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주입 속도와 거리에 따른 세가지 수액 가온기들의 성능에 대한 실험적 비교

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의학과

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Experimental comparison of performances of three types of fluid warmers according to flow rates and distances

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이 논문을 의학석사학위 신청 논문으로 제출함

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Contents

List of tables

List of Figures

국문초록

주입 속도와 거리에 따른 세가지 수액 가온기들의 성능에 대한 실험적 비교

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배경 수액 주입 속도와 수액 관 길이는 가온되어 전달되는 수액 온도에 영향을 미칠 수 있다. 이에 본 연구자는 서로 다른 가온 기술을 가지고 있는 3 가지 수액 가온기가 상기 요소에 따라 수액 가온 성능에 차이가 있는지를 실험적으로 평가하였다.

방법 저자는 제조사의 설명문에 따라 메가 에이서 키트(group M), 레인저(group R), 써모센스(group T)를 설정하고, 440 mL/h에서 2500 mL/h 까지 연속된 방법으로 수액을 주입하였다. 수액의 온도는 장치 입구, 장비로부터 76 cm (P_{out1})와 166 cm (P_{out2}) 에서 10분 동안 1분 간격으로 측정되었다. 이 방법을 최종 8 차례 반복 시행하였다.

결과 가온된 수액의 온도는 P_{out1}에서 650 mL/h 까지는 group M 이 group R과 group T 보다 의의 있게 높았으며, 440 mL/h에서 가장 높은 수액 온도를 보였다 (34.30 ± 1.13° C, $P < 0.000$). 그러나 1140 mL/h 이상의 주입 속도에서는 group T와 group R에서 의의 있게 높았으며, P_{out1}에서 2500 mL/h의 주입 속도에서 가장 높은 온도를 보였다 (36.67 ± 0.06° C 와 37.85 ± 0.39° C, $P < 0.000$). 전달된 수액의 온도는 P_{out1}에서 측정된 온도가 P_{out2}에서 측정된 온도보다 모든 수액 주입 속도에서 의의 있게 높았다 ($P < 0.000$).

결론 메가 에이서 키트는 낮은 수액 주입 속도에서 써모센서와 레인저와 비교하여 효과적으로 수액을 가온할 수 있는 반면, 레인저와 써모센스는 보다 높은 수액 주입 속도에서 효과적으로 수액을 가온하여 전달한다. 특히, 가온기의 성능은 짧은 수액관 길이를 사용하는 경우 더 효과적이다.

Introduction

Intraoperative hypothermia below 35° C, which can lead to postoperative hypothermia, commonly develops owing to the inhibition of normal thermoregulation [1]. Therefore, guidelines recommend that intravenous fluids should be warmed to 37° C using a fluid warmer to prevent and treat inadvertent perioperative hypothermia in adults if a volumes >500 mL is infused [1]. Many studies have reported that fluid warmers are helpful in reducing morbidity and complications by maintaining perioperative normothermia in patients in whom severe or moderate perioperative hypothermia was expected or developed [2, 3]. Unfortunately, patients with mild hypothermia have a same change to develop the side effects and complications, which is associated with severe or moderate hypothermia [4]. Therefore, a patient's core temperature should be monitored and fluid warmers should be used for preventing hypothermia during clinical routines [5].

Many types of fluid warmers based on different operating principles are available, such as dry heat, countercurrent water bath, countercurrent metal, and magnetic induction technology. An ideal fluid warmer should deliver fluids at ~37° C over a wide range of flow rates and clinical conditions [6, 7]. However, most manufacturers provide a device-specific acceptable range or maximum flow rate for this purpose. Our hospital typically uses Ranger (Arizant Healthcare, Inc., MN, USA) with countercurrent metal technology and Fluid Management System 2000 (FMS 2000, Belmont Instrument, Billerica, MA) with magnetic induction technology. Recently, two new types of fluid warmers were developed:

ThermoSens (Sewoon Medical Company, Seoul, Korea) with dry heat and Mega Acer Kit (Ace Medical, Seoul, Korea) with a newly designed heated circuit. Most studies of these devices investigated the effectiveness of warming at flow rates above 1000 mL/h, whereas a few investigated slow to moderate flow rates with different distances [8-11]. They reported that the temperature of the delivered warming fluid can be decreased or increased by controlling the flow rate and distance. Therefore, in my study, I compared the fluid warming performances of Mega Acer Kit, Ranger and ThermoSens according to different flow rates and distances from each device.

Materials and methods

The Institutional Review Board waived ethical approval for this laboratory investigation. I maintained the air-conditioned investigatory room’s temperature at 22 ± 2° C. All equipment, including a 1-L bag of 0.9% normal saline, was kept in this room for at least 24 h before testing to ensure calibration with the ambient temperature.

All devices were set-up with a warming temperature of 41° C according to the manufacturers’ instructions, and they were preheated for 10 min to calibrate each device’s condition. The infusion set was primed with 0.9% normal saline that was hung at 1 m height from the warming device and attached to a roller pump (TE-171, Terumo Corp., Tokyo, Japan). The following three warming devices were tested: (1) Mega Acer Kit (Group M, Ace Medical, Seoul, Korea), (2) Ranger (Group R, Arizant Healthcare, Inc., MN, USA), and (3) ThermoSens (Group T, Sewoon Medical Company, Seoul, Korea). Equal disatnce from each device to the proximal outlet point (P_{out1},76cm) and the distal outlet point (P_{out2},166cm) was achieved using two 55-cm and 90-cm fluid extension lines, 3-way connectors, and 18-gauge intravenous catheter connected to the outlet of the fluid warmers in series (Figure1). The se extended lines were exposed at a mbient room temperature. Three PT 100 temperature probes (KRGA-50, Kimo Instruments, Edenbridge, UK) were connected to a Kistock Datalogger (KTH350, Kimo Instruments, Edenbridge, UK). The probes were inserted at the inlet point (P_{in}) and P_{out1} and P_{out2}. An artificial lung was ventilated with 500 mL of tidal volume, 10 breath/min, and 6 L/min of oxygen and medical air without humidification.

Before starting the measurements, I calculated the flow rate during the full dropping using a graduated cylinder and stopwatch for a 10 min collection, and its mean flow rate was 2500 mL/h. 0.9% normal saline was then delivered at 5 different flow rates (440, 650, 860, 1140 and 2500 mL/h). In accordance with the current flow rate being used, the equilibrium period prior to use next infusion rate was applied to allow for rule out the effect of previous infusion rate. Thus, with respect to the volume loads, the equilibrium period took at least 10 min. The fluid temperatures at three recoding points (TP_{in},TP_{out1} and ▭TP_{out2}) as well as the room temperature were recorded automatically using the Kistock Datalogger at 1-min intervals for 10 min. After downloading the results to computer using software (Kilog, Kimo Instruments, Edenbridge, UK), I calculated the mean fluid temperatures of 10 values during 10 min at each flow rate for each device, and then I repeated each test eight times.

According to the mean fluid temperature at P_{out1} and P_{out2}, the expected change in mean body temperature(△MBT) was calculated in each group at flow rates as well as different distances, when a 70-kg patient received 1 L of 0.9% normal saline warmed. This was done using Horowitz's formula, as given below:

$$\triangle MBT = \frac{(TF - TPt)*(SF)*(Vol)}{(SPt)*(Wt)}$$

where △MBT is the change in the mean body temperature; TF, the temperature of the infused fluid; TPt, the patient’s baseline core temperature (37° C); SF, the specific heat of the infused fluid (1.0 kcal/L/° C for saline); Vol, the volume of the infused fluid (in L); SPt, the specific heat of human tissue (0.83 kcal/L/° C); and Wt, the weight of the patient (in kg) [8].

Statistical analysis was performed using the Statistical Package for the Social Sciences software package (SPSS, Version 20.0, SPSS Inc., Chicago, IL, USA). All measured values were represented as means ± SD. The temperatures of the delivered warmed fluid at three recoding points were analyzed using one-way analysis of variance (ANOVA) for analysis between groups. Whenever there were differences among the fluid warmers, a Sheffe post-hoc test was used to determine the flow rates at which they were different. I performed paired t-test for analysis of the flow rate’s effect on the fluid warming within groups according to the different recording point (P_{in}, P_{out1} and P_{out2}).The correlation analysis and linear regression analysis were used to determine the relationship between the distance and the flow rate, and the warming fluid temperature. Statistical significance was defined as P-values < 0.05.

Results

The ambient room temperature during experimental study was 21.40 ± 0.51° C. The TP_{in} showed no significant differences among the groups (21.90 ± 0.26° C, 21.94 ± 0.37° C and 22.06 ± 0.37° C in Group M, R and T, respectively, Figure 2 and 3. $P = 0.122$).

Within group, Group M showed the significantly decreased TP_{out1}, that was highest at the flow rate of 440 mL/h (34.30 ± 1.13° C), when the flow rate increased from 440 mL/h up to 2500 mL/h (Figure 2 and 3, $P < 0.000$). However, the TP_{out2} was significantly increased when the flow rate increased up to 1140mL/h, and then decreased when the flow rate increased up to 2500mL/h. It was highest at the flow rate of 860mL/h (29.22 ± 0.79° C, Figure 2 and 3, $P < 0.000$). On the other hand, in group T and R, TP_{out1} as well as TP_{out2} significantly increased when the flow rate increased up to 2500 mL/h (Figure 2 and 3, $P < 0.000$), and TP_{out1} and TP_{out2} was highest at the flow rate of 2500 mL/h (36.67 ± 0.06° C and 37.85 ± 0.39° C at the P_{out1},35.96± 0.11° C and 37.22 ± 0.15° C at the P_{out2}, in Group T and R, respectively Figure2 and 3, $P < 0.000$).

Between groups, TP_{out1} was significantly higher in group M than in groups R and T at below 860 mL/h, but it was significantly lower at above 1140 mL/h (Figure 3, $P < 0.000$). however, the value in group T was not significantly higher than that in group R even though it was significantly higher at several time points (Figure 2). TP_{out2} showed the similar results with the value at P_{out1}. TP_{out2} was significantly lower than TP_{out1} at all flow rates for each device even though I did not mark significance in figures (Figure 2 and 3).

None of the investigated fluid warmers provided a constant normothermic delivered temperature (above 36.5° C) at all flow rates and the distance tested except of the flow rate of 2500 mL/h in group T and R (Figure 2 and 3).

The delivered temperature depended on the flow rate and the distance in muptile regression analysis (Table 1). Correlations between the flow rate and the distance, and the delivered fluid temperature, assessed by pearson correlation, are presented as correlation coefficient (R) in table 1. The delivered fluid temperatures in group M had a strong and moderate inverse correlation with the flow rate and the distance ($R = -0.727$ and $R = -0.530$, respectively, Table 1, $P < 0.000$). The delivered fluid temperatures in group R had a strong correlation with the flow rate, but had a weak inverse correlation with the distance ($R = 0.885$ and $R = -0.354$, respectively, Table 1, $P < 0.000$). The delivered fluid temperatures in group T had a strong correlation with the flow rate, but had a moderate inverse correlation with the distance ($R = 0.829$ and $R = -0.459$, respectively, Table 1, $P < 0.000$). In the multiple linear regression analysis with the flow rate and the distance, These variables provided the best predictive model for the delivered fluid temperature with the significant multiple linear regression coefficients (R^2) (0.809, 0.908 and 0.899 in group M, R, and T, respectively, Table 1, $P < 0.000$).

The expected ΔMBT with TP_{out1} was significantly lower in group M than group T and R at flow rates upto 650mL/h, but it was higher in group M than group T and R at flow rates over 860mL/h at the P_{out1}, in a 70-kg patient 1h after warming fluid infusion by each device (Figure4, $P<0.000$). TP_{out2} was significantly lower than TP_{out1} with similar tendency at all flow rates for each device even though did not mark significance in figures (Figure 4, $P < 0.000$). When the flow rates increased up to 2500 mL/h, the

ΔMBT with TP_{out1} and TP_{out2} increased in group M from -0.05° C to -0.20° C and -0.16° C to -0.21° C, respectively, whereas its mean of ΔMBT in group T and R decreased from -0.11/-013° C to -0.01/0.01° C and -0.18/-0.19 to -0.02/0.00° C, respectively.

Discussion

My study's results showed that the fluid warming performance was significantly different for each investigated device depended on the flow rate and the distance. The fluid warming performance was significantly different for each investigated device according to increase the flow rate up to 2500 mL/h. Mega Acer Kit showed the most effective performance at the flow rates below 860 mL/h, whereas Ranger and ThermoSens were more effective for warming the fluid at the flow rate above 1140 mL/h. And the shorter tubing length was more effective for delivering higher temperature of warming fluid than the longer tubing length. However, none of the fluid warmers investigated in my study achieved a constant normothermic temperature (above 36.5° C) at all flow rates and the distance tested except of the flow rate of 2500 mL/h in Ranger and ThermoSens.

Fluid warmers based on various operating principles are used in our hospital. In my study, I used three different types of fluid warmers. Mega Acer Kit consists of a fluid line (length: 100 cm, volume: 5 mL) that is placed along a heating wire wrapped in cotton within a humidified and heated circuit; it mainly warms the fluid directly by using heated convective air currents [10, 12]. Ranger uses the countercurrent metal technology, and ThermoSens uses the dry heat technology [11, 13, 14]. An ideal fluid warmer should be capable of delivering fluids at 37° C over a wide range of flow rates and clinical conditions [6, 7]. The flow rate and distance can influenced the fluid warming performance by decrease or increase of the delivered warming fluid temperature [8, 9, 13, 15].

A few studies have reported on the use of Mega Acer Kit for fluid warming [10, 12]. Kim et al. [12] experimentally showed that Mega Acer Kit warmed fluid (33.9 ± 1.4° C) at its outlet site (18 cm) at flow rates of

400 mL/h with a device's set-up temperature of 38° under humidification. They also found that, in a clinical situation, the mean flow rate was 442 mL/h, at which the mean delivered fluid temperature was 31.0 ± 1.0° C at a distance of 118 cm from the device. On the other hand, Jung's study at the similar flow rate showed higher fluid temperatures than my study, that was 37.4 ± 1.7° C and 35.4 ± 1.0° C at 108 cm and 198 cm from the warmer [10]. My study revealed that Mega Acer Kit warmed fluid to the highest fluid temperature (34.3 ± 1.13° C) at 440 mL/h and 76 cm distance from warmer, which is similar to the result of Kim's study [12]. According to increasing the flow rate up to 2500 mL/h at the same distance, the delivered fluid temperature was above 30° C except of 2500 mL/h, even though the fluid temperature showed the more decreased trend. Therefore, the distance from the device influence the fluid warming performance. Interestingly. there were somewhat discrepancy with my results on the delivered fluid temperature. I could assume that it may be explained by the interaction of the humidity and temperature of the inspired gas on the performance of the warming fluid during ventilation, as shown in Kim et al.'s figures [12]. Their figures showed that the humidity and temperature of the inspired gas and the temperature of the delivered fluid were not constant without correlations during monitoring. Therefore, I did not operate the humidification system because I could not confirm this interaction before starting the study. On the other hand, even though I applied a shorter extended line and a higher device's set-up temperature (41° C) without humidification, Jung's study showed higher warmed fluid temperature compared to my study at similar flow rate [10]. I can carefully attribute this discrepancy to the fact that the fluid temperature at the inlet point and the room temperature were higher (by

~2° C), and that a cover was applied on the extended line to eliminate the indirect effect of room temperature in Jung's study [10]. Unfortunately, no previous studies have reported direct comparisons of these devices indicating whether Mega Acer Kit can deliver effective warming fluid to a patient after increasing up to 2500 mL/h. my study only showed the effect of flow rate on the performance of Mega Acer Kit. The delivered fluid temperature at 166 cm was significantly lower thant that at 76 cm distance after increasing up to 2500 mL/h. Mega Acer kit warmed fluid more effective below 860 mL/h compared with Ranger and ThermoSens. In addition, the regression analysis also showed that the delivered fluid temperatures were influenced by the flow rate and the distance with the strong and moderate inverse correlation coefficient. Therefore, Mega Acer Kit is suitable at below 860 mL/h, which is necessary to supply the perioperative fluild demands due to the fasting and intraoperative suspected fluid loss. Mega Acer Kit without humidification can effectively warm fluids when the fluids are stored higher room temperature, and deliver more effective warming fluid with a shorter extension line and lower flow rate.

The fluid warming performance of ThermoSens and Ranger were studied at different flow rates [8, 10, 11, 14]. At high flow rates above 1000 mL/h, ThermoSens and Ranger could deliver fluids at above 36 ° C regardless of the distance and infused fluid's temperature [8, 11]. Kim et al. [14] reported that ThermoSens, using the saline maintained at 20° C room temperature, warmed the fluid 39.4 ± 0.4° C and 39.7 ± 0.4° C at the flow rate of 1800 mL/h and 3000 mL/h 18 cm from the device, and the delivered fluid temperature decreased 1.6 ± 1.3° C and 1.2 ± 1.0° C after 60 cm from the outlet point. In the Ranger, Horowitz et al. revealed that the temperature of 21° C saline increased to 36.2° C at a flow rate of 1000 mL/h with about 60 cm distance from device [8]. My study showed that ThermoSens and Ranger could warm fluid more effective by increasing the flow rate up to 2500 mL/h, bur the longer distance induced the more decrease of delivered fluid temperature. At 2500mL/h, ThermoSens and Ranger could warm fluid above 36.0° C at 166 cm from device. Unfortunately, no previous studies have reported direct comparisons of these devices indicating whether ThermoSens and Ranger can deliver effective warming fluid to a patient at flow rates below 1000 mL/h except for Jung' s report [10]. However, I expect that the effects of ThermoSens and Ranger will be similar to those of FloTem and WarmFlo, respectively, which operate with similar warming methods. FloTem, with a 116-cm tubing line, requires a flow rate of at least above 300 mL/h to deliver fluid with a temperature above 32° C; fluid could not be delivered at temperatures above 35° C even when the flow rate was increased up to 1000 mL/h [16]. WarmFlo also could not deliver warming fluid at temperatures above 35° C at the distal site with a device' s set-up temperature of 42° C; however, it was possible to warm the fluid at flow rate of 600 mL/h or more. My study as well as Jung' s study showed that warming fluid temperature above 35° C could not be achieved at flow rates below 440 mL/h [10]. In addition, the regression analysis also showed that the delivered fluid temratures were influenced by the flow rate with strong correlation coefficient and the distance with weak and moderate inverse correlation coefficient. It means that the flow rate is more influenced than the distance in ThermoSens and Ranger on their performance. Therefore, using ThermoSens and Ranger is suitable at high flow rate rather than at low flow rates for warming and delivering fluid to a patient effectively.

The anticipated decrease in intraoperative body temperature when using a fluid warmer can be predicted by ΔMBT calculated using Horowitz’s form [8]. They suggested that a warming device should be used only if ΔMBT is expected to decrease by more than 0.5° C, because this degree of hypothermia can be clinically tolerated or reversed using a forced-air heater alone. Generally, most anesthesiologists do not use a fluid warmer at lower flow rates because of the minimal effect on the MBT. My results showed that the anticipated decrease in MBT was below 0.5° C at all flow rates with either unwarmed fluid or warming fluid in a 70-kg patient, and ΔMBT was smaller below 860 mL/h and larger above 860 mL/h in Mega Acer Kit than ThermoSense and Ranger. Therefore, Mega Acer kit is more suitable to decrease ΔMBT at slow flow rate, but ThermoSens and Ranger is at high flow rate. However, Even though the anticipated decrease in MBT was below 0.32° C with the infusion of normal saline at 23° C without any fluid warmer, the intraoperative core temperature could decrease below 35° C after 3 h at a flow rate of 400 mL/h [10]. Furthermore, intraoperative hypothermia below 35° C commonly develops owing to the impairment of central thermoregulation and heat loss through the exposed body surface during anesthesia and surgery [1, 17]. This means that a fluid warmer should be used for preventing and treating intraoperative hypothermia even if the anticipated decrease in MBT is below 0.5° C and the infused flow rate is low.

Based on my study, I suggest some recommendations for improving the performance of the warming devices. First, fluids at above room temperature should be used and delivered with as short an extension line as possible. The different tubing lengths can influence the final temperature of the delivered warming fluid entering the patient in a length-dependent manner [8-10]. In addition, some reports have shown that a warming device could warm fluid more effectively and constantly under various flow rates when fluid with higher temperature is used [14]. Second, the device-specific flow rate should be applied. Some devices such as Ranger and ThermoSens could effectively warm the fluid at higher flow rates; however, Mega Acer Kit could not, as mentioned above. Third, I should used a covered extension line whenever possible. If the tubing lines are protected against exposure to the low room temperature, the temperature of the delivered fluid will be higher than that in my study.

In conclusion, Mega Acer Kit can warm fluid more effectively compared with ThermoSens and Ranger with the smallest anticipated ΔMBT at the low flow rate whereas the ThermoSens and the Ranger are suitable at higher flow rates. Furthermore, the device performance may be more effective when shorter extension lines with a cover are applied.

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Table 1. Multiple regression analysis for delivered warming fluid temperature by each device

		Group M			Group R			Group T	
		D (cm)	F (mL/h)		D (cm)	F (mL/h)		D (cm)	F (mL/h)
Intercept	37.635			30.410			31.930		
B		-0.037	-0.003		-0.029	0.004		-0.031	0.003
SE	0.508	0.003	0.000	0.411	0.003	0.000	0.353	0.002	0.000
β		-0.530	-0.727		-0.354	0.885		-0.459	0.829
t	74.107	-10.636	-14.597	74.073	-10.245	25.648	90.354	-12.664	22.871
P-value		0.000*	0.000*		0.000*	0.000*		0.000*	0.000*
R^2	0.809			0.908			0.899		
Adjusted R^2	0.804			0.906			0.896		
F	163.109			381.400			341.720		
P-value	0.000*			0.000*			0.000*		
RE	Y = 37.635 -0.037*D - 0.003*FR			Y = 30.410 – 0.029*D + 0.004*F			Y = 31.930 -0.031*D + 0.003*F		

Group M: Mega Acer Kit. Group R: Ranger. Group T: ThermoSens.

B = unstandized regression coefficeint; β = Standard Regression Coefficient; F = F statistic, which evaluates the model; R2 = variance in the delivered fluid temperature by independent variables; t = t statistic, which evaluates independent variable, RE; regression equation, D: distance, F: flow rare. *: $P < 0.05$.

Legands for figures

Figure 1. Illustration of the laboratory settings used to test the Mega Acer kit, the Ranger and the ThermoSens. M: Group used the Mega Acer Kit. R: Group used the Ranger. T: Group used the ThermoSens. F: 0.9% normal saline. P_{in}, P_{out1} and P_{out2} are the inlet point, the proximal outlet point (76 cm) and the distal outlet point (166 cm) from device, respectively.

Figure 2. Fluid temperature warmed by warmers with different flow rates at P_{in}, P_{out1} and P_{out2}. The fluid temperature at P_{out1} and P_{out2} (TP_{out1} and TP_{out2}) was significantly decreased in Group M, and increased in group R and T when the flow rate increased up to 2500mL/h. All values are expressed as means and SD of eight trials for each warming device. Group M: Mega Acer Kit. Group R: Ranger. Group T: ThermoSens. *, †, ‡, §: $P < 0.05$ compared with the flow rate of 440, 650, 860 and 1140 mL/h, respectively.

Figure 3. Fluid temperature warmed by warmers at different flow rates according to the recoding points. TP_{out1} and TP_{out2} was significantly higher in group M than in groups R and T at below 860mL/h, but it was significantly lower at above 1140mL/h. None of the investigated fluid warmers provided a constant normothermic delivered temperature (above 36.5° C) at all flow rates and the distance except of the flow rate of 2500mL/h in group T and R. Group M: Mega Acer Kit. Group R: Ranger. Group T: ThermoSens. *, †:$P < 0.05$ compared with the group R and group T, respectively.

Figure 4. Expected change of the mean body temperature (ΔMBT) calculated by mean fluid temperature at Pout1 and Pout2 at different flow rates. The expected ΔMBT with TPout1 was significantly lower in group M than group T and R at flow rates up to 650 mL/h, but it was higher in group M than group T and R at flow rates over 860 mL/h. TPout2 was significantly lower than TPout1 with similar tendency at all flow rates. Group M: Mega Acer Kit. Group R: Ranger. Group T: ThermoSens. *, † : $P < 0.05$ compared with the group R and group T, respectively.

Figure 1.

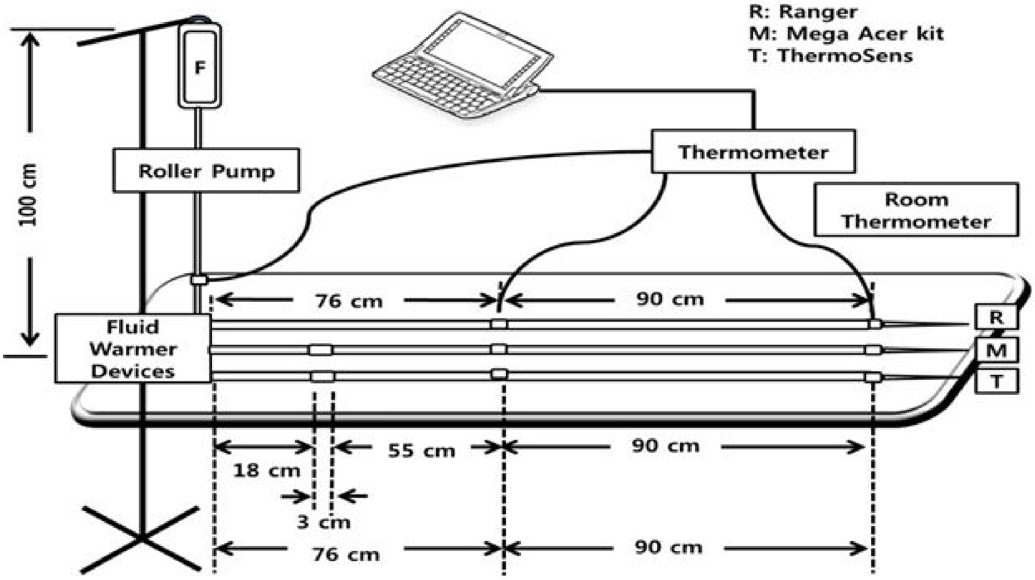

R: Ranger
M: Mega Acer kit
T: ThermoSens
F
Roller Pump
Thermometer
Room Thermometer
100 cm
Fluid Warmer Devices
76 cm
90 cm
R
M
T
18 cm
55 cm
90 cm
3 cm
76 cm
90 cm

Figure 2.

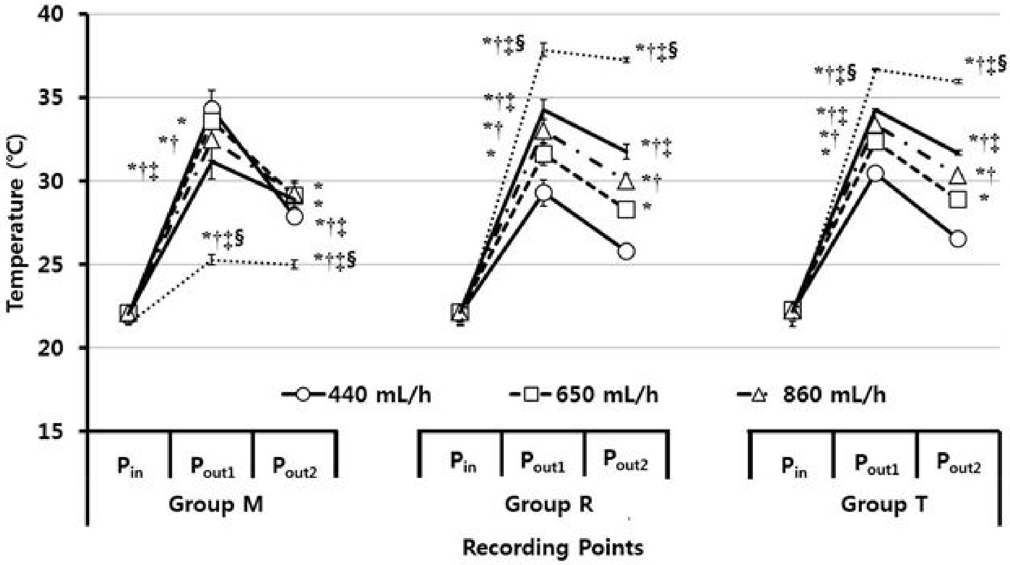

40
35
30
25
20
15
Temperature (℃)
*†‡§
*†‡
*†
*
440 mL/h
650 mL/h
860 mL/h
P_{in}
P_{out1}
P_{out2}
Group M
Group R
Group T
Recording Points

Figure 3.

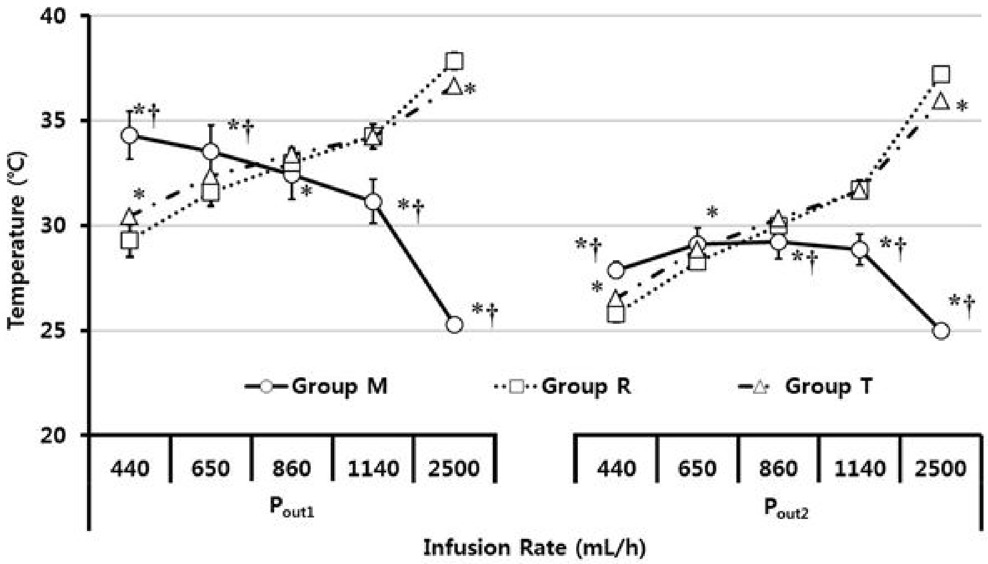
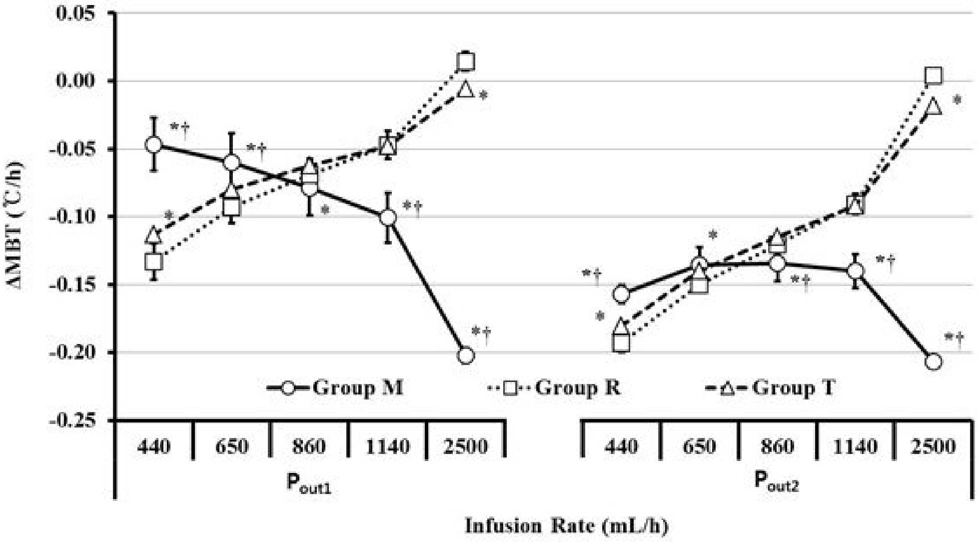

40
35
30
25
20
Temperature (℃)
*†
*†
*
*†
*†
*
*
Δ*
*†
*
*†
*
*†
*†
*†
Δ *
Group M
Group R
Group T
440
650
860
1140
2500
P_{out1}
440
650
860
1140
2500
P_{out2}
Infusion Rate (mL/h)

Figure 4.


0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
ΔMBT (℃/h)
*†
*
Group M
Group R
Group T
440
650
860
1140
2500
P_{out1}
P_{out2}
Infusion Rate (mL/h)