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Evaluation of four techniques of warming intravenous fluids

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Abstract

Purpose. This study was conducted to compare the fluid warming capabilities at different flow rates in four different warming systems.

Methods. The intravenous (IV) fluid warmers used in this study were a water-bath warmer, a forced-air warmer, a dry-heat plate warmer, and an IV fluid tube warmer. Ringer's solution at room temperature or at ice-cold temperature (120–3000 $ml \cdot h^{-1}$) was used as an IV fluid, and the IV fluid temperatures were measured with thermocouples at the end of a 1-m tube connected to the warmer.

Results. The temperature of the IV fluid delivered by the water bath and the forced-air warming system increased as the flow rate increased up to 1200 $ml \cdot h^{-1}$ but decreased with further increase of the flow rate. The temperature of the IV fluid delivered by the dry-heat plate warmer significantly increased as the flow rate increased within the range studied. The delivered temperature did not depend on the flow rate within the range studied when the IV fluid tube warmer was used.

Conclusion. It is important to choose a warmer according to its characteristics as well as its performance.

Key words: Flow rate · Temperature · Intravenous fluid · Warmer

Introduction

Hypothermia often occurs in anesthetized patients [1], especially in those with major trauma [2]. Factors that contribute to hypothermia include exposure to a cool environment and the severity of injury, as well as the anesthesia itself [1,3,4]. Rapid infusion of unwarmed crystalloid and blood may also result in considerable lowering of core temperature [5], which may cause cardiac arrhythmias, coagulopathy, and major alterations in response to pharmacological agents and has been associated with increased mortality [2,6,7]. Therefore, it is important to warm intravenous (IV) fluids before administrating them into the patient's body, and most anesthesiologists advocate the use of prewarmed IV fluids during major surgery. However, the ability of IV fluid warmers to deliver normothermic fluids may be limited by several factors, including limited heat-transfer capability of materials, limited surface area of the heat-exchange mechanism, and heat loss after IV tubing leaves the warmer [8–11]. The purpose of the present study was to compare the fluid-warming capabilities at different various flow rates of IV fluids in four different warming systems during simulated clinical conditions.

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Materials and methods

The IV fluid warmers used in this study were a conventional water-bath warmer (Hakko blood warmer HBW-5; Hakko, Tokyo, Japan), a forced-air warmer (Bair Hugger 241 Blood/Fluid Warming System; Augustine Medical, Eden Prairie, MN, USA), a dry-heat plate warmer (Medi-Temp II, Gaymar Industries, Orchard Park, NY, USA), and an IV fluid tube warmer (Hotline HL-90, Level 1 Technologies, Marshfield, MA, USA) (Table 1). Each fluid warmer needs each specially designed IV tube, warmer coil M/MB, FWS-2410, REF D25310CE, or REF L-70, respectively. The temperatures of the warmers were set to 37°–38°C, 42°–43°C, 38°–40°C, and 40°–42°C, respectively. These selected values were the highest setting or presetting temperatures. The conventional water-bath warmer system warms the IV fluid with prewarmed water, whereas the forced-air warmer system warms the IV fluid in a duct of warmed air to the blanket. The dry-heat plate warmer system warms the IV fluid in a cassette between the heat plates, and the IV fluid tube warmer system warms the IV fluid in a specially designed tube, which has a central

Table 1. Characteristics of the four fluid warmers tested in this study

Equipment	HBW-5 (Hakko)	Bair Hugger 241 Blood/Fluid Warming System (Augustine Medical)	Medi-Temp II (Gaymar Industries)	Hotline HL-90 (Level 1)
Cost of equipment (yen)	99 500	410 000	498 000	398 000
Name of tube	Warmer Coil M/MB	FWS-2410	REF D25310CE	REF L-70
Cost of tube (yen)	16 400/20	26 000/10	28 000/10	2900
Type of warming	Hot-water warmer	Forced-air warmer	Dry-heat plate warmer	Intravenous fluid tube warmer
Temperature of warmer (°C)	37–38	42–43	38–40	40–42
Volume for filling up (ml)	36	34	48	20
Merits	Cheap	Simultaneous use of forced-air warming system	Includes a bubble trap	Efficient warming
Demerits	Inefficient warming	Needs a blanket (5800 yen)	Significant temperature drop after warming	Thick and long tube

lumen (internal diameter, 3.0 mm) and is surrounded by an outer layer through which warm water circulates down one side and then back up to the reservoir. The fluid warmers and supplies were provided by the manufacturers. The infusion rate was controlled by a BP-102 infusion pump (Musashi Engineering, Tokyo, Japan) with Terufusion IV tube TS-A350PK027 (Terumo, Tokyo, Japan). The IV fluid temperatures were measured with thermocouples (Luer lock sensor, Mallinckrodt Japan, Tokyo, Japan) and with a temperature monitor (Mon-a-Therm model 6510, Mallinckrodt Japan) at the end of a 1-m tube connected to the warmer. The IV fluid temperature was measured at the end of the specially designed tube only in the case of the IV fluid tube warmer (1.2 m long). The ambient room temperature was set to 22°–24°C and measured continuously with the same temperature monitor as described above during the study.

A bottle of acetated Ringer's solution (Veen-F, Nikken Chemicals, Tokyo, Japan) at room temperature (21°–23°C) or at ice-cold temperature (4°–6°C) was connected to the IV infusion set of each warmer; the set was primed with the solution, attached to the pump, and connected to the appropriate IV fluid warmer tubing. The temperature of the IV fluid was also monitored during the study, and the temperature of the ice-cold IV fluid was maintained by ice surrounding the IV fluid bottle. The acetated Ringer's solution was infused at rates of 120, 300, 600, 1200, 1800, and 3000 $ml \cdot h^{-1}$. The delivered temperature of IV fluids was recorded when it fluctuated by 0.1°C or less for 3 min.

The delivered temperatures were tested for differences among warmers and flow rates with repeated-measures analysis of variance (ANOVA), and for differences in the temperatures of IV fluids with the unpaired *t*-test. Fisher's least significant difference test was used to determine the flow rates at which they were different. For all comparisons, $P < 0.05$ was considered to indicate a significant difference. All values are expressed as means of two trials for each warmer.

Results

The ambient temperature measured during evaluation of the warming methods ranged from 22.2° to 23.6°C (mean, 23.0°C; SD, 0.44°C). The initial temperatures of the solution at room temperature and of the ice-cold solution measured during the experiments ranged from 21.1° to 22.8°C (mean, 21.8°C; SD, 0.32°C) and from 2.9° to 5.2°C (mean, 4.2°C; SD, 0.37°C), respectively.

The temperature of the IV fluid delivered by the water-bath warming system increased when the flow rate increased up to 600–1200 $ml \cdot h^{-1}$ and decreased when the flow rate increased from 600–1200 $ml \cdot h^{-1}$ up to 3000 $ml \cdot h^{-1}$ (Fig. 1A). At flow rates of less than 600 $ml \cdot h^{-1}$, there was no significant difference in the delivered temperature between the IV fluids initially at room temperature and those initially at ice-cold temperature, but the decrease in the delivered temperature was significantly greater in the initially ice-cold fluid than in the fluid initially at room temperature when the flow rate was over 1200 $ml \cdot h^{-1}$. A similar tendency in delivered temperature was observed when the forced-air warming system was used (Fig. 1B). The temperature of the fluid delivered by the dry-heat plate warmer system significantly increased when the flow rate increased within the range studied (Fig. 1C), and there was no significant difference in the delivered temperature between the IV fluids initially at room temperature

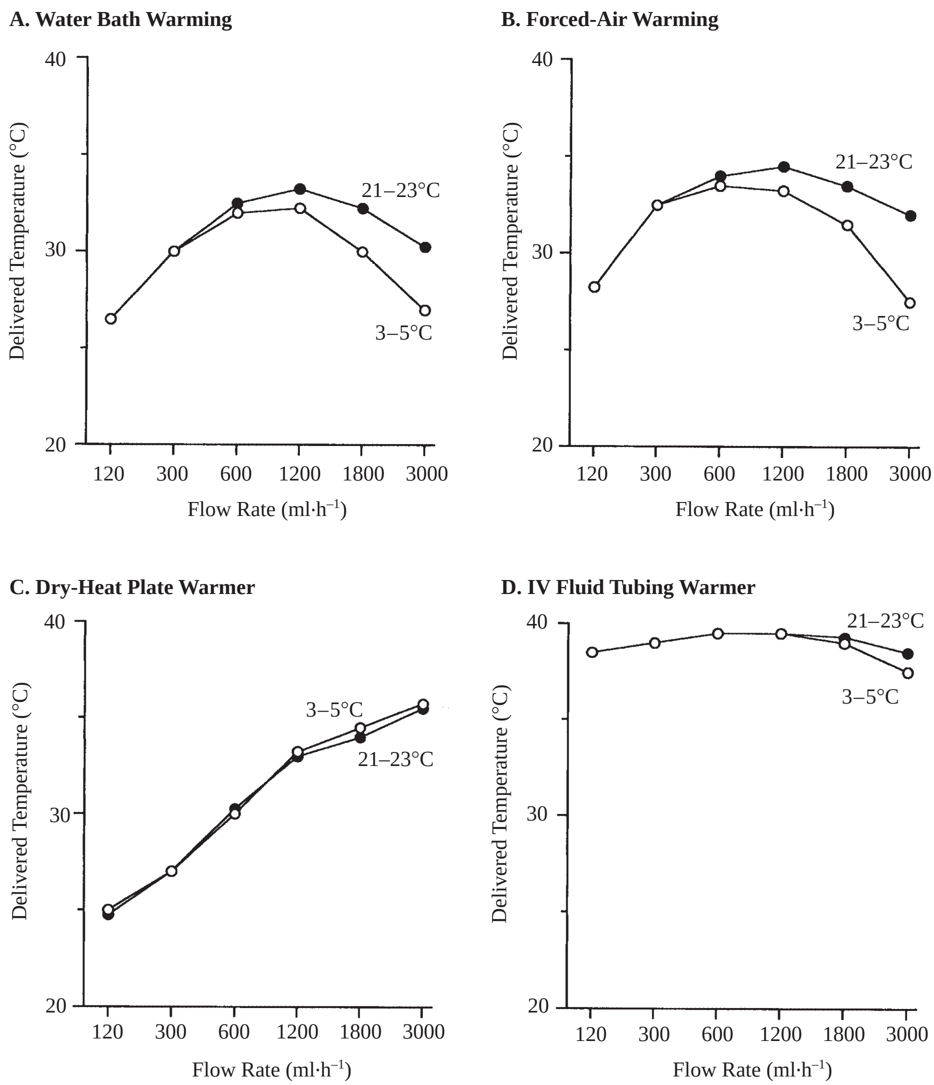

Fig. 1. Relationship between flow rate of intravenous fluid and delivered temperature in each warmer. All values are expressed as means of two trials for each warmer

and those initially at ice-cold temperature. The delivered temperature did not depend on the flow rate within the range studied when the IV fluid tube warming system was used (Fig. 1D), but the delivered temperature was slightly but significantly lower for the initially ice-cold fluid than for the fluid initially at room temperature only at the highest flow rate (3000 $ml \cdot h^{-1}$) tested.

When the delivered temperature was compared for each initial temperature of IV fluid (3°–5°C or 21°–23°C) tested (Fig. 2), the IV tube warming system provided a constant normothermic delivered temperature at all flow rates tested. The temperature of the IV fluid delivered by the forced-air warming system was significantly higher than that of the IV fluid delivered by the water-bath warmer system at all flow rates tested. The temperature of the IV fluid delivered by the dry-heat plate warming system was significantly lower than those of the IV fluids delivered by the water-bath and forced-air warming systems at flow rates up to 1200 $ml \cdot h^{-1}$ but was significantly higher at flow rates over 1800 $ml \cdot h^{-1}$.

Discussion

Although the IV fluid temperature in the tube near the warmer was not measured in this study, all of the currently available warmers tested are believed to be capable of heating fluids to 37°–40°C as the infusate leaves the heat-exchanging portion of the warmer at sufficiently low flow rates. The warmer with triple-lumen technology (Hotline HL-90) kept fluids at higher temperatures at the end of the tubing at flow rates from 120 to 3000 $ml \cdot h^{-1}$. In the other warming techniques, similar decreases in the delivered temperature with decrease in flow rate were observed. The potential benefit

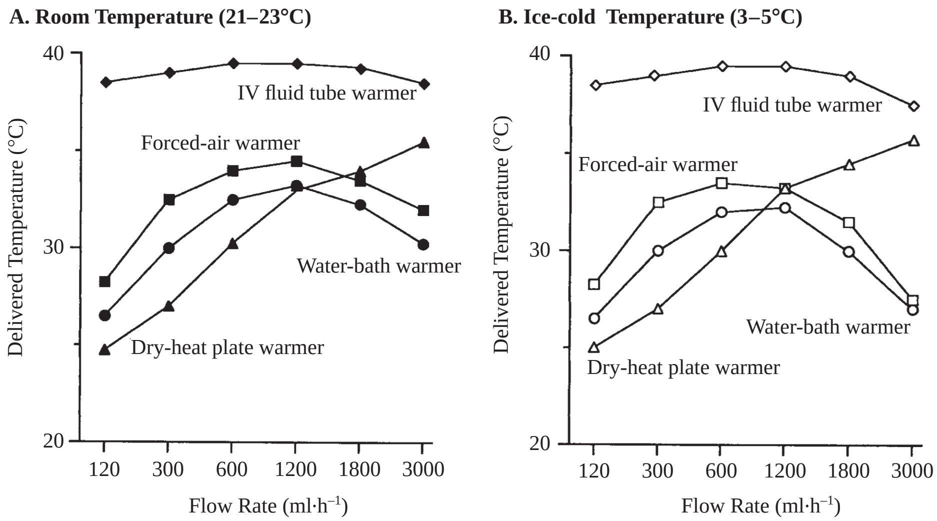

Fig. 2. Relationship between flow rate of intravenous fluid and delivered temperature for each temperature of IV fluid tested: ice-cold (3°–5°C) or room temperature (21°–23°C). All values are expressed as means of two trials for each warmer

of warmed IV fluids seems to be negated by the loss of heat caused by radiation to the environment [8,12], and the fluid might no longer be warm enough to be of any thermal benefit when it enteres the circulation. The heat loss of the warmed IV fluid would be obvious in children, because the flow rate of IV solutions for children is less than that for adults.

The performance of the water-bath and forced-air warming systems was not as good as that of the other two systems, because the delivered temperature decreased when the flow rate was increased from 1200 to 3000 ml·h^{-1}. However, the decrease in the temperature of the warmed IV fluid after the warmer was the greatest in the dry-heat plate warming system, because the delivered temperature was less than those with the water-bath and forced-air warming systems at flow rates from 300 to 1200 ml·h^{-1}. The dry-heat plate warmer system includes a bubble trap, and 48 ml of fluid is needed to fill up the tube (Table 1). Therefore, this specific tubing system has a rather higher radiation effect after the warmer, especially at lower flow rates.

The characteristics of the four kinds of warmer tested in this study are shown in Table 1. Although the IV fluid tube warmer system was the most effective [13,14], the tube itself is thick, long, and heavy. The water-bath warmer system was the least effective, but it is the cheapest among the warmers tested. The forced-air warming system requires a blanket that costs 5800 yen, but the patient can also be warmed with this blanket. The IV fluid warmer is a potential source of air bubble emboli [15], and the dry-heat plate warmer originally includes a bubble trap system. It is, therefore, important to select a warmer according to its characteristics as well as its performance.

In conclusion, an IV tube warmer is the most effective system for warming IV fluid at any flow rate. A dry-heat plate warmer is also effective for warming IV fluid, but the warmed fluid is cooled in the tube, especially at low flow rates. It is important to choose a warmer according to its characteristics.

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