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ORIGINAL ARTICLE

Effect of a new heated and humidified breathing circuit with a fluid-warming device on intraoperative core temperature: a prospective randomized study

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Abstract
Background The effect of the Mega Acer kit@, a new heated and humidified breathing circuit (HHBC) containing a fluid-warming device, was investigated on intraoperative core temperature (T_c).
Methods A total of 102 patients undergoing elective craniotomies were randomly divided into three groups based on the breathing circuit used: a conventional breathing circuit (group C, $n = 34$), a Fisher & Paykel HHBC (group F, $n = 34$), and the Mega (group M, $n = 34$). From baseline to the end of the surgery, T_c and infusion fluid temperature (T_f) were recorded at 15-min intervals. If T_c became lower than 35.5 °C, a forced-air warmer was used.
Results Baseline temperatures were 36.7 ± 0.3, 36.6 ± 0.2, and 36.6 ± 0.2 °C in groups C, M, and F, respectively. T_c at the end of surgery dropped from baseline values by 1.0 ± 0.4, 0.5 ± 0.5, and 0.8 ± 0.5 °C in groups C, M, and F, respectively. From 60 min of post-induction to the end of surgery, T_c was higher in group M than group C ($p < 0.05$). From 105 min of post-induction to the end of surgery, T_c was higher in group M than group F ($p < 0.05$). The number of patients receiving forced-air warmer and total forced-air warmer using time were significantly lower in group M than groups C and F ($p < 0.05$). T_f was higher in group M than groups C and F throughout the study period (31.0 ± 1.0 vs. 23.5 ± 0.5 and 24.0 ± 0.4 °C; $p < 0.01$).
Conclusions The Mega significantly reduced the drop in intraoperative T_c by delivering warm fluids, compared with the other breathing circuits tested.
Trial Registration Clinicaltrials.gov identifier: NCT01831843.

Keywords Breathing circuit · Infusion fluid temperature · Intraoperative core temperature

Introduction

Perioperative hypothermia is known to increase perioperative complications; it can reduce platelet function, impair enzymes of the coagulation pathway, prolong the duration of action of anesthetic drugs, and increase surgical wound infection, negative nitrogen balance, and shivering [1–4]. As a result, perioperative hypothermia increases surgical blood loss and transfusion requirements, and delays post-anesthetic recovery [3]. Many warming devices have been developed to prevent perioperative hypothermia, such as fluid-warming devices, forced-air warming blankets, heat-pads, and heated and humidified breathing circuits (HHBCs) [5–8].

General anesthesia imposes some perioperative risks related to the mechanically ventilated breathing circuit [9]. Cold and dry inhaled gases result in decreased mucociliary function and the accumulation of secretions. An HHBC adds moisture and warmth to inspiratory gases from a temperature-regulated water reservoir. So, it can improve mucus transportability by cilia and make mucus wet [10]. In addition, an HHBC may help prevent intraoperative hypothermia due to cold inhaled gases by decreasing

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evaporation of water from the surface of the tracheobronchial mucous membrane. Some studies have discussed the efficacy of HHBCs on prevention of intraoperative hypothermia in clinical practice, but it remains controversial [11–17].

Recently, a new HHBC containing a fluid-warming unit has been developed. It has dual benefits in fluid-warming and in preventing heat loss from the respiratory tract. In this circuit, when fluid passes through the inspiratory gas limb, in which an inner conduit for fluid is placed just near the electrically heated wire, fluid is warmed by stealing heat from the heated wire. We hypothesized that this new HHBC would more effectively maintain intraoperative core temperature than a regular HHBC by delivering warm fluids.

In this study, we compared the effects of a regular HHBC and the new HHBC on intraoperative core temperature in neurosurgical patients undergoing elective craniotomies.

Materials and methods

Laboratory test of the new HHBC

The ability for fluid-warming of the Mega Acer kit®, which was used in group M, was in vitro tested. A schematic view of the Mega is shown in Fig. 1. The temperature of the fluid leaving the breathing circuit system was measured with a fluid thermometry (Mini digital thermometer TPM-10, Shenzhen Capital Electronics Co., Ltd., Guangdong, China), which was placed distal to the outlet of the fluid tube. The devices were tested at flow rates of 100, 200, 300, 400, and 500 ml/h with a set temperature of 38 °C. An infusion pump (Infusomat® P, B. Braun Melsungen AG, Germany) was used to deliver fluid at a given rate. We measured the infusion fluid temperature four times in each fluid delivery rate in ten experimental settings. At rates of 100, 200, 300, 400, and 500 ml/h, the infusion fluid temperature was 29.1 ± 1.4, 32.4 ± 1.3, 33.9 ± 1.4, 33.6 ± 1.4, and 32.7 ± 1.3 °C, respectively.

Subjects

This study was approved by the Institutional Review Board of Seoul National University Hospital. Written informed consent was obtained from patients. This was a prospective single-blind, randomized study of 111 patients with American Society of Anesthesiologists physical status classification I or II, aged 20–70 years, who underwent elective craniotomies between January 2013 and July 2013.

Exclusion criteria

The exclusion criteria included preoperative body temperature above 38.5 °C, thyroid dysfunction, autonomic neuropathy, uncontrolled diabetes mellitus, or a history of a recent (within 2 weeks) upper respiratory infection.

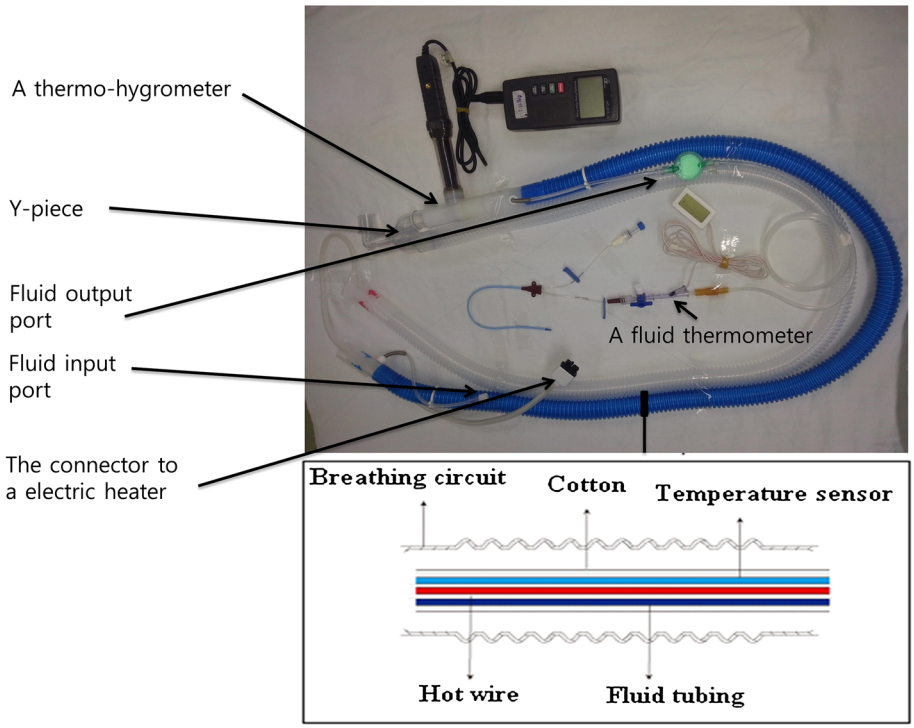

Fig. 1 Schematic diagram of the Mega Acer kit®. When fluid passes through the inner conduit in the inspiratory limb, fluid with ambient temperature is warmed by stealing the heat from the electrically heated hot wire placed around a fluid tube, and then warm fluid is administrated to the patient via an infusion port in a double-lumen subclavian venous catheter, which is connected to an extension line with the length of 100 cm. To eliminate air bubbles, a small filter is placed distal to the fluid output port in the inspiratory limb. A thermo-hygrometer is placed immediately distal to the Y-piece to measure the humidity and temperature of the inspiratory gas. The temperature of infused fluid is measured with a fluid thermometer, which is placed distal to a fluid infusion port in the subclavian venous catheter

Patients with any of the following conditions during the surgery were also excluded: need for more than 10 units of red blood cells due to estimated blood loss over 5,000 ml, and intentional hypothermia, meaning a body temperature below 35 °C. Patients whose anesthetic time was <4 h were also excluded because their data were considered as missing data in statistical analysis. Patients undergoing craniotomy in the prone position were excluded because the effect of a circulating water mattress on intraoperative body temperature was overlooked.

Group assignment

Using a research randomizer program (ver. 4.0), patients were randomly divided into three groups: a conventional breathing circuit (disposable breathing circuit, Acemedical, Seoul, South Korea) was used in group C, a HHBC (RT 212 adult inspiratory heated breathing circuit, Fisher & Paykel Healthcare, Auckland, New Zealand) in group F, and a new HHBC with a fluid-warming unit (Mega Acer kit, Acemedical, Seoul, South Korea; Fig. 1) in group M. The assignments were concealed in opaque envelopes and opened immediately before induction by a nurse who was blinded to this study and was in charge of preparing the breathing circuits.

Pre-anesthetic preparation

Before induction, the HHBC and the new HHBC with a warming device were previously warmed with a set temperature of 38 °C. On the inspiratory limb of each breathing circuit, a thermo-hygrometer measurement device (HT-315 Pro kit, Lutron Electronic Enterprise Co., Ltd., Taipei, Taiwan) was placed immediately distal to the Y-piece to measure the humidity and temperature of the inspiratory gas. A circulating water mattress placed on the operating table was set at 38 °C. The ambient temperature and humidity were also measured.

Anesthetic induction

Patients were fasted from midnight and entered the operating room without premedication. After standard monitoring, baseline body temperature was measured with a non-contact infrared thermometer (ThermoFlash Lx-26, JXB Co. Ltd., Guangzhou, China) at the mid-forehead of the patient.

Anesthesia was induced with propofol 4–5 μg/ml and remifentanil 4–5 ng/ml at the effect site, using a target-controlled infusion pump. Rocuronium (0.6 mg/kg) was used to facilitate intubation. Patients were intubated and mechanically ventilated using 50 % oxygen, a constant tidal volume of 8 ml/kg and an inspiration/expiration ratio 1:2. Total fresh gas flow was maintained at 3 l/min throughout the operation. After successful intubation, an esophageal stethoscope (Deroyal, Powell, TN, USA) was introduced into the oral cavity to measure the core temperature. Its tip was placed on a point of the esophagus where strong heart sounds with weak breath sounds are detected [18].

To secure an additional intravenous line, central venous catheterization was performed on the subclavian vein in all patients, and a fluid thermometry (Mini digital thermometer TPM-10, Shenzhen Capital Electronics Co., Ltd., Guangdong, China) was placed distal to an infusion port in a double-lumen subclavian venous catheter, which was connected to a fluid extension tube with the length of 100 cm (Extension tube®, Insung Medical, Seoul, South Korea) to measure the temperature of fluids infused through the subclavian vein (Fig. 1). Warm fluids were delivered in only patients using the Mega Acer kit.

Measurements

Every 15 min until the end of the surgery, core temperature, temperature and relative humidity of the inspiratory gas, and temperature of the fluids were recorded. After patients were positioned for surgery, the lower extremities and trunk were covered with blankets and a forced-air warmer (Bair Hugger patient warmer 505, Arizant Healthcare Inc., Eden Prairie, MN, USA) was applied if the core temperature fell below 35.5 °C. Total forced-air warmer using time was also recorded. At the end of surgery, estimated blood loss and total amounts of fluid administration were noted.

Our primary outcome measured was intraoperative core temperature. Secondary outcome measured the number of patients receiving forced-air warmer, the forced-air warmer using time, the temperature and relative humidity of the inspiratory gas, and the temperature of fluids.

Statistical analysis

In a previous study with airway heating and humidification, core temperature decreased 0.5 (0.4) °C 3 h after anesthetic induction [12]. To demonstrate a 0.3 °C difference in core temperature as significant at the type I error level of 0.025 with a power of 80 %, we needed a minimum of 34 patients per group. To compensate for possible dropouts (10 %), 37 patients per group were required for the study.

Statistical analyses were performed using SPSS software (ver. 20.0; SPSS Inc., Chicago, IL, USA). Parametric and nonparametric data were compared using a cross table with the Chi-squared test and ANOVA, respectively. The core and infusion fluid temperatures, and temperature and relative humidity of the inspiratory gas were compared using a repeated-measures ANOVA for time-by-group effect, followed by ANOVA with a Bonferroni test to compare the

Table 1 Demographic data of patients using three different breathing circuits

	Group C ($n = 34$)	Group F ($n = 34$)	Group M ($n = 34$)
Age (years)	47.9 ± 14.9	50.7 ± 11.3	49.4 ± 12.5
Sex (F/M)	16/18	17/17	20/14
Weight (kg)	63.7 ± 12.1	66.3 ± 10.2	65.0 ± 11.6
Height (cm)	164.2 ± 8.5	164.4 ± 8.5	160.5 ± 10.1
BMI (kg/m^2)	23.6 ± 3.5	24.5 ± 2.6	25.1 ± 3.5
ASA class (1/2)	15/19	14/20	8/26
Diagnostic criteria (*n*)			
Tumor	28	27	30
Vascular	5	6	0
Others	1	1	4
Temperature in OR (°C)	23.2 ± 0.8	22.7 ± 0.9	22.8 ± 1.1
Relative humidity in OR (%)	42.6 ± 16.9	39.6 ± 15.1	37.0 ± 15.8

Data are presented as mean (SD) or number. The Mega Acer kit®, a new heated and humidified breathing circuit with a fluid-warming device, is used in group M. The heated and humidified breathing circuit manufactured by Fisher & Paykel Healthcare is used in group F. A conventional breathing circuit is used in group C

ASA American Society of Anesthesiologists physical status, *OR* operating room

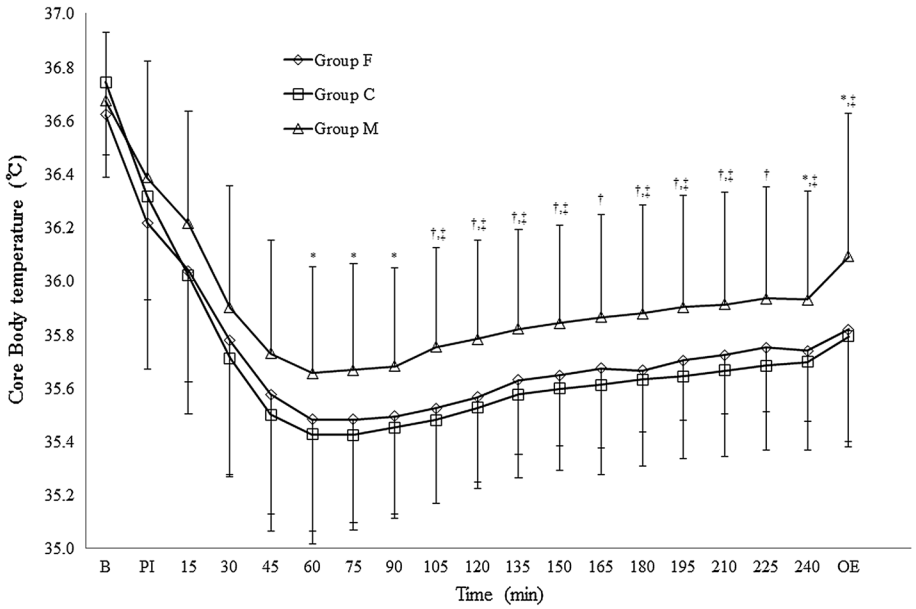

Fig. 2 Changes in core temperature over time. The Mega Acer kit®, a new heated and humidified breathing circuit with a fluid-warming device, is used in group M. The heated and humidified breathing circuit manufactured by Fisher & Paykel Healthcare is used in group F. A conventional breathing circuit is used in group C. *B* Baseline, *PI* post-induction, *OE* the end of operation. *$p < 0.05$ vs. group C, †$p < 0.01$ vs. group C, ‡$p < 0.05$ vs. group F

data at each time point. A p value of <0.05 was considered statistically significant.

Results

In total, 111 patients were enrolled in this study and nine patients (three in each group) were excluded from the data analysis because their anesthetic durations were <4 h or the surgery was performed in the prone position. Regarding demographic data, except for the proportions of patients with cerebrovascular problems, there was no significant difference between the groups (Table 1).

Baseline body temperatures were similar among the three groups (group C: 36.7 ± 0.3 °C, group F: 36.6 ± 0.2 °C, group M: 36.6 ± 0.2 °C). In all groups, core temperature decreased from baseline values during the first 60 min but did not decrease further after that time (Fig. 2). Core temperatures at the end of surgery had decreased from baseline values by 1.0 ± 0.4, 0.5 ± 0.5, and 0.8 ± 0.5 °C in groups C, M, and F, respectively. The changes in temperature over time were significantly different among the

Table 2 Intraoperative data of patients using three different breathing circuits

	Group C ($n = 34$)	Group F ($n = 34$)	Group M ($n = 34$)
Total anesthesia time (min)	387.7 ± 115.8	395.7 ± 126.2	423.8 ± 150.2
Fluid infused (ml/kg/h)	6.9 ± 2.1	7.0 ± 2.6	6.8 ± 2.0
Fluid infused through SCV (ml/kg/h)	4.0 ± 1.5	4.3 ± 2.0	4.1 ± 1.3
Total forced-air warmer using time [min, median (IQR)]	63.5 (18.8–106.8)*	57.5 (23.5–105)*	17.5 (0–65)
No. of patients using air warmer (*n*)	27*	29†	18
Intraoperative estimated blood loss (ml)	881.6 ± 729.5	791.8 (549.0)	851.5 ± 558.3
Transfused RBC (unit)	0.8 ± 1.4	0.8 ± 1.2	0.7 ± 1.2
Transfused patient (*n*)	12	13	13
Use of a rapid warm blood infuser (*n*)	1	3	0
Use of vasopressor (*n*)	15	18	19
Use of continuous vasopressor infusion (*n*)	1	3	1
Total doses of remifentanil (μg/kg/h)	7.7 ± 2.4	7.5 ± 2.4	7.2 ± 2.0
Total doses of propofol (mg/kg/h)	8.2 ± 1.3	8.1 ± 1.4	8.0 ± 1.6

Data are presented as mean (SD), median (IQR), or number. The Mega Acer kit®, a new heated and humidified breathing circuit with a fluid-warming device, is used in group M. The heated and humidified breathing circuit manufactured by Fisher & Paykel Healthcare is used in group F. A conventional breathing circuit is used in group C

SCV subclavian vein, *RBC* red blood cell

* $p < 0.05$ vs. group M, † $p < 0.01$ vs. group M

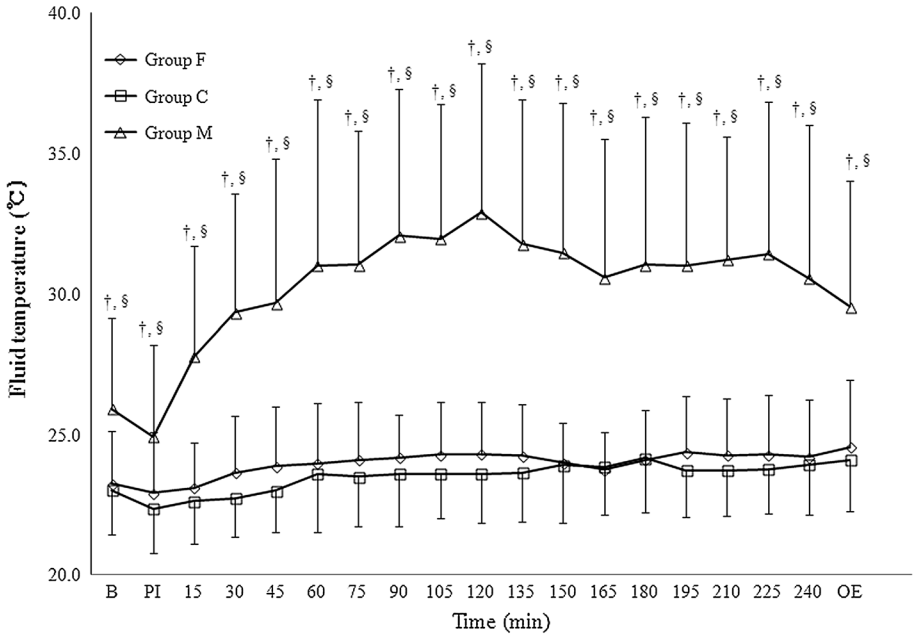

Fig. 3 Changes in infusion fluid temperature over time. The Mega Acer kit®, a new heated and humidified breathing circuit with a fluid-warming device, is used in group M. The heated and humidified breathing circuit manufactured by Fisher & Paykel Healthcare is used in group F. A conventional breathing circuit is used in group C. *B* Baseline, *PI* post-induction, *OE* the end of operation. †$p < 0.01$ vs. group C, §$p < 0.01$ vs. group F

groups ($p < 0.05$). From 60 min of post-intubation to the end of surgery, core temperature was significantly higher in group M than group C ($p < 0.05$). In addition, from 105 min of post-induction to the end of surgery, core temperature was significantly higher in group M than group F ($p < 0.05$).

There were no significant differences in total anesthetic time, total amounts of fluid administered through the subclavian vein (infusion fluid temperature monitoring site) intraoperatively, total doses of remifentanil or propofol, or transfused red blood cells among the three groups (Table 2). The number of patients who received warm air using the Bair-Hugger patient warmer was significantly lower in group M than group C and F (52.9 vs. 79.4 and 85.3 %, $p < 0.05$). Total forced-air warmer using time was significantly lower in group M than other groups ($p < 0.05$).

The temperature of fluids administered through the subclavian vein was significantly higher in group M than in the other

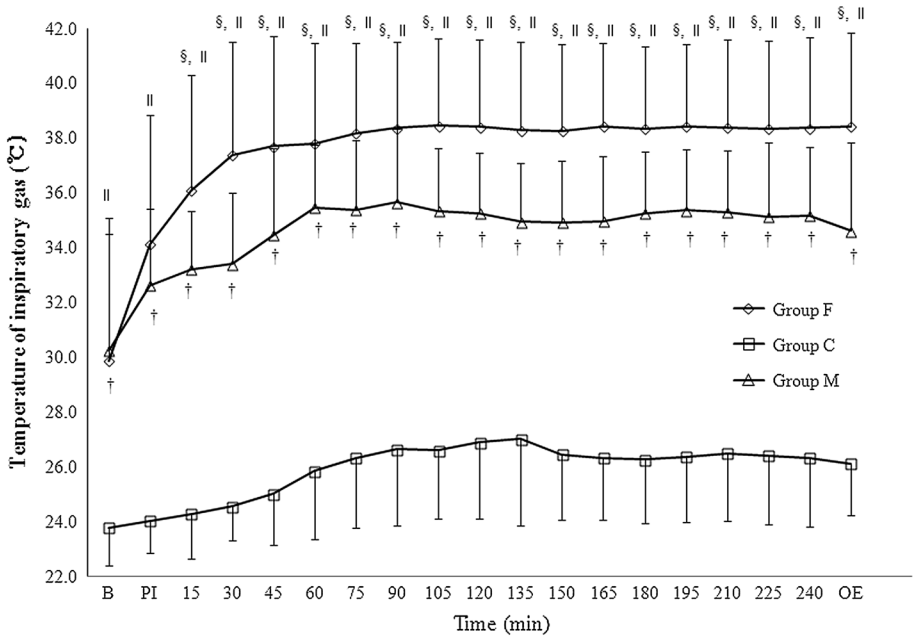

Fig. 4 Changes in temperature of inspiratory gas over time. The Mega Acer kit®, a new heated and humidified breathing circuit with a fluid-warming device, is used in group M. The heated and humidified breathing circuit manufactured by Fisher & Paykel Healthcare is used in group F. A conventional breathing circuit is used in group C. *B* Baseline, *PI* post-induction, *OE* the end of operation. $^{\|}p < 0.01$ vs. group C, $^{\S}p < 0.01$ vs. group F, $^{\dagger}p < 0.05$ vs. group C

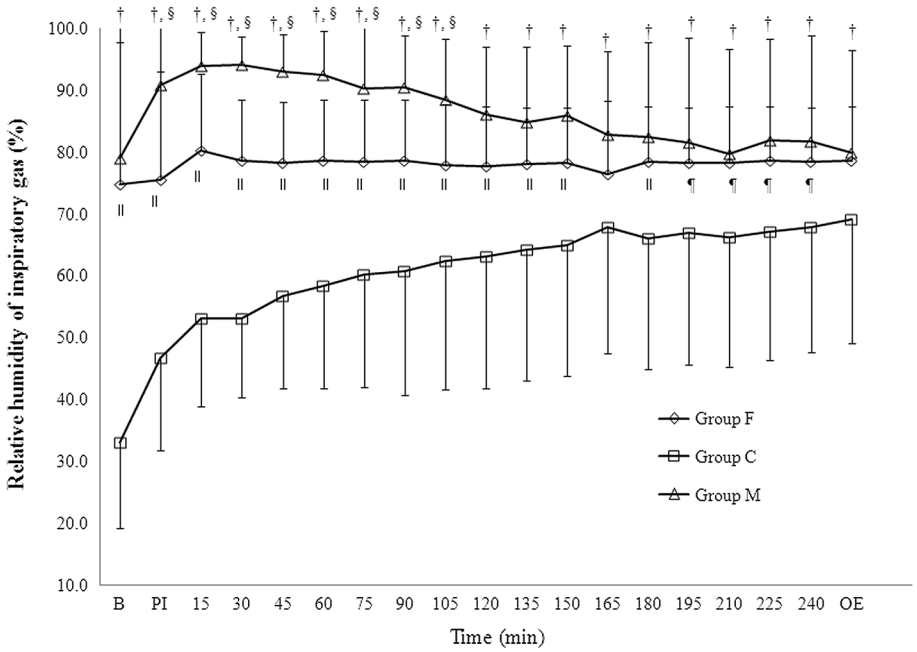

Fig. 5 Changes in relative humidity of inspiratory gas over time. The Mega Acer kit@, a new heated and humidified breathing circuit with a fluid-warming device, is used in group M. The heated and humidified breathing circuit manufactured by Fisher & Paykel Healthcare is used in group F. A conventional breathing circuit is used in group C. *B* Baseline, *PI* post-induction, *OE* the end of operation. $^{\dagger}p < 0.01$ vs. group C, $^{\S}p < 0.01$ vs. group F, $^{\|}p < 0.01$ vs. group C, $p < 0.05$ vs. group C

groups throughout the study period ($p < 0.01$, Fig. 3). The mean infusion fluid temperatures were 23.5 ± 0.5 °C in group C, 24.0 ± 0.4 °C in group F, and 31.0 ± 1.0 °C in group M.

The temperature of the inspiratory gas was significantly higher in group F than in group C throughout the study period ($p < 0.01$, Fig. 4), and in group M beyond 15 min post-induction ($p < 0.01$). Also, the temperature of the inspiratory gas was significantly higher in group M than in group C throughout the study period ($p < 0.05$). The mean inspiratory gas temperatures were 25.9 ± 1.0 °C in group C, 37.4 ± 2.1 °C in group F, and 34.5 ± 1.3 °C in group M.

With respect to the relative humidity of the inspiratory gas, group M had a significantly higher relative humidity than the other groups (Fig. 5). The mean relative humidities of the inspiratory gas were 60.4 ± 9.0 % in group C, 78.0 ± 1.2 % in group F, and 86.3 ± 5.2 % in group M.

Discussion

This study showed that a new HHBC containing a fluid-warming device was superior to a conventional HHBC and

a conventional breathing circuit in maintaining intraoperative core temperature in patients undergoing craniotomies.

Unintentional hypothermia occurs commonly during surgery due to heat redistribution and heat loss. Additionally, general anesthesia per se depresses the compensatory mechanisms of body thermoregulation [9, 19]. Core temperature usually decreases by 0.5–1.5 °C during the first hour after the induction of general anesthesia [9, 20]. Heat redistribution between the core thermal region and peripheral thermal region, and heat loss due to anesthetic-induced vasodilation contribute to this core hypothermia. After that time, the hypothermic response is mainly due to heat loss to the environment through radiation, evaporation, convection, and conduction [19].

In the present study, we showed that none of the devices tested could prevent a decrease in core temperature during the first hour of anesthesia. Consistent with our results, Lee et al. [12] found that a HHBC did not prevent the core temperature drop until 30 min after induction. Goldberg et al. [14] also showed that the temperature drop was greatest in the first hour of surgery, even though they used a HHBC. Such findings suggest that the greatest heat loss occurs during the first hour of anesthesia, and the preventative effects of the HHBC on intraoperative hypothermia may be seen obviously beyond 1 h of anesthesia, but not during the first hour.

In this study, from 1-h post-anesthetic induction, core temperature was significantly higher in patients using the new HHBC, compared with the other breathing circuits. This finding is, in part, explained by the differences in infusion fluid temperatures among the groups. The main difference between the Mega Acer kit and the HHBC or the conventional breathing circuit is that the Mega Acer kit has a fluid-warming device; the other devices do not. In this study, the total amounts of fluid infused through the subclavian vein were comparable among the groups. However, the temperature of fluids infused through the subclavian vein was markedly higher with the Mega Acer kit. That is, warm fluids were delivered in patients using the Mega Acer kit. In a previous study [7], using the Hotline fluid warmer (SIMS Level 1, Inc., Rockland, MA, USA), core temperatures were significantly lower in the controls compared with the warm fluid group at the end of surgery. Another investigation by Camus et al. [5] also showed that infusion of warmed fluids help to prevent hypothermia at the end of surgery. Various other studies have also revealed beneficial effects of fluid warmers in the prevention of hypothermia [21–23]. Interestingly, our result showed that the infusion fluid temperature was the highest at the infusion rate of 300 ml/h and slightly decreased at the infusion rate of more than 300 ml/h and less than 300 ml/h. Such findings can be in part explained by differences in the transit time of fluid in the inspiratory limb and the exposure time of fluid to ambient temperature after fluid leaves the inspiratory limb. At the infusion rate of more than 300 ml/h, because the transit time of fluid in the inspiratory limb is relatively short, the infusion fluid temperature can be decreased by dropping heat gain. In addition, at the infusion rate of less than 300 ml/h, because the transit time of fluid out the inspiratory limb is relatively long, the infusion fluid temperature can also be decreased by increasing heat loss. If the distance between the subclavian vein and the fluid output port in the inspiratory limb is short, the Mega Acer kit may be effective in delivering warm fluids and thereby in decreasing the drop in intraoperative core temperature.

In this study, when the core temperature dropped below 35.5 °C, a forced-air warmer was used, presenting a potential source of interference. In previous studies [12, 15, 17], other warming devices were not allowed, thus the result showed the independent efficacy of a HHBC, but we thought it was unethical to let a patient's core temperature fall to 35.5 °C or less. So we used active warming devices such as forced-air warmer and warmed circulating water mattress additionally. As a result, we observed relatively small differences in core temperatures among the groups. Rather, we checked the number of subjects receiving the forced-air warmer and the forced-air warmer using time in each group. We thought that these variables may reflect indirectly the incidence and severity of the intraoperative hypothermia.

The present study showed that the effect of an HHBC alone on intraoperative core temperature was similar to that of a conventional breathing circuit. A literature review showed inconsistent results concerning the efficacy of HHBCs in preventing intraoperative hypothermia. In contrast to our result, most previous studies have shown that an HHBC can maintain intraoperative body temperature better than a conventional breathing circuit [12, 13, 24]. However, consistent with our finding, two other studies demonstrated that a HHBC did not prevent a drop in temperature, compared with a conventional breathing circuit, in patients undergoing various lower abdominal surgeries and in patients with major burns [14, 17]. Another study showed the ineffectiveness of an HHBC in preventing the afterdrop in body temperature after rewarming in patients undergoing hypothermic cardiopulmonary bypass [16]. Differences in patient selection, surgery type, sample size, and duration of intraoperative core temperature measurements may explain, at least in part, why the HHBC produces differing results in terms of intraoperative hypothermia.

An HHBC offers some advantages. Inhalation of humidified gases protects the tracheobronchial ciliated epithelium from injury due to the inhalation of dry gases [25]. Also, humidified gas eases the flow of mucus—this may help to remove bronchial secretions and prevent plugging of endotracheal tubes [26]. In a previous study, active humidification of

inspired gases may reduce the incidence and severity of sore throat and cough after thyroid surgery [27].

This study has several limitations. First, this was a single-blind study. Blinding to the amounts of fluid administered through the subclavian vein was not possible because the breathing circuit could not be disguised. Also, the amounts of fluid infused through the subclavian vein were modest in this study. A low fluid infusion rate can affect intraoperative core temperature in patients using the Mega Acer breathing kit by decreasing the amounts of warm fluid infusion. Patient selection, surgery type, and total anesthetic time may also limit the generalizability of the results. In order to prevent intraoperative hypothermia, it can be desirable to deliver warm fluids intraoperatively. In this study, fluids at room temperature were delivered to the patients because warm fluid infusion can influence the core temperature and it may distort our main result, the beneficial effect of the Mega Acer breathing kit with additional fluid-warming ability. Similar to previous studies evaluating the effect of an HHBC on intraoperative core temperature [12, 15, 17], fresh gas flow of 3 l/min was used during the entire study period in this study. Low fresh gas flow can affect core temperature by increasing the amount of rebreathing gas. In this study, core temperature was measured only at the esophagus. Therefore, caution is needed in interpreting intraoperative core temperature because heated and humidified breathing gases can influence the esophageal temperature. Finally, forehead skin temperature using an infrared thermometer was measured before anesthetic induction and considered as a baseline value in this study because of non-invasiveness and ease. However, there is a little problem in comparing forehead skin temperature with esophageal temperature because of the lack of precision between forehead skin (peripheral) temperature and esophageal (core) temperature [28].

In conclusion, the present study showed that the Mega Acer kit, a new HHBC with a fluid-warming device, reduced the drop in intraoperative core temperature more effectively and decreased the duration and incidence of forced-air warming more significantly in patients undergoing craniotomies than other breathing circuits tested by delivering warmed fluids.

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Conflict of interest The authors declare that they have no competing interests.

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