 ± 4.3[1,2]	32.1 ± 4.1[1,2]	34.2 ± 4.6[1,2]	33.9 ± 5[1,2]	34.8 ± 3.2[1,2]	34.8 ± 3.5[1,2]	34.7 ± 3.8[1,2]	35.0 ± 3.7[1,2]
25.2 ± 5.4[1–3,5,6]	27.4 ± 4.2[1–3,5,6]	28.9 ± 4.2[1–3]	30.2 ± 4[1–3]	31.2 ± 4.4[1–3]	31.7 ± 4.7[1,2]	31.4 ± 4.0[1,2]	31.5 ± 3.9[1,2]
35.8 ± 1.4[1,2,4–6]	35.9 ± 1.4[1–6]	35.7 ± 1.7[1,2,4–6]	36.4 ± 1[1,2,4–6]	36.6 ± 1.5[1,2,4–6]	36.8 ± 1.5[1,2,4,6]	36.4 ± 1.8[1,2,4,6]	36.5 ± 1.7[1,2,4,6]
34.0 ± 3.4[1,2,4]	35.5 ± 1.8[1–6]	36.3 ± 1.7[1,2,4–6]	36.2 ± 2[1,2,4–6]	35.1 ± 3.5[1,2,4]	35.9 ± 2.1[1,2,4,6]	36.1 ± 1.9[1,2,4]	36.1 ± 1.9[1,2,4]
18.0 ± 4.1	20.4 ± 3.9	20.8 ± 3.9	22.1 ± 4	22.8 ± 4.0	23.6 ± 4.2	23.3 ± 4.5	23.3 ± 4.5
14.3 ± 2.6	15.2 ± 2.2[1]	16.3 ± 2.1[1]	17.2 ± 2[1]	17.9 ± 2.1[1]	18.9 ± 2.8[1]	18.8 ± 3.1[1]	19.4 ± 3.1[1]
31.0 ± 1.4[1,2]	31.5 ± 1.4[1,2]	31.6 ± 1.4[1,2]	32.5 ± 1[1,2]	32.9 ± 1.7[1,2]	33.3 ± 2.0[1,2]	33.3 ± 2.0[1,2]	33.3 ± 2.0[1,2]
30.2 ± 2.3[1,2]	31.1 ± 1.6[1,2]	31.5 ± 2.2[1,2]	30.8 ± 4[1,2]	32.7 ± 1.9[1,2]	32.2 ± 2.7[1,2]	32.7 ± 1.6[1,2]	33.0 ± 1.5[1,2]

Cato, Dräger Cato anesthetic machine; Aestiva, Aestiva 3000

[a] Total flow was 5 $l \cdot min^{-1}$ during first 10 min; thereafter the flow was reduced to 0.5 or 1 $l \cdot min^{-1}$

[1] $P < 0.05$ vs group 5; [2] $P < 0.05$ vs group 6; [3] $P < 0.05$ vs group 1; [4] $P < 0.05$ vs group 2; [5] $P < 0.05$ vs group 7; [6] $P < 0.05$ vs group 8

between groups 3 and 4 from 60 to 150 min ($P < 0.05$) (Table 3). During high-flow anesthesia, AH in the groups with HME was significantly higher than in the groups without HME ($P < 0.05$). AH was significantly lower in groups 5 and 6 than in the other groups with HME from 0 to 150 min. There were significant differences in AH between group 2 and group 3 or 4 during the study period. There were also significant differences in AH between group 2 and group 7 or 8 for 60 min after the induction of anesthesia. Among the groups with HME, AH in group 3 was significantly higher than in group 8 from 15 to 150 min after the induction of anesthesia. There were significant differences in AH between groups 3 and 7 up to 105 min after induction, between groups 4 and 7 up to 90 min, and between groups 4 and 8 up to 120 min.

No patient in the present study suffered from pulmonary complications during or after anesthesia.

Discussion

The main finding of the present study was that when the HME was not used, the inspired temperature and AH with Cato were significantly higher than with Aestiva, a result consistent with the design of the Dräger Cato machine. Similar to when HME was used, the inspired temperature of Cato without HME rapidly increased immediately after the induction of anesthesia, because the temperature of the hotplate for heating the breathing system in the Dräger Cato machine reaches approximately 60°C [7]. Once the FGF has been reduced, the circle system permits a much higher delivery of exhaled gases to the CO_2 absorber. In that case, there are two sources of water vapor: rebreathing of exhaled gas and release from the CO_2 absorbent. In an exothermic reaction, 2 mol of water and 14 kcal are liberated from each mole of CO_2 absorbed [8]. Therefore, the lower the FGF, the greater the temperature and humidity in both machines. In addition, the inspired gas of Cato was warmer and more humid than that of Aestiva, because exhaled gas passes through the heated and wet canister three times before it goes to the patient. The present study also showed that these effects of FGF and the anesthetic machine on the inspired temperature and humidity were facilitated with the use of HME.

When both the temperature and the humidity sensors are placed between the endotracheal tube and the Y-piece of the anesthetic circuit, the phase of the respiratory cycle interferes with measurements. During the expiratory pause, dry fresh gas enters the inspiratory limb. As inspiration starts, this gas flows past the sensors, which therefore record minimal values [9]. In the present study, we used a Moiscope, which quickly (1 s) responds to changes in temperature and humidity. Therefore, we believe that the values in the present study, which were recorded as the minimal values, represent the true inspiratory temperature and humidity. Chalon et al. [9] reported that the differences between the minimal and maximal values were reduced when the FGF was reduced. Indeed, the differences were reduced in the present study, as the time after the shift to low-flow anesthesia. Finally, after the steady state was reached, there was no fluctuation with the respiratory cycle.

Both under- and overhumidification and warming might have negative effects on pulmonary function [2–4,10,11]. The American National Standards Institute (ANSI) states that 30 mg $H_2O \cdot l^{-1}$ should be provided by heat and moisture-providing devices, if they are to replace physiologic levels of respiratory dry gases [12]. Generalizing the results of many studies [11,13–15], the optimal range of inspired humidification during artificial ventilation is probably between 23 and 33 mg $H_2O \cdot l^{-1}$, and the optimal temperature is between 28° and 32°C, although the precise optimal ranges are yet to be determined. Consequently, the present study suggests that the Aestiva/5 machine does not reach the optimal range without the use of an HME, even if used for minimal low-flow anesthesia (0.5 $l \cdot min^{-1}$), whereas the Dräger Cato machine satisfies these optimal conditions under low-flow anesthesia (1.0 $l \cdot min^{-1}$) without the HME. Further study is required to determine the optimal range of inspired humidification and warming in humans during anesthesia.

In summary, the present results indicate that the Dräger Cato was more effective for warming and humidifying anesthetic gas than the Aestiva/5. Although the precise optimal ranges of temperature and humidity during anesthesia are unknown, the present study indicates that the Aestiva/5 without HME does not reach the optimal range of temperature and humidification, even if minimal low-flow anesthesia (0.5 $l \cdot min^{-1}$) is used, whereas the Dräger Cato machine without HME reaches the range.

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