原 著

Warming of Crystalloid Fluid can Alter Accuracy of the Containing Volume Level due to Changes in the Container's Shape

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Abstract

Warming of crystalloid fluid can cause expansion of the fluid container, resulting in misevaluation of the fluid level. However, how warming modifies the estimation of remaining fluid volume in the containers, and how much pre-warmed fluid decreases its temperature after running down have not been well studied. In this study, we examined differences between the ruler and the fluid level, and fluid temperatures at the end of infusion among three fluid containers, USP in VIAFLEX™ (the Baxter), LACTEC™ (the Otsuka), and USP in EXCEL™ (the B. Braun), with and without warming to 38℃. In results, warming of the Baxter and the B. Braun at 38℃ caused the fluid levels to be less than the corresponding ruler levels, whereas warming of the Otsuka did not cause the phenomenon. The fluid temperature at the end of infusion line was above 31.7℃ without any differences among three containers. In conclusion, the remaining fluid volume of pre-warmed containers may be falsely informed during infusion due to changes in containers' shapes upon warming in the Baxter and in the B. Braun, but not in the Otsuka. Pre-warmed fluids to 38℃ may not be sufficiently effective to treat hypothermia.

Key words; infusion, fluid, soft containers, temperature

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Introduction

Warm fluid resuscitation is of importance for patients with hypothermia corresponding with hypovolemic shock[1]. Among available procedures to serve active warming of crystalloid fluid, preparation of warm fluid using a fluid warming cabinet appears an attractive method to immediately administer warm fluid to patients with hypothermia in the setting of emergency medicine[2,3]. Warming of crystalloid fluid possibly causes fluid container expansion, which is dependent on such as the container's shape, materials and/or containing air. However, effects of warming on fluid container expansion have not been studied. In addition, it has not been well evaluated whether crystalloid fluid in the soft containers warming around body temperature keeps its temperature after running down in the infusion line.

Therefore, the current study using fluid soft containers made from different materials in a simulated clinical condition was conducted to examine whether warming of crystalloid fluid containers modifies the information about the remaining fluid volume during infusion, whether the modified information is due to changes in the container shape, and how much pre-warmed fluid decreases its temperature after running down in the infusion line.

Methods

We evaluated flexible plastic containers of 500 ml lactated Ringer solution from different materials, including Lactated Ringer's Injection USP in VIAFLEX™ container (polyvinyl chloride, the Baxter) from Baxter Healthcare Co., Deerfield, IL USA, Lactec™ (polyethylene, the Otsuka) from Otsuka pharmaceutical Co., Chiyoda-ku, Tokyo, Japan and Lactated Ringer's Injection USP in EXCEL™ container (copolymer of ethylene and propylene, the B. Braun) from B. Braun Medical Inc., Irvine, CA, USA[4~6]. The ambient temperature was strictly maintained at 23℃ throughout the following experiments.

In the first set of experiments, air (ml) in each group of containers without infusion was measured by withdrawing it using a 50 ml injector with a 3-way stopcock. In addition, the remaining fluid volume after 500 ml withdrawal of containing fluid was determined for each group of containers.

In the second set of experiments, difference (mm) between the ruler on each container expressing the remaining fluid volume and the fluid level was measured at every 100 ml not-warmed (23℃) or pre-warmed (38℃) fluid infusion in the different speed of 500 ml/15 min or 30 min using the blood transfusion pump (Telfusion™ BP-101, Terumo Co., Shibuya, Tokyo, Japan) (**Fig. 1**). When the fluid level was above the ruler, it was expressed as a plus difference (**Fig. 1**). Fluid temperature during infusion at the container bottom and at the end of infusion line (130 cm in length of Telfusion™ TB-PU300L, Terumo Co., Shibuya, Tokyo, Japan) was simultaneously evaluated using thermometers (DATA COLLECTOR AM-7002 HS, Adachi Keiki Inc., Meguro, Tokyo, Japan) (**Fig. 1**). The fluid warming cabinet (Forced Convection Oven™ FC-610, Toyo Seisakusho Kaisha Ltd., Kashiwa, Chiba, Japan) uses a low-heat-density electro-

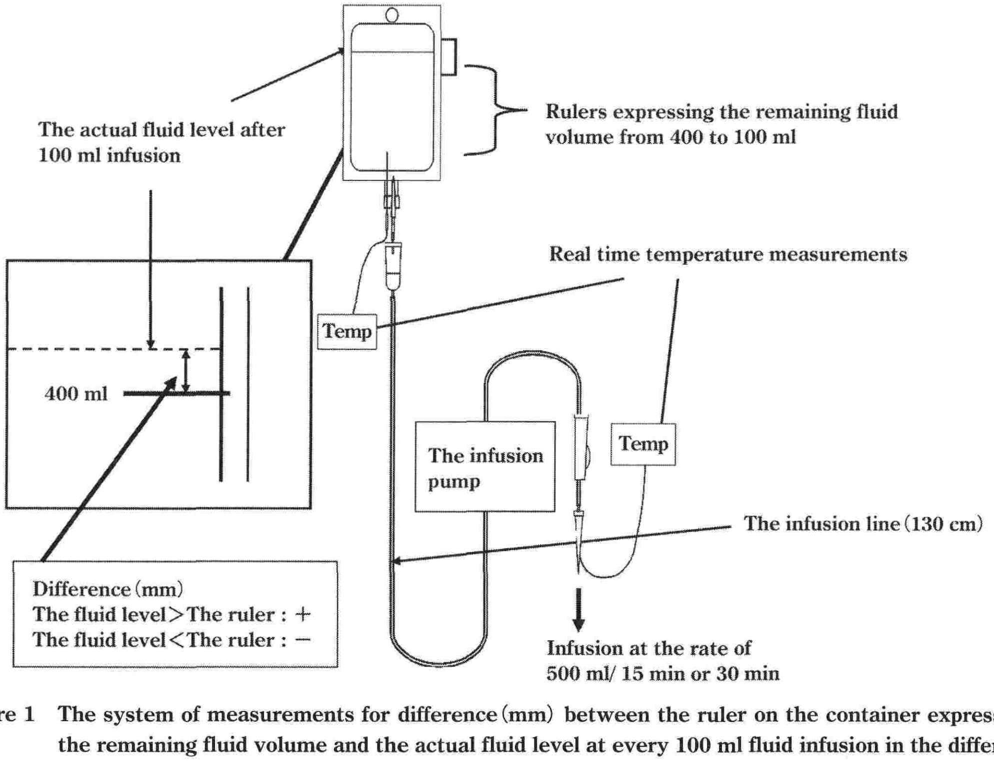

Figure 1 The system of measurements for difference (mm) between the ruler on the container expressing the remaining fluid volume and the actual fluid level at every 100 ml fluid infusion in the different speed of 500 ml/15 min or 30 min through the infusion pump

When the actual fluid level was above the ruler, it was expressed as a plus difference. Fluid temperatures during infusion at the container bottom and at the end of infusion line were simultaneously evaluated using thermometers.

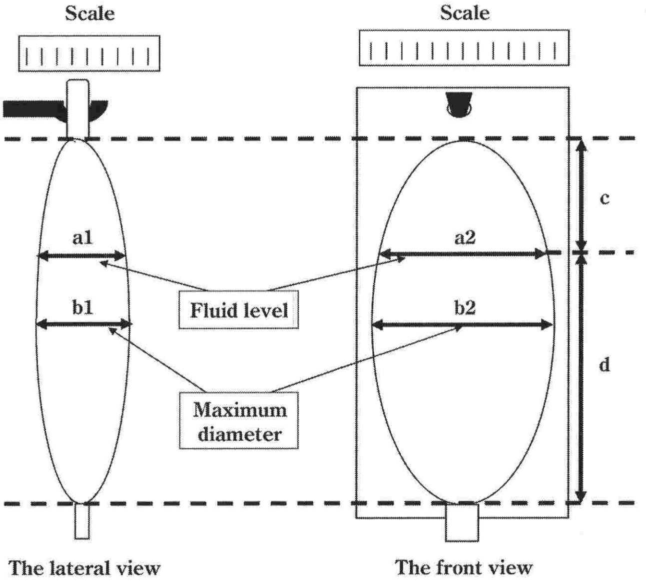

Figure 2 The system of measurements for the lateral and front views of each pre-warmed container with a scale after withdrawing 200 ml of fluid in the speed of 500 ml/15 min

Dimensions (at the fluid level [a1] and at the maximal diameter [b1] in the lateral view; at the fluid level [a2], at the maximal diameter [b2], between the top and the fluid level [c] and between the fluid level and the bottom in the front view) in the obtained JPEG files were further analyzed using the image analysis software.

thermal cable array to provide even heating of fluid containers. Our preliminary study demonstrated that fluid temperatures in all containers reach plateau at 6 hrs in our warming cabinet set at 38℃, consistently with a previous study showing that the effect of storage time in a 40℃ warming cabinet on a temperature of lactated Ringer's solution[7]. Therefore, in the current study, all warmed fluid containers were evaluated after 6 hrs warming.

In the third set of experiments, the typical lateral and front views of each pre-warmed container with a scale after withdrawing 200 ml of fluid in the speed of 500 ml/15 min were recorded as JPEG image files by the digital camera (LUMIX™ type DMC-FX7-S, Panasonic Co., Osaka, Japan) (**Fig. 2**). Dimensions (at the fluid level [a1] and at the maximal diameter [b1] in the lateral view; at the fluid level [a2], at the maximal diameter [b2], between the top and the fluid level [c] and between the fluid level and the bottom in the front view) in the obtained JPEG files were further analyzed using the image analysis software with the sensitivity to 0.001 mm (SensivMeasure™, Mitani Co., Fukui, Japan) (**Fig. 2**). We adopted the space containing fluid and air as dimensions of a fluid container and calibrated the software using a scale in each image file upon every analysis (**Fig. 2**).

Statistical Analysis

Data are shown as means ± SD. Differences were considered to be statistically significant when P was <0.05. Power calculations were done using Sample Power 2.0™ (SPSS Japan Inc., Tokyo, Japan) with the differences between the ruler on the container showing the remaining fluid volume and the actual fluid level, and those of dimensions of fluid containers between 23 and 38℃ as the primary and secondary end points, respectively. We calculated that a sample size of 9 gave 84% power to detect changes of 3.7 mm or that of 6 gave 85% power to detect changes of 2.3 mm in the differences between the ruler and the fluid level, and those of dimensions at a significance level of 0.05 (SD = 2.5 or 1.2), respectively. Statistical analysis was performed using repeated measures of analysis of variance, followed by Student-Newman-Keuls test in StatView™ version 5.0 (SAS Institute Inc., Cary, NC).

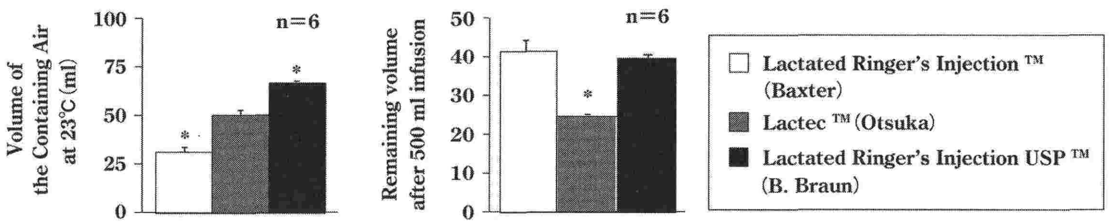

Figure 3

Air (ml) without infusion at 23℃ (**Left**) and the remaining fluid volume after 500 ml withdrawal of containing fluid (**Right**) in each group of containers are shown.

*Difference between the Otsuka and others is statistically significant ($p < 0.05$).

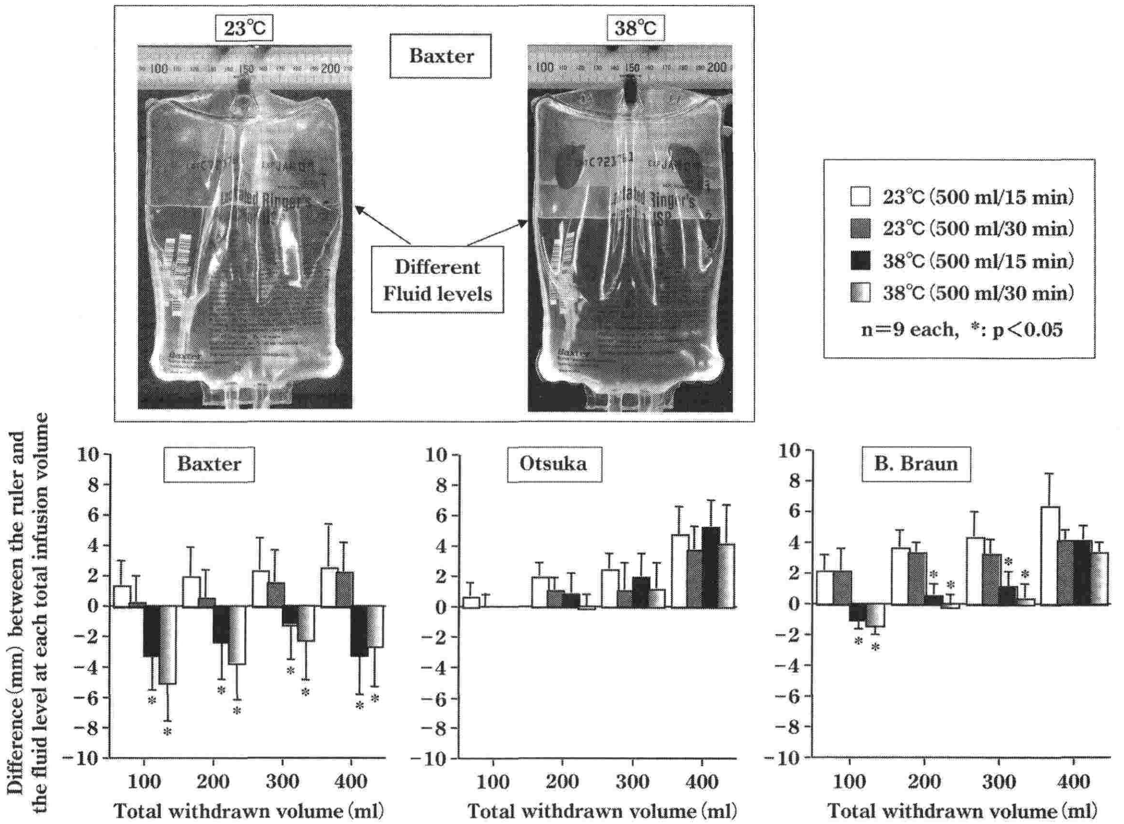

Figure 4

Differences (mm) between the ruler on the container expressing the remaining fluid volume and the actual fluid level at every 100 ml fluid infusion in the different speed of 500 ml/15 min or 30 min are shown.

*Difference between 23℃ and 38℃ at each infusion speed is statistically significant ($p < 0.05$).

Results

Air in the container before infusion at 23℃ was more in the B. Braun and less in the Baxter than the Otsuka (**Fig. 3**). However, the remaining fluid volume after 500 ml withdrawal was least in the Otsuka without any difference between the Baxter and B. Braun (**Fig. 3**).

In both infusion rates of 500 ml/15 min and 30 min, the differences between the ruler and the actual fluid level measured at every 100 ml infusion became minus or less in the Baxter and in the B. Braun after warming (**Fig. 4**). In contrast, the differences were not noted in the Otsuka (**Fig. 4**).

Table 1 Dimensions (mm) of fluid containers after withdrawing 200 ml of fluid at 23 or 38℃

The lateral view

Container	Temperature	a1	b1
Baxter	23℃	31.4±1.2	56.0±1.0
	38℃	34.5±0.7*	58.3±1.2*
Otsuka	23℃	27.4±3.1	39.8±1.6
	38℃	26.0±2.4	38.7±1.1
B. Braun	23℃	27.5±0.6	46.4±1.1
	38℃	24.5±0.1*	46.4±0.7

Data are expressed as mean±SD (n=6 each, *: $p<0.05$ vs. 23℃). a1 or b1 represents the dimension at the fluid level and the maximal diameter, respectively.

The front view

Container	Temperature	a2	b2	c	d
Baxter	23℃	112.3±1.5	112.5±1.5	62.0±1.3	108.9±1.1
	38℃	110.8±0.7	110.8±0.7	67.5±2.4*	103.2±0.7*
Otsuka	23℃	110.3±1.1	117.7±0.5	80.9±3.2	119.5±1.5
	38℃	108.1±1.5	118.1±0.8	82.3±2.9	118.3±3.1
B. Braun	23℃	114.5±2.4	117.2±1.4	87.3±1.5	110.8±1.6
	38℃	113.7±1.0	114.8±1.1	92.1±2.8*	109.5±1.7

Data are expressed as mean±SD (n=6 each, *: $p<0.05$ vs. 23℃). a2, b2, c or d represents the dimension at the fluid level, the maximal diameter and that between the top and the fluid level, the fluid level and the bottom, respectively.

Containers after withdrawing 200 ml of prewarmed fluid in the speed of 500 ml/15 min were evaluated. In the lateral view, dimensions at the fluid level and at the maximal diameter became larger in the Baxter, whereas those at the fluid level became smaller in the B. Braun, and these changes were seen only in the lateral view (**Table 1**). The dimensions between the top and the fluid level became larger in the Baxter and in the B. Braun, whereas those between the fluid level and the bottom became smaller in the Baxter (**Table 1**). Warming made the dimensions between the top and the bottom larger in the B. Braun (**Table 1**). Dimensions did not change in the Otsuka throughout above studies (**Table 1**).

The fluid temperatures at the end of infusion line during the infusion at 500 ml/15 min or 30 min were from 34.3 to 36.4℃ and 31.7 to 35.7 °C, respectively (**Fig. 5**). There was no difference in changes of fluid temperatures among the containers (**Fig. 5**).

Discussion

Dimensions between the top and the fluid level became larger in the Baxter and in the B. Braun, verifying downward shifts of the fluid levels during infusion of pre-warmed fluid in these containers. In the lateral views, dimensions at the fluid level and at the maximal diameter became larger in the Baxter, whereas those at the fluid level became smaller in the B. Braun. Therefore, containers after warming appear to expand or deflate in front and in rear in the Baxter and in the B. Braun, respectively. In addition, warming made the dimensions between the top and the bottom larger in the B. Braun, indicating that warming modifies the vertical length of the whole container. In contrast, dimensions in the Otsuka did not change throughout these studies, supporting no shift of the fluid levels during infusion in this container after warming. The manufacturing process probably plays some roles in changes of the fluid containers' shapes after warming. Indeed, the distinct materials including polyvinyl chloride, polyethylene or copolymer of ethylene and propylene for the container of the Baxter, the Otsuka and the B. Braun are capable of producing the differential expanding properties after the warming[4~6]. Thus, some bag materials may become softer and more pliable upon warm-

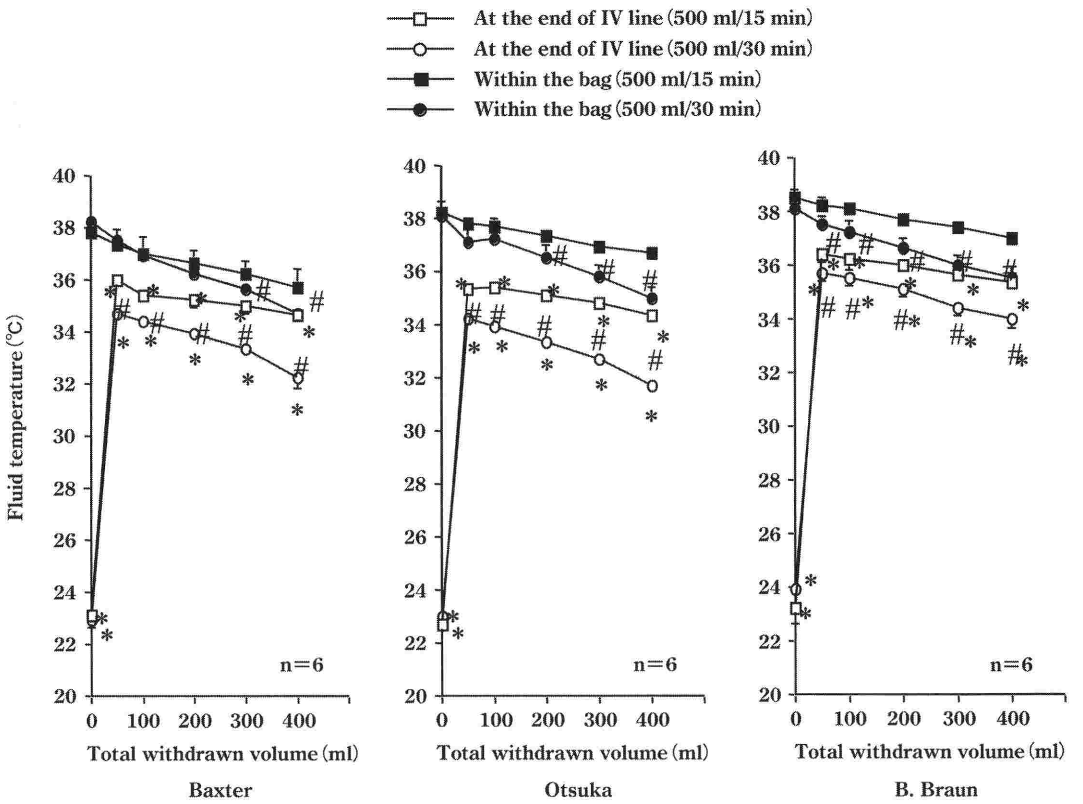

Figure 5

Changes in fluid temperatures (℃) during infusion at the container bottom and at the end of infusion line are shown. *Difference within the bag of each fluid speed and # difference at the same site compared with the faster speed are statistically significant ($p < 0.05$).

ing and somewhat stretched due to the gravity. In the Baxter, air in the container before infusion at 23℃ was least among containers tested, neglecting the role of air volume in the container expansion after warming. It is also interesting to note that the range of remaining fluid volume after 500 ml withdrawal was from 25 to 40 ml depending on the type of containers. Such extra-volume in the container is probably a reason why the fluid levels were above each ruler at every 100 ml infusion in all containers without warming.

The fluid temperatures at the end of infusion line were above 31.7 to 34.3℃ without any differences among containers. Therefore, pre-warmed crystalloid fluids to 38℃ may not be sufficiently effective on the treatment of hypothermia. Our conclusion is consistent with a previous study demonstrating that warming of fluid to 40℃ produces, if any, the minimal effect on body temperatures in patients undergoing surgery[8]. It is also worth noting that fluid temperatures at the bottom of containers were not different among groups, neglecting the effects of fluid temperatures on the changes in containers' shapes after warming in the current study.

Conclusions

We firstly provide the evidence that the remaining fluid volume in pre-warmed containers to 38℃ is falsely informed during infusion in the Baxter and in the B. Braun, but not in the Otsuka, and that this is probably due to changes of containers' shapes upon warming. It is crucial to note that warming of crystalloid fluid containers can modify the information about the remaining fluid volume during infusion as well as the container shape although such inaccuracy or modification is probably acceptable in our clinical practice. In addition, pre-warmed fluids to 38℃ may not be sufficiently effective on the treatment of hypothermia.

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