Experimental Study of Warming Intravenous Fluids in a Cold Environment

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INTRODUCTION

Primary hypothermia accounts for an estimated 700 deaths per year in the United States.[1] The incidence of secondary hypothermia, which typically occurs in the setting of illness, trauma, or intoxication, is unknown and probably exceeds that of primary hypothermia. Hypothermia can be lethal, but early appropriate therapy may be lifesaving. A 1987 survey of 428 cases of hypothermia found a mortality rate of 23% for patients with an initial temperature < 32.2ºC and a mortality rate of only 7% for patients with an initial temperature between 32.2ºC and 35ºC.[3] Two prospective studies have found that aggressive treatment of hypothermia improves outcomes.[5,6] For hypothermic patients receiving care in the Emergency Department or in a prehospital setting with road access, electrical devices are commonly and effectively used for warming intravenous fluids. For patients in remote environments and combat settings, there is no standard method of warming fluids prior to administration. Heating fluids on a stove or against a care provider's body are practiced but we found no published studies evaluating these methods. Two flameless heat packs from Meal Ready to Eat (MRE) packages have been shown to increase the temperature of a one liter bag of fluid from 10ºC to 38ºC in 8 minutes, but other types of heat packs and the effect of MRE heat packs on fluid temperature during infusion in a cold environment have not been studied.[9]

We conducted an experimental study to evaluate various methods of warming intravenous fluid for a bolus infusion in a cold environment with lightweight equipment typically available to a wilderness rescuer.

MATERIALS AND METHODS

All tests were performed in a 5ºC cold room, and all equipment was stored for at least 24 hours in the cold room prior to testing to ensure equilibration with the ambient temperature. One liter and 500 mL bags of 0.9% sodium chloride intravenous fluid (Hospira, Inc. Lake Forest, IL) were infused through a 254 cm long, 3.05 mm internal diameter intravenous line (Kawasumi Laboratories, Inc. Tampa, FL) and heated using various methods. Heat packs studied included: 1) Kwik-Heat® Instant Hot Packs (Cardinal Health, Inc. Dublin, OH) containing anhydrous sodium thiosulfate, 2) Wilderness IV Warmer heat packs (Ultimate Hot Pack, Inc. Lander, WY) containing calcium chloride, and 3) MRE heat packs (TrueTech, Inc. Riverhead, NY) containing a magnesium-iron alloy. Heat packs were activated either by squeezing the heat pack to combine the active substance with water contained in a separate pouch within the heat pack (Kwik-Heat® Instant Hot Packs) or by adding 5ºC water following manufacturer instructions (Wilderness IV Warmer and MRE heat packs).

Stove methods employed a Pocket Rocket stove and IsoPro (isobutane) fuel canister (Mountain Safety Research, Inc. Seattle, WA) to heat a 500 mL bag of fluid inside a metal pot with a diameter of 15 cm, a height of 8 cm, and a volume of 1,400 mL. One liter bags of fluid were not studied using the stove method because they were too large to fit in commonly used backpacking pots. After placing the 500 mL bag of fluid inside the pot, we added 800 mL of 5ºC water, which almost filled the pot. A 15 cm long mercury thermometer with the bulb held against the intravenous fluid bag was used to measure the temperature of the fluid of the bag during the stove trials (Figure 1c).

1 Liter methods

1) 1 Kwik-Heat® Instant Hot Pack attached to 1 L of fluid
2) 1 Kwik-Heat® Instant Hot Pack attached to 1 L of fluid plus insulation
3) 1 Kwik-Heat® Instant Hot Pack attached to 1 L of fluid and 1 Kwik-Heat® Instant Hot Pack attached to a coil of intravenous tubing plus insulation
4) 2 Kwik-Heat® Instant Hot Packs attached to 1 L of fluid plus insulation
5) Wilderness IV Warmer attached to 1 L of fluid
6) 2 MRE hot packs attached to 1 L of fluid plus insulation

500 mL methods

7) 1 Kwik-Heat® Instant Hot Pack attached to 500 mL of fluid and 1 Kwik-Heat® Instant Hot Pack attached to a coil of intravenous tubing plus insulation
8) 2 Kwik-Heat® Instant Hot Packs attached to 500 mL of fluid plus insulation
9) Wilderness IV Warmer attached to 500 mL of fluid
10) 2 MRE hot packs attached to 500 mL of fluid plus insulation
11) 2 MRE hot packs attached to 500 mL of fluid plus insulation with 10 minute delay and removal of fluid from hot packs
12) Stove and metal pot filled with water to heat 500 mL of fluid to 45ºC
13) Stove and metal pot filled with water to heat 500 mL of fluid to 60ºC
14) Stove and metal pot filled with water to heat 500 mL of fluid to 75ºC

Equipment weight and mean setup time for each method are reported. Setup time is defined as the time beginning with unassembled cold equipment until the beginning of fluid infusion. For methods using heat packs, setup time includes the 5 minute or 10 minute (method 11) delay to allow heat packs to warm the fluid. Similarly, for stove methods, the setup time includes the time required to heat the fluid. The mean infusion temperature for each trial was calculated from the temperature measured each second during the course of the infusion. Mean and maximum infusion temperatures are reported for each trial. Mean infusion temperatures for the various methods are compared using an analysis of variance test.

Figure 1. Pictures showing (A.) intravenous fluid bag with heat pack attached, a coil of intravenous tubing is between the heat pack and the intravenous fluid bag, (B.) intravenous fluid bag with coil, heat pack, and insulating fleece jacket attached, ready for infusion, (C.) 500 mL bag of fluid on stove with temperature probe on bag.

RESULTS

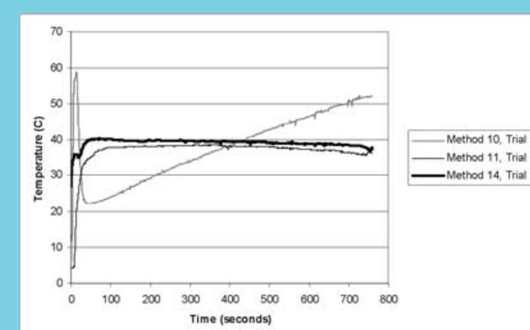
Equipment weight, setup times, and mean and peak temperatures are listed in the Table. The weight of the fleece insulating jacket (340 gm) is not included in equipment weights. The MRE heat pack (9.5 gm) is much lighter than the Kwik-Heat® Instant Hot Pack (205 gm) or the heat pack for the Wilderness IV Warmer (336 gm). Setup times ranged from 5 to 11 minutes and were longest for the two methods with the mean temperatures that achieved the most desirable temperature profiles (methods 11, 14). The mean ambient temperature for all trials was 4.9ºC (SD 0.3, range 4.4-5.4ºC). The mean infusion time for methods with 1 liter boluses was 29 minutes (range 28-31 min) and with 500 mL boluses was 14 minutes (range 12-18 min).

The peak temperatures of methods 6 and 10 were than 50.3 and 58.8ºC respectively. A graph of infusion temperature vs. time for the first trial of methods 10, 11, and 14 illustrates the temperature profile over time for these methods (Figure 2). The peak temperatures in methods 6 and 10 occur at the beginning of the infusion, when the heat packs against the coiled intravenous tubing cause high temperatures in the coil prior to infusion, and at the end of the infusion, when the volume of fluid remaining in the bag is small. These high fluid temperatures do not occur with methods 11 and 14 because for these methods the fluid bag is removed from the heat source prior to infusion.

Table One: Equipment weight, mean setup time, and mean and maximum temperatures at site of infusion for the 14 methods. KH, Kwik Heat Hot Pack; WIVW, Wilderness IV Warmer; MRE, Meal Ready to Eat heat pack; PR, Pocket Rocket stove.

Method and Description	Weight (gm)	Setup Time	Trial 1 Mean Temp (ºC)	Trial 2 Mean Temp (ºC)	Maximum Temp (ºC)
1 Liter methods					
1. 1 KH on bag	205	5 m 51 sec	7.0	7.6	18.9
2. 1 KH on bag	205	5 m 54 sec	7.1	7.6	20.6
3. 1 KH on bag, 1 on coil	410	5 m 52 sec	8.4	8.7	14.8
4. 2 KH on bag	410	5 m 57 sec	9.5	10.0	17.8
5. Wilderness IV Warmer	665	7 m 57 sec	8.7	9.1	11.5
6. 2 MRE on bag	19	6 m 15 sec	23.8	26.0	50.3
500 mL methods					
7. 1 KH on bag, 1 on coil	410	5 m 52 sec	10.7	10.4	12.5
8. 2 KH on bag	410	5 m 57 sec	12.4	12.0	21.2
9. Wilderness IV Warmer	665	7 m 57 sec	9.9	10.2	15.3
10. 2 MRE on bag	19	6 m 15 sec	38.5	29.2	58.8
11. 2 MRE on bag, 10 min delay	19	11 m 5 sec	36.7	36.8	39.2
12. Stove heating to 45ºC	485	5 m 5 sec	19.1	21.6	23.1
13. Stove heating to 60ºC	485	5 m 41 sec	24.7	27.8	26.2
14. Stove heating to 75ºC	485	8 m 20 sec	39.0	39.0	40.3

Figure 2: Temperature vs. time for trial 1 of method 10 (2 MREs on 500 mL), 11 (2 MRE on 500 mL for 10 minutes then remove fluid from heat source), and 14 (stove heating 500 mL to 75ºC the remove from heat source). Time zero represents the beginning of the infusion. Delays of 6 min 15 sec, 11 min 5 sec, and 8 min 20 sec occurred prior to infusion for methods 10, 11, and 14 respectively. Note the spikes in the temperature of methods 10 at the beginning (58ºC) and the end (52ºC) of the infusion



DISCUSSION

For both the 500 mL and 1 liter fluid volumes, the Kwik-Heat® Instant Hot Packs and Wilderness IV Warmer achieved only small increases in fluid temperature. The approximately 5ºC increase in fluid temperature which occurred when these methods were applied to 500 mL bags of fluid may have some clinical value but falls far short of the goal of warming the fluid to between 35 and 40ºC. Only two methods, the attachment of two MRE heat packs and the use of an isobutane stove applied to 500 mL bags of fluid were able to increase the fluid temperature to a level acceptable for infusion.

The high initial and final temperatures noted during method 10 (Figure 2) would be unacceptable to administer to a patient because the generally accepted maximum temperature for infused fluids is 42ºC.[11,12] In method 11, we were able to eliminate these high peak temperatures by heating the fluid and then removing the fluid from the heat source prior to infusion. Because of the potential risk to the patient of infusing overheated fluids, we think that, in general, methods of heating fluids in which the fluid is heated rapidly then removed from the heat source prior to infusion are preferable to methods in which the heat source remains on the bag of fluid during the infusion.

LIMITATIONS

We used a 5ºC cold room and fluids in order to simulate a cold environment. Much variation exists in the actual conditions encountered in prehospital settings, which limits the application of these results. Variations in wind, humidity, altitude, and sun exposure may affect the performance of the methods we describe. The ideal method of warming intravenous fluids would consistently and quickly warm fluids to an infusion temperature of 38 to 40ºC regardless of the starting temperature of the fluids or the ambient temperature. Further testing of selected methods is needed to determine if this is possible.

We chose to study bolus infusions because we felt this was the most important type of fluid administration in a prehospital setting. In some settings, maintenance fluids are more appropriate. Non-bolus infusions have different thermal profiles than bolus infusions, and our results are not directly applicable to situations requiring maintenance fluids.

We only conducted two measurements of each method, which allowed us to efficiently evaluate a large number of different methods. The small differences in mean temperatures between the two trials of each method suggest that the mean temperatures we obtained are representative. We think that the large difference (38.5 vs. 29.2ºC) in temperature that occurred between the two trials of method 10 resulted from our adding an inadequate amount of water to the MRE heat pack in the second trial. According to manufacturer instructions on the heat pack, MRE heat packs need to be completely saturated in order to be properly activated. After recognizing the large difference in temperature between the two trials of method 10, we repeated the method a third time and obtained a mean infusion temperature of 38.1ºC, similar to the results of trial 1.

Method 14 used a stove to heat a 500 ml bag of fluid to 75ºC. This method achieved a mean infusion temperature of 39ºC and a peak temperature of 40.3ºC. During the heating of the fluid, the temperature of the plastic was measured at 75ºC and may have been hotter on the surface touching the bottom of the pot. Although intravenous fluids are commonly heated to 40ºC without any known danger to the patient, higher temperatures may result in changes in the plastic that may release plastic compounds into the intravenous fluid. This concern also applies to methods using the MRE heat packs, which according to the manufacturer can reach temperatures up to 125ºC. After each trial, the plastic bag containing the intravenous fluid was examined by visual inspection. We were unable to identify damage to the plastic from any of the methods.

CONCLUSION

Our results suggest two general conclusions about warming intravenous fluids in a remote, cold environment. The first is that it is easier to warm 500 mL bags of fluid than 1 L bags of fluid. Since 500 mL bags of fluid are also as easy or easier to pack and carry than 1 L bags, our findings suggest that 500 mL bags of fluid may be more suitable for use in remote settings in which warming intravenous fluid is likely to be necessary. The second general conclusion suggested by our results is that methods in which the fluid is rapidly warmed then removed from the heat source provide for more stable temperatures during infusions than do methods in which the heat source remains in contact with the bag of fluid. By removing the fluid from the heat source, we were able to avoid overheating the fluid in the latter part of the infusion. Furthermore, during bolus infusions we demonstrate that only minimal cooling of the fluid occurs even in the absence of a continuous heat source.

Of the methods we studied, only the MRE heat packs and the stove were able to heat the IV fluid to a temperature above 30ºC. In comparing the two methods with the most desirable temperature profiles, method 11 (2 MRE heat packs on 500 mL of fluid) is lighter and less expensive but has a slightly longer setup time than method 14 (stove heating 500 ml of fluid to 75ºC). We regard the use of the stove as the better of these two methods because we believe that the use of a stove will allow for more control in the heating of fluids given a variety of ambient and initial fluid temperatures. Further study of these two methods is warranted to determine whether either approach can provide a consistent infusion temperature regardless of ambient and initial fluid temperatures.

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