Effective methods of in-line intravenous fluid warming at low to moderate infusion rates

Lt Col C. CARL BOSTEK, CRNA, MSN, USAF, NC
Minot Air Force Base, North Dakota

Three methods of warming intravenous (IV) fluids were examined. An in-line blood warmer was generally ineffective at flow rates of < 250 mL/hr but did produce temperatures of 30 to 31°C at the catheter when the infusion rate was 500 to 1,000 mL/hr and the tubing was insulated. An in-line hot water bath produced temperatures of ≥ 30°C at flow rates of 200 to 1,000 mL/hr with uninsulated tubing. The addition of insulation maintained an infusate temperature of ≥ 30°C at a rate of 100 mL/hr. Application of a K-Thermia® pad to the IV tubing close to the patient maintained an infusate temperature of ≥ 30°C at rates of 50 to 200 mL/hr. Warming at rates of 200 to 1,000 mL/hr is most effective with an in-line hot water bath. Warming at low infusion rates is best accomplished with a K-Thermia pad. The use of in-line blood warmers for routine fluid warming is ineffective.

Key words: Hypothermia prevention, intravenous fluid temperature, intravenous fluid warming.

Introduction

The incidence of hypothermia has been reported to be as high as 60% during elective surgery.[1] Decreased oxygen delivery resulting from a left shift of the oxyhemoglobin dissociation curve, decreased tissue perfusion secondary to vasoconstriction, an increased incidence of deep vein thrombosis and pulmonary embolism, increased plasma levels of catecholamines and thyroid hormones, coagulopathy, increases in oxygen consumption during light general anesthesia, increases in carbon dioxide production and oxygen consumption up to 300% as a result of shivering, and, possibly, prolonged emergence and recovery from anesthesia are all potential sequelae of hypothermia.[2, 3]

Causes of hypothermia in the operating room include the use of unwarmed intravenous (IV) and irrigation solutions, unheated dry gases, low room temperatures, and the administration of drugs which impair thermoregulation. The metabolic cost of heating unwarmed fluids is approximately 16% of basal heat production when fluid requirements reach 6 mL/kg per hour in a 70-kg patient.[2] This level is readily exceeded when infusion rates are increased to compensate for decreases in blood pressure or periods of increased blood loss. Thus, the body heat expended to warm IV fluids administered at room temperature is a significant portion of basal heat production.

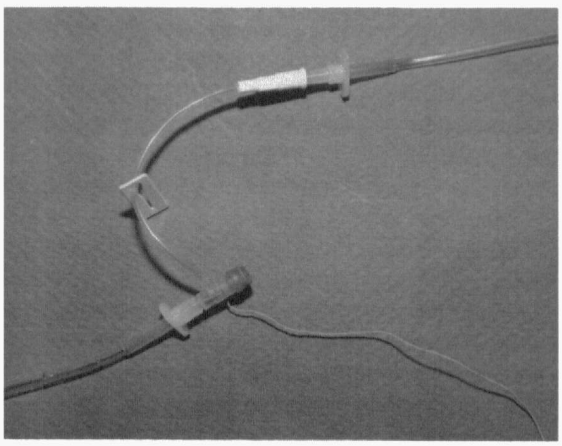
Heat loss can be reduced by preheating IV fluids or by in-line warming during administration. But neither method provides near body temperature infusate unless flow rates are ≥ 1 L/hr.[4-7] Allowing for basal metabolic requirement, 6 mL/kg per hour for interstitial losses, and replacement of nothing by mouth induced fluid deficit over 3 hours, the fluid requirement during the first 3 hours of a major abdominal case will approximate 850 mL/hr in a 70-kg patient. This infusion rate is too slow to provide near body temperature infusate when using preheated fluids or an in-line blood warmer.

The purpose of this study was to evaluate the effectiveness of two alternative in-line warming techniques at loss infusion rates. Warming was accomplished by immersing IV tubing in a high-temperature water bath or by wrapping a K-Thermia® pad around the IV tubing close to the insertion site. Results of warming by these methods were compared with in-line warming using a common blood warmer.

Methods and procedures

In all groups, a Mon-a-therm® Model 6000 (Mon-A-Therm, Inc., St. Louis, Missouri) with a specially modified skin sensor probe was used to measure temperature at the distal end of the IV extension tubing by threading the probe into an Extension Set with "T" (Abbott Hospitals, Inc., North Chicago, Illinois) (Figure 1). Flow rates of 50, 100, 150, 200, 250, 500, and 1,000 mL/hr were achieved using an AVI Guardian™ 100 Infusion Pump (AVI, Inc., St. Paul, Minnesota) positioned between the IV bag and the heating device. A flow rate of 6,000 mL/hr was the maximum attained through unrestricted IV tubing.

Figure I
Distal end of infusion setup



Modified skin temperature probe has been inserted under the rubber stopper into the T-piece to simulate measurement of infusate temperature at the catheter site. An extension tube was attached to the distal end of the T-piece to prevent evaporation of infusate at that point.

For Group I, fluids were warmed by passing them through a Pharmaseal® warming coil (Pharmaseal Co., Valencia, California) in a Pharmaseal DW 1000 Blood Warmer (Table I). In Group Ia, a single length of Pharmaseal K50L extension tubing (capacity 3.3 mL, length 84 cm) and a Pharmaseal K52 extension tube with stopcock were attached to the distal end of the coil. In Group Ib, only a K52 was attached, and in Group Ic, a K52 was insulated with a strip of "egg crate" foam insulation (E.R. Carpenter Co., Medical Products Division, Russellville, Kentucky).

In Group II, half the length of a K50L extension tubing was coiled into a water bath (Marquest Medical Products, Inc., Englewood, Colorado) heated by an MR 430 Servo Controlled Heated Respiratory Humidifier set at 37°C (Isothermal/Fisher & Paykel, Ltd., Riverside, California). The actual temperature of the water was 65°C. Approximately 38 cm of the extension tube was distal to the water bath. In Group IIa, the tubing distal to the bath was exposed to room air, while in Group IIb, it was insulated with a strip of blue foam insulation. To test for the presence of plasticizer—the chemical responsible for the flexibility of IV bags and tubing—an extension tube was filled with preservative-free sterile water and heated for 8 hours. The heated infusate was then spectrophotometrically scanned at wavelengths from 200 to 750 nm.

For Group III, a single length of K50L extension tubing was coiled inside a 20 x 30-cm K-Thermia Pad heated by an Aquamatic K-Thermia Model RK-600 (Gorman-Rupp Industries, Bellville, Ohio) which had been folded in half along its length and again along its width to form a pad approximately 10 x 15 cm. In Group IIIa, the heater was set to 38°C, and the T-piece was left exposed to room air. In Group IIIb, the heater was set to 41°C, and the T-piece was again left exposed

Table I
Summary of warming methods and insulation used by groups and subgroups

	Group I			*Group II*		*Group III*		
Warming method	Pharmaseal warmer			Water bath		K-Thermia		
Subgroup	a	b	c	a	b	a at 37°C	b at 41°C	c at 41°C
Tubing plus extensions	K50/K52	K52	K52	38 cm	38 cm	10 cm	10 cm	10 cm
Insulation	–	–	Foam	–	Foam	–	–	Pad

to room air. In Group IIIc, the heater was set to 41°C, but the T-piece was surrounded by the K-Thermia pad.

In all groups, the IV solution had been stabilized overnight at room temperature, and in-line temperatures were allowed to stabilize for 5 to 10 minutes after changes in flow rate. Five temperatures were recorded at 15-second intervals for each flow rate. Room and IV bag temperatures ranged from 21.3 to 23.1°C.

Results

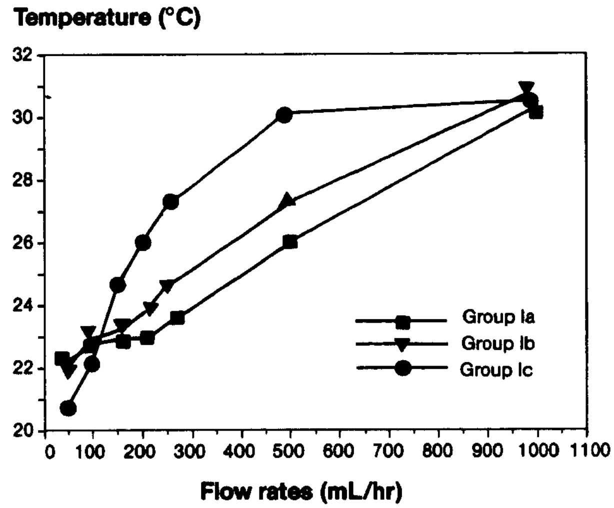
SPSS 4.0 (Statistical Package for Social Sciences, version 4.0) on a DEC VAX/VMS was used for statistical analysis. Analysis of variance revealed statistically significant differences among the groups at the .05 level. The Tukey-B procedure was used for pairwise comparisons. Statistically significant differences are summarized in Table II. In the following discussion, temperature measurements are reported as means plus or minus (±) one standard deviation.

In Group I, the most effective warming occurred when a single extension tube was used and insulation was applied from the warming coil to the insertion site (Figure 2). Fluid temperatures at the catheter when using the Pharmaseal blood warmer with insulation and a single extension tube were never above 30°C at low or moderate flow rates. At a rate of 1 L/hr, the infusate temperature at the catheter was 30.72 ± .22°C with two extension tubes and no insulation, 30.66 ± .11°C with an uninsulated K52 extension, and 30.54 ± .06°C with an insulated K52 extension. Increasing the flow rate through the blood warmer to 6 L/hr produced infusate temperatures at the catheter of 33.64 ± .06°C with two extension tubes and no insulation, 33.68 ± .13°C with an uninsulated K52 extension tube, and 34.54 ± .11°C with an insulated K52 extension. Except for flow rates of 50, 100, and 1,000 mL/hr, the use of insulation with only a K52 extension tube provided significantly greater warming ($P < .05$).

In Group II, the most effective heating occurred when insulation was applied to the extension tube leading from the water bath (Figure 3). Infusate temperatures ≥ 30°C at the catheter were achieved with the water bath and uninsulated tubing at flow rates of 200 to 1,000 mL/hr. When the tubing was insulated, temperatures ≥ 30°C were achieved with flow rates of 100 to 1,000 mL/hr. The warmest temperature attained was 38 ± .04°C at a flow of 500 mL/hr. The use of insulation provided significantly greater heat retention at all flow rates from 50 to 500 mL/hr ($P < .05$).

Figure 2

Mean (± 1 standard deviation) temperatures of intravenous infusate at the catheter site after warming with an in-line blood warmer



Group Ia—Two extension tubes and a T-piece
Group Ib—One extension tube and a T-piece
Group Ic—Insulation added to one extension tube and T-piece

In Group III, warming was most effective when the K-Thermia pad completely covered the extension tube and insertion site (Figure 4). The lowest flows provided the most effective warming: infusate temperature was 38.4 ± .04°C at 50 mL/hr, 34.2 ± .04°C at 100 mL/hr, 32.1 ± .07°C at 150 mL/hr, and 30.1 ± .07°C at 200 mL/hr. The use of a warming temperature of 41°C with the extension tube provided significantly greater warming at rates of 50, 100, and 150 mL/hr ($P < .05$).

Discussion

Warming of IV fluids is traditionally accomplished by preheating the bottles in warming cabi-

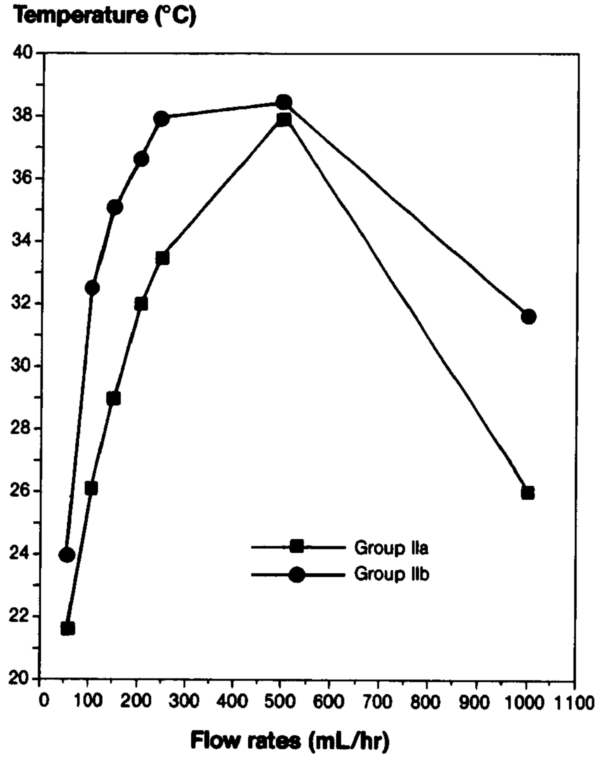
Table II

ANOVA showed these warming methods to be significantly different at the .05 level at the infusion rates indicated.

	Warmer	*Water bath*
Water bath	---, 100, 150, 200, 250, 500, 1000, 6000	
K-Thermia	50, 100, 150, 200, 250, 500	50, 100, --, 200, 250, 500

Figure 3

Mean (± 1 standard deviation) temperatures of intravenous infusate at the catheter site after warming with an in-line hot water bath



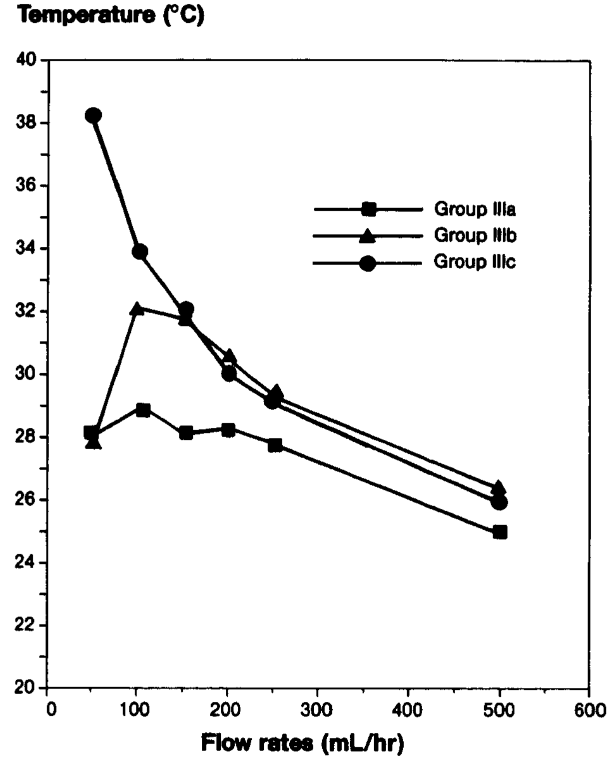
Approximately 40 cm of the first extension tube was threaded into the hot water bath. The remaining tubing was long enough to reach from the bath to a patient.

Group Ia—One extension tube plus T-piece

Group Ib—Insulation added to one extension tube plus T-piece

Figure 4

Mean (± 1 standard deviation) temperatures of intravenous infusate at the catheter site after warming with a K-Thermia pad



Group IIIa—Heater set to 38°C with the T-piece exposed to room air

Group IIIb—Heater set to 41°C with the T-piece exposed to room air

Group IIIc—Heater was set to 41°C but the T-piece was surrounded by the pad

nets or running the IV tubing through an in-line blood warmer. Neither of these methods has proven completely satisfactory. This study examined the effectiveness of insulating the tubing between an in-line blood warmer, use of a hot water bath with minimal tubing between the bath and the patient, and use of a K-Thermia pad to produce near body temperature infusate at the catheter. Norman, Ahmad, and Zeig warmed bags of crystalloid in warming cabinets to 50°C and found that, over 1 hour, the temperature of infusate at the catheter decreased linearly from 37 to 31°C when the infusion was run at 1,000 mL/hr. Solution that was heated initially to 60°C decreased in temperature at the catheter from 36.5 to 31°C after 1 hour and 27°C after 2 hours when run at 500 mL/hr. The tubing length was 275 cm, infusion pumps were not used, and the ambient room temperature was 23 to 25°C.[5]

Skrivanek and Hein infused crystalloid solutions through a Pharmaseal blood warmer at rates of 1 to 12 L/hr. Ambient room temperature was 20.4 to 20.9°C. The temperature at the catheter site was 26°C when the infusion rate was 1 L/hr, 32.5°C at 2.4 L/hr, 29°C at 6 L/hr, and 26°C at 12 L/hr with two extension tubes attached to the IV tubing. With no extension tubes, the temperatures at the infusion site were 27.5°C, 31°C, 32°C, and 27°C, respectively. An attempt to prevent heat loss by wrapping the IV tubing between the blood warmer and catheter with aluminum foil failed to increase infusate temperatures.[6]

Aldrete also investigated the effect of infusion rate and tubing length on the temperature of infusate at the catheter site. The temperature of infusate at the catheter remained approximately 25°C throughout the infusion period when the bag was warmed initially to 34.4°C and the infusion rate was set to 100 mL/min (6 L/hr) using an IVAC pump. When infused at 20 mL/min (1.2 L/hr), the temperature at the catheter remained approximately 23°C. Warming the bags to 41.4°C provided an infusate temperature of 33.5°C at the catheter (100 mL/min) when the IV tubing was 180 cm long. Increasing the tubing length to 230 cm decreased the temperature of the infusate to approximately 31.8°C. When bags were heated to 42.8°C and the fluid passed through a blood warmer at 36°C, the temperature of infusate at the catheter was 28 to 30°C. Significant heat was lost from the IV fluid, since the blood warmer was cooler than the infusate.[7]

Regardless of the method, preheating IV fluids only provides infusate temperatures ≥ 30°C when the initial fluid temperature is ≥ 40°C and flow rates exceed 500 mL/hr. This occurs because the large surface area of IV tubing allows rapid cooling of warm fluids. And since surface area varies directly with tubing length, the use of extensions will speed cooling. Furthermore, blood warmers are generally ineffective in providing body temperature infusate at the catheter because of the distance between the warmer outlet and the catheter site and because the warmer only reaches a temperature of approximately 37°C. The use of foam insulation slows heat loss from tubing, but this is of no clinical significance at low rates.

The K-Thermia pad warms the air surrounding the IV tubing. The heat in the air is conducted across the tubing to the fluid, making for an inefficient warming system. The pad provides good warming at low rates if there is no exposed tubing, because low flows allow plenty of time for the infusate to warm. At higher flows, the pad is ineffective, largely because of the poor heat conduction.

The water bath is the most efficient warming system studied, because of the high temperature of the bath and the excellent heat conduction between the water and the tubing. It provides for near body temperature infusate over the widest range of temperatures (**Figure 5**). However, a potential problem with this technique was recognized when the IV tubing in the bath was seen to become opaque with prolonged heating, raising the possibility that plasticizer would diffuse into the IV fluid.

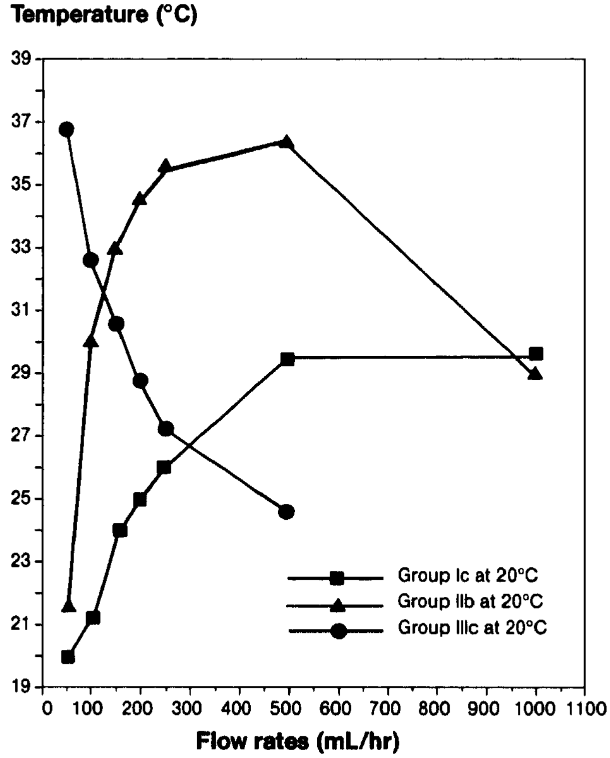
Plasticizers are important components of many plastic articles used in medical practice because they provide flexibility. Plasticizers, especially the phthalates, have been tested extensively in animal models and have been found safe when ingested orally. Phthalate plasticizers, however, will kill myocardial cells in tissue culture and can induce acute respiratory distress when injected IV at doses of 200 mg/kg of body weight.[8,9] Blood and plasma proteins will leach plasticizer from intravenous bags and tubing made from polyvinyl chloride (PVC), but crystalloid solutions will not.[10-12] Furthermore, microwave warming of plastic IV bags containing crystalloid solutions shows no increase in plasticizer concentration when compared to control fluids at room temperature.[13]

In this study, IV tubing filled with sterile water was heated in the water bath for 8 hours. Spectrophotometric analysis showed no change in optical density of the heated solution when compared with sterile water that was not heated in IV tubing. This observation, though not definitive, makes it seem unlikely that leaching of plasticizer into heated IV tubing is a major problem.

No single method of warming IV fluids can provide body temperature infusate at the catheter

Figure 5

Comparison of mean (± 1 standard deviation) temperatures of intravenous infusate at the catheter site after warming with the most effective method from each group



Group Ic— In-line blood warmer with one extension tube plus T-piece, insulated.

Group IIb—In-line hot water bath, one extension tube plus T-piece, insulated.

Group IIIc—K-Thermia pad covering all tubing and set to 41°C.

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