Effect of intravenous fluid warming devices on intraoperative core temperature during maintenance fluid therapy: a prospective randomized controlled trial

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We investigated the effects of intravenous fluid warmers on intraoperative core temperatures at low flow rates during the maintenance fluid therapy. We conducted a prospective, non-blinded, randomized controlled trial in 99 patients, scheduled for elective spinal fusion surgery with more than 3 hours of general anesthesia. They were randomly distributed into groups using Mega Acer Kit (group M; n=30), Ranger (group R; n=32), or ThermoSens (group T; n=32). The infused flow rate of the fluid was determined as one-third of the preoperative fluid deficit (4–2–1 rules) during fasting times, and the third space loss during surgery (2 mL/kg), per hour. The primary outcome was intraoperative final and lowest esophageal temperature ($T_{\text{eso_Final}}$, lowest T_{eso}). $T_{\text{eso_Final}}$, lowest T_{eso} , and intraoperative T_{eso} were not significantly different between groups ($p=0.512$, and $p=0.393$, $p=0.066$, respectively). However, the temperature change from baseline T_{eso} to $T_{\text{eso_Final}}$ was significantly different between the groups ($p=0.044$), which of group M were significantly lower than group T ($p=0.033$). After adjustment with baseline T_{eso} , the differences of least squares means showed the significant differences between groups M and T at 2.5 hours ($p=0.020$) and 3 hours ($p=0.006$). The Mega Acer Kit, Ranger, and ThermoSens have a similar effect on intraoperative core temperatures with the low flow rates, but The Mega Acer Kit is more effective at controlling core temperature than the ThermoSens if the fluid infusion time is over 2.5 hours.

Keywords: Body temperature changes; Heating/instrumentation; Hypothermia; Intravenous infusions; Maintenance flow rate

INTRODUCTION

Due to the inhibition of normal thermoregulation, intraoperative hypothermia commonly develops within the first 40 minutes of anesthesia [1]. It may also lead to delayed recovery and postoperative complications such as surgical wound infections, coagulopathy, and cardiac events [2]. It

has been previously reported that patients with postoperative hypothermia have a four-fold increase in mortality as well as a two-fold rise in complication rates compared to normothermic patients [3]. Therefore, it is important to monitor and maintain the intraoperative core temperature. It is also recommended to warm intravenous fluids, with infusion volumes greater than 500 mL, to 37°C using fluid

warming devices to prevent or treat inadvertent perioperative hypothermia in adults [1,4,5].

A number of fluid-warming devices have been used to prevent or treat hypothermia. The effectiveness of these devices have been investigated for rapid infusions of large volumes in patients when severe or moderate perioperative hypothermia was expected or developed. The devices were found to be helpful in maintaining body temperature, while reducing hypothermia-related morbidity and complications [3,6-8].

Unfortunately, patients may still develop perioperative hypothermia after intravenous maintenance fluid therapy with low to moderate flow rates, which can be prevented by warming the intravenous fluid during infusion [9]. However, these fluid warmers are generally not used in cases requiring low to moderate flow rates, and there are very few relevant studies [10,11].

In our hospital, the Mega Acer Kit, the 3M Ranger Blood/Fluid Warming System, and the ThermoSens are commonly applied for the prevention and treatment of hypothermia. The Mega Acer Kit has a unique heating mechanism, distinct from that of ThermoSens and Ranger. Specifically, the Mega Acer Kit is made up of a heated and humidified circuit, regulating the fluid warming function with a convective warming system that can warm the fluid directly using heated convective air currents [12,13]. In contrast, ThermoSens and Ranger employ a dry heat technology. While the ThermoSens uses plastic cassettes in contact with a heating plate [10,14], the Ranger uses a flat plastic sheet in contact with a counter-current metal heating plate [15].

Some authors, in previous experimental studies, have suggested that these intravenous fluid warmers achieve optimal fluid warming performance at a device-specific flow rate. This optimal performance is achieved at a low to moderate flow rate (<860 mL/h) using the Mega Acer Kit, and at a high flow rate (>1,140 mL/h) using the Ranger as well as the ThermoSens with shorter tubing [16,17]. Therefore, we hypothesized that the Mega Acer Kit would have a more effective fluid warming performance with low flow rates, resulting in smaller drops in the intraoperative core temperature and the lower core temperature (final as well as lowest), compared to the other devices in this clinical study.

Overall, we investigated whether these fluid warmers were effective at reducing the loss of core temperature and the

incidence of hypothermia (<36.0°C) during low flow rate intravenous maintenance fluid therapy for the treatment of preoperative and intraoperative fluid deficits. Moreover, we also assessed whether the fluid warming performance of each device was adequate at these flow rates.

MATERIALS AND METHODS

This prospective, randomized, controlled and non-blinded trial was approved by the Institutional Review Board of Chosun University Hospital Korea (date of first registration: 28/03/2016, registration number: CHOSUN 2016-02-003-001) and was registered at the Clinical Trial Registry of Korea (CRIS: <https://cris.nih.go.kr/>, date of first registration: 01/07/2016, registration number: KCT0001957).

Written informed consent was obtained from each participant and a legal surrogate. This study was conducted in accordance with the tenets of the Declaration of Helsinki, 1964 and all subsequent revisions.

The study included patients who were scheduled to undergo elective spinal fusion surgery with at least 3 h of general anesthesia at our institution, with the American Society of Anesthesiologists (ASA) Physical Status classification I or II. The patients identified as suitable for this study were asked to participate in this trial, which took place from June 2016 to September 2017. Patients with a preoperative body temperature abnormality (below 36°C or above 38°C), thyroid disease, diabetes, hypertension, brain tumors, coagulopathy, and emergent situations were excluded.

Randomization and masking

Ninety nine patients were assigned sequential numbers in order of enrollment and were randomly distributed into three groups to receive intravenous warming fluid through either the Mega Acer Kit (Ace Medical, Seoul, Korea) without humidification (Group M), the 3M Ranger Blood/Fluid Warming System (Ranger: Arizant Healthcare Inc., MN, USA) with a standard flow disposable set (Group R), or the ThermoSens Warming Unit (ThermoSens: Sewoon Medical Company, Seoul, Korea) with a sterile single use blood & fluid warmer set (Group T). Assignments were made through a computer-generated random number table, prepared prior to start of the study, with the random permuted block method (1:1:1 allocation ratio and a block size of 3). Although

patients were blinded to the study devices, the investigators were not.

Procedures

Patients were transported to the operating room following premedication with intramuscular midazolam (0.05 mg/kg). Prior to anesthesia induction, standard patient monitoring devices were used to obtain electrocardiograms, non-invasive blood pressure, end-tidal partial pressure of carbon dioxide, and peripheral oxygen saturation. Tympanic membrane temperature (T_{tym}) was then measured using ThermoScan (IRT4020: Braun GmbH, Kronberg, Germany).

The distal esophageal temperature (T_{eso}) was measured using an esophageal stethoscope with a temperature sensor (DeRoyal Industries, Inc., Powell, USA) after intravenous anesthesia induction with propofol, remifentanyl, and rocuronium. All patients received the mechanical ventilation via the Mega Acer Kit without humidification. While we did not control the intraoperative management of anesthetic induction-related hypotension (above 20% decrease or 90 mmHg of baseline systolic blood pressure), we did allow for fluid loading less than 0.5 mL/kg and drug therapy with phenylephrine (100 μ g) or ephedrine (5 mg), repeated as necessary before operating each device. The patient's fluid line was then switched with the prepared fluid line attached to each study device. The infused flow rate of fluid (mL/h) of each device was determined as one-third of the preoperative fluid deficit during fasting times (calculated with "4-2-1" formula based on weight and fasting time) and 2 mL/kg (replacement of fluid deficit due to third space loss during surgery as anticipated with minimal to moderate tissue trauma), per hour [9].

Intravenous fluid warmer setting

In order to calibrate the devices, each was set to a warming temperature of 41°C and preheated for 10 minutes for Group M, 5 minutes for Group R and with no preheating for Group T. The infusion set was primed with normal saline hung at a height of 1 m from the warming device and attached to a roller pump (TE-171, Terumo Corp., Tokyo, Japan) [9]. The outlet fluid temperature (T_{Pout}) was measured at an outlet point, which was at 76 cm from each device [9]. The distance of the intravenous line from each device to the patients was 131 cm, and the warming fluid was delivered to

Fig. 1. Diagrammatic representation of the measurement method. F: intravenous fluid (0.9% normal saline), RP: roller pump, WD: warming device, DL: Kistock datalogger, T_{eso} : distal esophageal temperature, T_{Pin} : fluid temperature at the inlet point of each fluid warmer, T_{Pout} : fluid temperature at the outlet point of each fluid warmer, T_{tym} : tympanic membrane temperature, T_r : room temperature.

the patients through this intravenous line exposed to ambient room temperature (Fig. 1) [16]. Two PT 100 temperature probes, as per IEC 751 standard [response time: $t_{0.63}=32$ s ($V_{\text{air}}=2$ m/s), accuracy: $\pm 0.4\%$ of reading $\pm 0.3^\circ\text{C}$; KRGA-50, Kimo Instruments, Edenbridge, UK], were connected to a Kistock Datalogger (KTH350: Kimo Instruments, Edenbridge, UK). The probes were inserted at the inlet and outlet points of each fluid warming device.

Data collection

The fluid temperatures at the inlet and outlet points of each fluid warmer (T_{Pin} , T_{Pout}), distal esophageal and tympanic membrane temperatures (T_{eso} and T_{tym}), and room temperature (T_r) were recorded using the Kistock Datalogger before and immediately after anesthesia induction (baseline), and then at 30-min intervals for 3 h of device operation.

The age, sex, ASA physical status, height, weight, body mass index (BMI), urine output, estimated blood loss (EBL),

and infusion rates of intravenous fluid were also noted. If a patients' blood loss exceeded the maximal allowable blood loss [body weight (kg) $\times$ average blood volume (75 mL/kg for men or 65 mL/kg for women) $\times$ (initial hemoglobin (g/dL) - 8.0 of hemoglobin (g/dL) / initial hemoglobin (g/dL)] or if they demonstrated hemodynamic instability requiring additional fluid infusion and blood transfusion, they were excluded from the data analysis. In this study, the minimum permitted hemoglobin level was set at 8.0 g/dL as the reference point for transfusion.

We recorded the final and lowest T_{tym} and T_{eso} ($T_{\text{tym_Final}}$, $T_{\text{eso_Final}}$, $T_{\text{tym_Lowest}}$, and $T_{\text{eso_Lowest}}$) values as well as their differences from the baseline values ($\Delta T_{\text{tym_Final}}$, $\Delta T_{\text{eso_Final}}$, $\Delta T_{\text{tym_Lowest}}$, $\Delta T_{\text{eso_Lowest}}$). We defined the heating capability for each device as the difference of T_{Pout} 0.5 h after operating the warming device and before anesthesia induction. We classified the $T_{\text{eso_Final}}$ and the $T_{\text{eso_Lowest}}$ using grade 1 ($T_{\text{eso}} \geq 36.0^\circ\text{C}$), grade 2 ($35.0^\circ\text{C} \leq T_{\text{eso}} < 36.0^\circ\text{C}$), and grade 3 ($T_{\text{eso}} < 35.0^\circ\text{C}$), and noted the incidences.

Sample size and statistical analyses

The primary outcomes of this study were the $T_{\text{eso_Final}}$ and the lowest T_{eso} , and the secondary outcome was the incidence of hypothermia (grades 2 and 3). The necessary sample size calculations for one-way ANOVA were completed using G*Power software (ver. 3.1.9.1, Heinrich-Heine-Universität Düsseldorf, Germany), where the level of statistical significance was set as $\alpha=0.05$ and $\beta=0.1$, with a large effect size of 0.4 (defined by Cohen for one-way ANOVA analysis) that was based on assumptions, as there were no data to calculate the effect size [18]. The study required a total of 84 patients; thus, we enrolled 99 patients, allowing for a dropout rate of approximately 15%.

SPSS (Windows ver. 24.0, IBM Corp., Armonk, NY, USA) was used for all statistical analyses. Categorical variables were presented as number (percentage) of patients (n [%]), and continuous variables were reported as means (95% confidential intervals [CI]) or medians (interquartile range [IQR]).

The normality of probability distribution was analyzed with the Kolmogorov-Smirnova test and Shapiro-Wilk test. The continuous normally distributed variables were analyzed with one-way ANOVA followed by Scheffe's post-hoc test in the presence of a homogeneity of variance according to Levene's test. If the variables had non-homogeneity, we

performed the Games-Howell post-hoc test. The continuous variables with non-normal probability distribution were analyzed with the Kruskal-Wallis test followed by pairwise-comparisons. Nominal variables were analyzed with the χ^2 or Fisher's exact test. The repeated measured variables were analyzed with repeated measures analysis of variance (ANOVA). In addition, the T_{eso} between groups were also compared using linear mixed modeling with restricted maximum likelihood estimation, the specifying fixed effects (group, time, other confounders, and group-by-time interaction), and the correlation structure modeled by a first-order autoregressive (AR1) covariance matrix. This analysis was conducted separately for detection of potential confounders, which had a significant association with the baseline T_{eso} ($T_{\text{eso_Base}}$) ($p < 0.2$). After adjustment with $T_{\text{eso_Base}}$, the comparison of the group-by-time least squares means by time in T_{eso} was further evaluated using a mixed effects model with Bonferroni correction. p -values < 0.05 were considered statistically significant.

RESULTS

Study population

A total of 99 patients were enrolled in the study. However, as the surgery was completed early in three patients and was canceled in another two patients, these patients were excluded, leaving 94 for the final data analysis (Fig. 2). There were no patients who had more than the maximal allowable blood loss and hemodynamic instability requiring additional fluid infusion and blood transfusion.

Importantly, no statistically significant differences were observed in demographic data, intraoperative EBL, urine output, or infusion rate (Table 1). The mean infused flow rate (mL/h) of each device was 380.3 (362.2-398.4), 392.5 (371.7-413.3), 404.3 (384.6-424.0) in groups M, R, and T, respectively ($p=0.220$). No significant difference in the room temperature (T_r) was observed between the three groups throughout the study period (Fig. 3A).

Performance of the intravenous fluid warmers

There was no significant difference in T_{Pin} throughout the study period between the three groups, except for T_{Pin} before and 3 h after operating the warming device in group M, where there was a significant difference compared with

Fig. 2. CONSORT (Consolidated Standards of Reporting Trials) diagram. Group M: group using Mega Acer Kit, Group R: group using Ranger, Group T: group using ThermoSens.

Table 1. Demographic and intraoperative data

	Group M (n=30)	Group R (n=32)	Group T (n=32)
Age (yr)	60.3 (54.8–65.8)	64.3 (60.2–68.4)	64.6 (61.6–67.6)
Sex (male/female)	10/20	9/23	11/21
Height (cm) ^a	157.0 (153.0–162.3)	155.0 (153.0–164.5)	158.0 (152.0–167.3)
Weight (kg)	58.6 (54.8–62.5)	61.3 (56.8–65.7)	63.8 (59.6–68.0)
BMI (kg/m ²)	23.2 (22.2–24.1)	24.4 (23.1–25.7)	24.9 (23.6–26.2)
ASA physical status (I/II)	15/15	11/21	11/21
EBL (mL) ^a	300.0 (100.0–300.0)	300.0 (225.0–500.0)	300.0 (200.0–300.0)
Surgical time (min) ^a	215.0 (200.0–255.0)	240.0 (207.5–322.3)	230.0 (211.3–277.5)
Urine output (mL) ^a	450.0 (200.0–825.0)	450.0 (300.0–700.0)	400.0 (212.5–600.0)
Infusion rate (mL/h)	380.3 (362.2–398.4)	392.5 (371.7–413.3)	404.3 (384.6–424.0)

The values are expressed as mean (95% confidential intervals), median (interquartile range), or number of patients. There were no significant differences between groups. ASA: American Society of Anesthesiologists, BMI: body mass index, EBL: Estimated blood loss. ^amedian (interquartile range). $p < 0.05$ was considered to indicate statistical significance.

that of group T ($p=0.020$, $p=0.017$, respectively) (Fig. 3B). We observed a significant differences in the T_{Pout} values between the three groups throughout the study period ($p < 0.001$), and T_{Pout} was the highest in group M, followed by group T,

and lowest in group R (Fig. 3C). The heating capability for groups M, R, and T were 13.6°C , 7.3°C , and 8.0°C , respectively.

Fig. 3. Temperatures of inlet (T_{pin}) and outlet points (T_{pout}) of the warming device and operating room (T_r) (°C). T_r (A), T_{pin} (B), T_{pout} (C) at each measured time point. Before: before anesthesia induction, Baseline: immediately after anesthesia induction. * $p < 0.05$ compared with group R, † $p < 0.05$ compared with group T.

Temperatures of the tympanic membrane and distal esophagus

There were no statistically significant differences in the values of T_{tym} and T_{eso} between the groups throughout the study period (Fig. 4A and B). The T_{tym_Final} , T_{eso_Final} , T_{tym_Lowest} , and T_{eso_Lowest} were not significantly different between the groups ($p=0.820$, $p=0.512$, $p=0.965$, $p=0.393$, respectively) (Table 2). Nevertheless, the temperature change from baseline T_{eso} to T_{eso_Final} (ΔT_{eso_Final}) was significantly different between the groups ($p=0.044$), while the T_{tym_Final} , T_{tym_Lowest} , and T_{eso_Lowest} (ΔT_{tym_Final} , ΔT_{tym_Lowest} , and ΔT_{eso_Lowest}) were not significantly different between the groups ($p=0.383$, $p=0.496$, $p=0.076$, respectively) (Table 2). ΔT_{eso_Final} of group M was also significantly lower than that of group T ($p=0.033$).

In the final linear mixed modeling, the time of assessment, group (groups M, R, and T), T_{eso_Base} ($p < 0.001$), and group-by-time interaction were included as the fixed effects. There was a significant overall correlated fixed effect

in time ($p < 0.001$), T_{eso_Base} ($p < 0.001$), and group-by-time interaction ($p=0.017$) as potentially important predictors of the dependent variable. After adjustment with T_{eso_Base} , the group-by-time interactions showed significant differences in all groups ($p < 0.001$), and they were significantly different at 2.5 ($p=0.025$) and 3 hours ($p=0.007$) after device operation. The overall least squares mean values showed no significant differences between groups after Bonferroni correction. Within each time, the differences of least squares means showed significant differences between groups M and T at 2.5 ($p=0.020$) and 3 hours ($p=0.006$) after operating the devices. (Fig. 4C).

Incidence of intraoperative hypothermia

The incidence of intraoperative hypothermia, based on the T_{eso_Final} and T_{eso_Lowest} , was not significantly different between the three groups ($p=0.964$, $p=0.877$) (Table 3). The incidences of hypothermia $< 36.0^\circ\text{C}$ based on the T_{eso_Lowest} were 73.3%, 78.1%, and 78.1% ($p=0.877$), while those of

Fig. 4. Temperatures at the tympanic membrane and distal esophagus (T_{tym} , T_{eso}), and T_{eso} LS-Mean (°C). T_{tym} at each measuring time point (A), vT_{eso} at each measured time point (B), T_{eso} LS-Mean after adjustment with T_{eso_Base} (linear mixed model) (C). T_{eso_Base} : T_{eso} at baseline time point, LS-Mean: least squares means. [†] $p < 0.05$ compared with group T.

Table 2. Final and lowest temperatures at the tympanic membrane and distal esophagus (°C)

	Group M (n=30)	Group R (n=32)	Group T (n=32)	p value
T_{tym_Final}	36.0 (35.8–36.2)	36.0 (35.8–36.1)	36.0 (35.8–36.1)	0.820
T_{eso_Final}	35.7 (35.5–35.9)	35.6 (35.4–35.8)	35.6 (35.3–35.8)	0.512
T_{tym_Lowest}	35.9 (35.7–36.1)	35.9 (35.7–36.0)	35.9 (35.7–36.0)	0.965
T_{eso_Lowest}	35.7 (35.3–35.8)	35.6 (35.4–35.7)	35.5 (35.3–35.7)	0.393
ΔT_{tym_Final}	-0.62 [-0.83–(-0.41)]	-0.77 [-0.92–(-0.62)]	-0.76 [-0.92–(-0.60)]	0.383
$\Delta T_{eso_Final}^a$	-0.63 [-0.79–(-0.46)]*	-0.81 [-0.97–(-0.46)]	-0.90 [-1.05–(-0.75)]	0.044
ΔT_{tym_Lowest}	-0.75 [-0.92–(-0.56)]	-0.87 [-0.99–(-0.74)]	-0.83 [-0.98–(-0.68)]	0.496
ΔT_{eso_Lowest}	-0.72 [-0.86–(-0.58)]	-0.87 [-1.00–(-0.73)]	-0.94 [-1.08–(-0.80)]	0.076

The values are expressed as mean (95% confidential intervals) and median (interquartile range). There were no significant differences between the groups. T_{tym} : tympanic membrane temperature, T_{eso} : distal esophageal temperature, T_{tym_Final} : final T_{tym} , T_{eso_Final} : final T_{eso} , T_{tym_Lowest} , T_{eso_Lowest} : Lowest T_{tym} , Lowest T_{eso} , ΔT_{tym_Final} , ΔT_{eso_Final} : differences of T_{tym_Final} , T_{eso_Final} from each baseline value, ΔT_{tym_Lowest} , ΔT_{eso_Lowest} : differences of T_{tym_Lowest} , T_{eso_Lowest} from each baseline value. $p < 0.05$ was considered to indicate statistical significance. * $p < 0.05$ compared with group T. ^amedian (interquartile range).

hypothermia $< 35.0^{\circ}\text{C}$ were 10.0%, 9.4%, 15.6% in the M, R, and T groups, respectively ($p = 0.916$).

DISCUSSION

Here, we demonstrated that, at the flow rate necessary for intraoperative maintenance fluid therapy, none of the devices, Mega Acer Kit, Ranger, nor ThermoSens, showed

Table 3. Incidence of intraoperative hypothermia based on the final and lowest distal esophageal temperatures

Parameter Grade	Group M (n=30)	Group R (n=32)	Group T (n=32)	p value (1 vs. 2 and 3 / 1 vs. 2 vs. 3)
$T_{\text{eso_Final}}$				0.964 / 0.586
1: $T_{\text{eso}} \geq 36.0^{\circ}\text{C}$	10 (33.3%)	10 (31.3%)	11 (34.4%)	
2 and 3: $T_{\text{eso}} < 36.0^{\circ}\text{C}$	20 (66.7%)	22 (68.8%)	24 (65.6%)	
2: $35.0^{\circ}\text{C} \leq T_{\text{eso}} < 36.0^{\circ}\text{C}$	18 (60.0%)	19 (59.4%)	15 (46.9%)	
3: $T_{\text{eso}} < 35.0^{\circ}\text{C}$	2 (6.7%)	3 (9.4%)	6 (18.8%)	
$T_{\text{eso_Lowest}}$				0.877 / 0.916
1: $T_{\text{eso}} \geq 36.0^{\circ}\text{C}$	8 (26.7%)	7 (21.9%)	7 (21.9%)	
2 and 3: $T_{\text{eso}} < 36.0^{\circ}\text{C}$	24 (73.3%)	26 (78.1%)	24 (78.1%)	
2: $35.0^{\circ}\text{C} \leq T_{\text{eso}} < 36.0^{\circ}\text{C}$	19 (63.3%)	22 (68.8%)	20 (62.5%)	
3: $T_{\text{eso}} < 35.0^{\circ}\text{C}$	3 (10.0%)	3 (9.4%)	5 (15.6%)	

The values are expressed as numbers of patients (%). There were no significant differences between the groups. T_{eso} : distal esophageal temperature, $T_{\text{eso_Final}}$: final T_{eso} , $T_{\text{eso_Lowest}}$: lowest T_{eso} . Grade 1: $T_{\text{eso}} \geq 36.0^{\circ}\text{C}$, grade 2: $35.0^{\circ}\text{C} \leq T_{\text{eso}} < 36.0^{\circ}\text{C}$, grade 3: $T_{\text{eso}} < 35.0^{\circ}\text{C}$.

sufficient performance in reducing the loss of intraoperative core temperature. However, the Mega Acer Kit and Ranger were more effective at controlling the core temperature than ThermoSens after 2.5 hours, despite the absence of a statistically significant difference in the incidence of intraoperative hypothermia ($<36^{\circ}\text{C}$). In addition, in terms of heating capability, the Mega Acer Kit was more effective than Ranger and ThermoSens, but none of them delivered normothermic (37°C) fluid to patients.

Most studies with the Mega Acer Kit, ThermoSens, or Ranger using low to moderate flow rates, similar to this study, were performed to investigate the performance in a laboratory setting [9,10,12-14,16,19], and only a few were performed to evaluate their clinical effects on core temperature changes [12,13]. Importantly, they demonstrated that the Mega Acer Kit was effective in maintaining the intraoperative core temperature at above 35°C , which was significantly higher in groups using the Mega Acer Kit compared to groups using the Ranger throughout the study period [12,13]. The maximal losses of intraoperative core temperature were found to be $-0.5 \pm 0.5^{\circ}\text{C}$ and -1.4°C from baseline values to the end of surgery when using the Mega Acer Kit and the Ranger respectively, while it was -1.7°C in the group without a warmer [12,13]. This study also showed similar trends for final T_{eso} (35.7°C , 35.6°C , and 35.6°C with the Mega Acer Kit, the Ranger, and the ThermoSens, respectively) and $\Delta T_{\text{eso_Final}}$ (-0.63°C , -0.81°C , and -0.90°C , respectively) in patients who underwent spinal fusion surgery.

Unfortunately, none of the fluid warmers used in this study

were effective in offsetting intraoperative redistribution hypothermia, although their use could prevent a marked decrease in T_{eso} . In the study by Jung et al. [12], the incidence of lowest T_{eso} ($<35.0^{\circ}\text{C}$) was 100% in the group without the use of a fluid warmer and 0% and 57% in the groups using the Mega Acer Kit and Ranger, respectively. However, in this study, the Mega Acer Kit, Ranger, and ThermoSens had a non-significant difference in the incidence of hypothermia $<35.0^{\circ}\text{C}$ (10.0%, 9.4%, and 15.6%, respectively) as well as that of hypothermia $<36.0^{\circ}\text{C}$ (73.3%, 78.1%, and 78.1%, respectively) based on the lowest T_{eso} . Nevertheless, the Mega Acer Kit was shown to have higher intraoperative core temperatures, higher final and lowest T_{eso} , and lower degree decrement from baseline values compared with the Ranger and ThermoSens.

These higher incidences of hypothermia may be explained by several factors. First, although the body temperature was within the inclusion criteria at preanesthetic evaluation, it would be decreased by the influence of intraoperative management for anesthetic induction-related hypotension, allowing for cold fluid loading within less than 0.5 mL/kg as necessary, before operation of each device. Therefore, in the analysis with linear mixed modeling, we found that the $T_{\text{eso_Base}}$ was a factor influencing the intraoperative T_{eso} changes with time, and that the patients with lower $T_{\text{eso_Base}}$ showed a greater decrement in intraoperative T_{eso} . After adjustment with $T_{\text{eso_Base}}$, we also found that the Mega Acer Kit group showed a significant difference compared with the ThermoSens group at 2.5 and 3 hours

after device use.

Second, the final delivered fluid temperature can influence the change in intraoperative T_{eso} . Ideally, fluids at approximately 37°C should be delivered to the patient for prevent intraoperative hypothermia [20,21]. The final delivered fluid temperature was decreased significantly through increase in the length of the extended tube [15,22,23], despite some fluid warmers being able to warm the intravenous fluid up to 37°C [12,14]. At low and moderate flow rates, the ThermoSens, the Ranger, and other warmers with similar technology could not deliver normothermic fluid (37°C) at a tubing distance greater than 75 cm [24–26]. The Mega Acer Kit was also unsuccessful in delivering fluid temperatures greater than 35°C above a tubing distance of 75 cm at 300–1,000 mL/h [9,12]. Relatedly, this study further showed that the final delivered fluid temperature was not 37°C in the clinical setting, when a long extended tube was used.

Third, the presence of a covering on the extended tubing line can also influence the change in intraoperative T_{eso} by increasing the final delivered fluid temperature. In an experimental study [9], which had a similar study design, it was found that when covering the extended tube with a drape, the delivered fluid temperature was slightly higher than that in this study when using tubing at 76 cm from the device with 440 mL/h for 60 minutes. Therefore, if we had covered the extended tube in our study, the delivered fluid temperature would have been higher.

The present study had some limitations. First, we could not confirm which of the devices were more effective at reducing the decrease of core temperature and the incidence of hypothermia, because there was no group that did not use the fluid warmer as the control group. Second, we did not control the factors explained as reasonable causes of higher incidences of hypothermia.

In conclusion, the Mega Acer Kit, Ranger, and ThermoSens, alone, did not sufficiently reduce the loss of intraoperative core temperature during intravenous maintenance fluid therapy to effectively maintain the intraoperative temperature at $\geq 36^\circ\text{C}$. The heating capability of the Mega Acer Kit was greater than that of Ranger and ThermoSens, but neither delivered normothermic (37°C) fluid to patients. However, after adjustment of the core temperature following induction of anesthesia, the Mega Acer Kit was more effective for the management of core temperature than

the ThermoSens at over 2.5 hours after device use. For this reason, we may expect to find evidence that the Mega Acer Kit is more beneficial than the Ranger and the ThermoSens as an intraoperative warming device at lower flow rates, if the loading fluid is warm, with shorter extended tubing and a covering on the fluid line. Therefore, after controlling the influencing factors, further studies are needed to verify the efficacy of intravenous fluid warmers on core temperature.

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CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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