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Differences in Flow Rate Accuracy in Natural Instillation Using Different Infusion Temperature Management Methods: A Pilot Study

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ABSTRACT

Appropriate management of flow rate during infusion is essential. Only a few studies have quantitatively investigated the flow rate errors resulting from infusion temperature control. The aim of this study was to investigate the variation in flow rate accuracy caused by different infusion temperature managements using a gravimetric method to measure the actual flow rates. The results showed that the actual flow rate of the heated infusions was significantly lower than that of room-temperature infusions, consistent with the findings of previous studies. A possible reason for this observation is that following the initiation of the measurements, the infusion temperature gradually decreased over time, thereby increasing the surface tension and viscosity and eventually decreasing the flow rate of the dripping chamber. When a heated infusion is administered, it is essential to consider the effect of elevated infusion temperatures and recognize that flow rate accuracy may be compromised.

Abbreviations: RTM: Room-Temperature Management; TM: Thermal Management; PTM: Postheating Thermal Management

Introduction

Appropriate management of flow rate during infusion is essential. Taxol® infusion (paclitaxel; PTX) is a drug that requires careful attention during intravenous administration with a drop controller. The flow rate must be controlled when a PTX solution is administered using a natural dripping method or a dropping-control-type infusion pump, as the flow rate may decrease [1]. Flow rate errors are reportedly not attributed to variations in the concentration of infusion, placement of an infusion set and pump, or the insertion site of a central venous catheter [2]. Although a dropping-control-type infusion pump is sometimes used to administer an infusion, natural instillation and dropping controllers are more widely employed to adjust the drop count. The drop count within the drip chamber of an infusion set is observed either visually or mechanically, and the infusion flow per unit time is calculated by multiplying the droplet size. Previous studies have shown that the drop size influences the infusion flow rate and can be influenced by the characteristics of the solution, such as density, concentration, surface tension, and dropping speed [1]. Proper administration, with special attention to the drop flow and speed, is required to mitigate the risk of heart failure, arrhythmia, pulmonary edema, and metabolic disorders caused by exceeding the permissible flow.

An infusion may be warmed and administered to prevent perioperative hypothermia in severely injured patients [3]. A heating device is used when available; otherwise, the infusion is heated in a microwave [4,5]. In disaster medicine, hot water bottles are currently used for heating an infusion and maintaining its warmth, with occasional reports on its usage [3]. Although heating an infusion is presumed to decrease its viscosity and eventually increase the flow rate, some researchers have quantitatively examined flow rate errors [6,7]. The aim of this study was to investigate the variation in flow rate accuracy resulting from different types of infusion temperature control using a gravimetric method to measure the actual flow rates. The findings of this study are expected to contribute to the clarification and proper management of infusions.

Materials and Methods

A slim plastic-type 20-drop (Terufusion TI-U250P, Terumo, Japan) containing an intermediate tube with a highly visible drip chamber was used for the infusion set, and Terumo saline (1000 mL, Terumo, Japan) was used for infusion. The flow rate was set to 400 mL/h at a 60 min measurement period. The infusion set was installed in an infusion bag and primed, and a height difference of 1 m was set between the solution level in the infusion bag and the tip of the infusion set (Figure 1). The weight of the saline dropped from the infusion was measured using an electronic balance (EJ-610, AND, Japan), and the actual flow rate was calculated based on the measurement time. The accumulated droplets, which were calculated using drip infusion management tools (Dr-Mark, Mark Electronics Co., Ltd., Japan) based on the drop count within the drip chamber, were designated as the measured flow rates and recorded on a laptop (Inspiron, Dell Technologies Inc., TX, USA). The error rate was determined by comparing the actual flow rate obtained using the electronic balance and the measured flow rate obtained using drip infusion management tools. The infusion temperature control was divided into three groups based on different conditions, and an infusion bag was randomly applied to each group. The first was room-temperature management (RTM) using an infusion stored at normal temperature. In the Second group, thermal management (TM) was applied, in which the infusion was heated to 42 °C in a microwave, and the flow rate was then measured [8]. The third group was postheating thermal management (PTM), in which the infusion bag was heated to 42 °C in the microwave, and the infusion temperature was maintained at 42 °C. A hot water bottle (Yutaron Ice, Japan) was used for sustained heat retention. A thermistor (Sato, Japan) was installed in the infusion bag to measure the infusion temperature from the start of the experiment to the end. The measurements were performed at room temperature (24±0.5 °C) and relative humidity of 50%±10%, as established in a guideline for pharmaceutical departments [9].

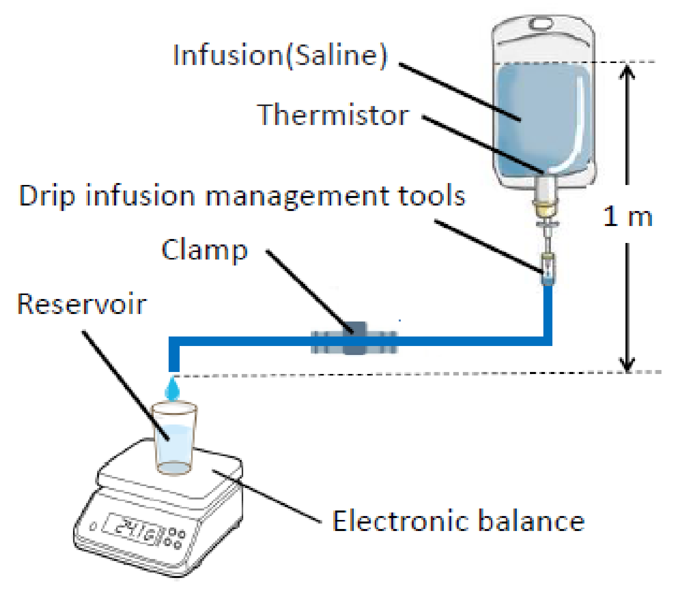

Figure 1: Appearance of flow measurement using gravimetric method.

Results

After 60 min following the initiation of the measurements, the average infusion temperature increased by 0.5±0.2 °C from 24±0.7 °C for RTM, decreased by 7.1±0.5 °C from 42±0.1 °C for TM, and decreased by 3.1±0.4 °C from 42±0.1 °C for PTM (Figure 2). The infusion temperature decreased the most in the case of the TM method. During the 60 min PTM measurements, the infusion temperature was not retained at 42 °C. The actual flow rate of TM was significantly lower than that of RTM (Figure 3), and the actual flow rates of TM and PTM were more widely dispersed than that of RTM. The measured flow rate of TM decreased over time compared with that of RTM (Figure 4). PTM showed a more significant variation than RTM. Significant differences were observed between the measured and actual flow rates obtained using the RTM and TM methods (Figure 5). The TM and PT results indicated wide dispersion in the actual and measured flow rates. TM and PTM showed lower error rates than RTM (Figure 6). All error rates were within 10% for all conditions.

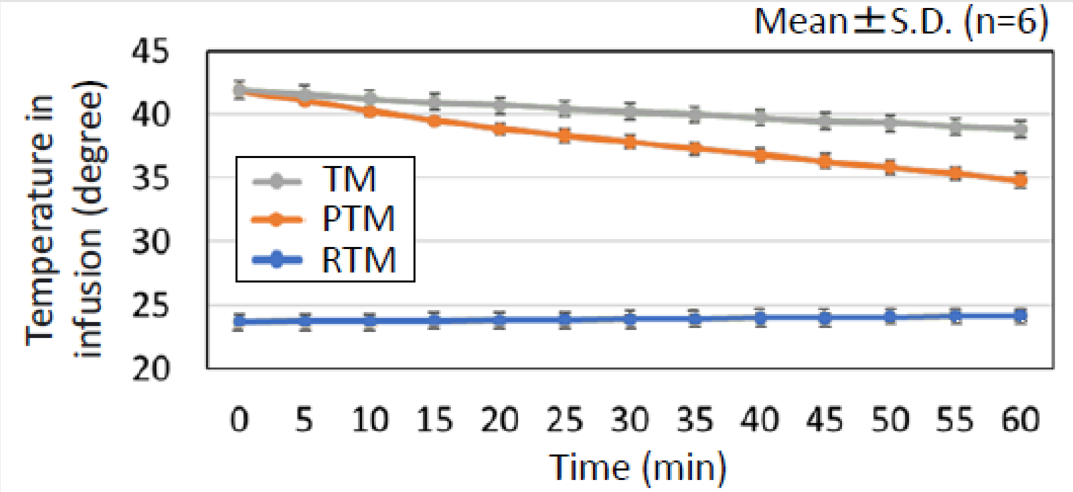

Figure 2: Temperature in infusion.

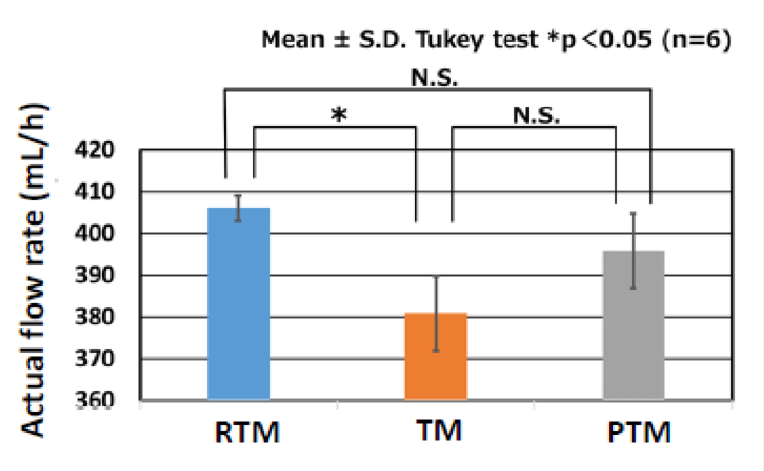

Figure 3: Actual flow rate of three temperature management groups.

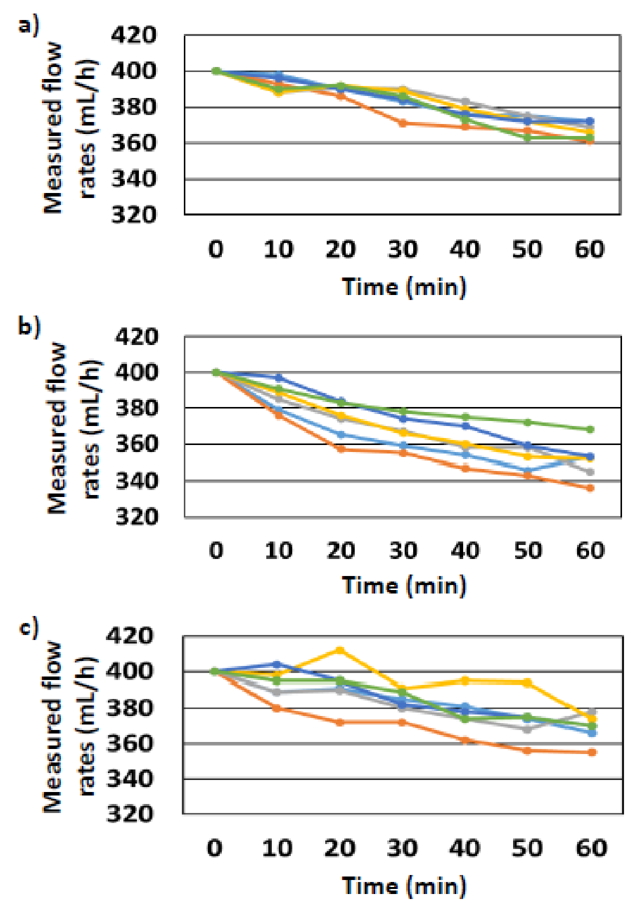

Figure 4: Measured flow rate:

a) Room-temperature management: RTM;
b) Thermal management: TM;
c) Postheating thermal management: PTM.

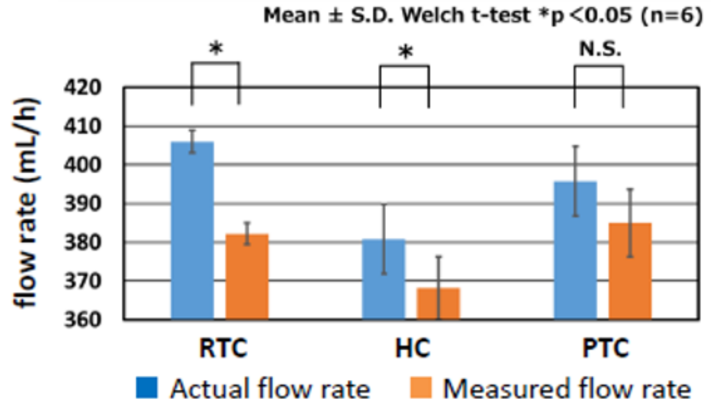

Figure 5: Measured flow rate of three temperature management groups.

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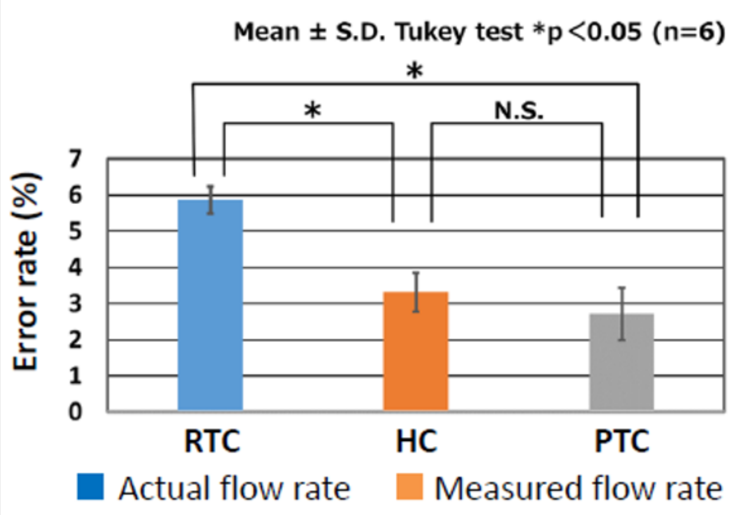

Figure 6: Error rates of actual and measured flow rates.

Discussion

Infusion is an essential medical therapy employed for various purposes, including hydration, adjustment to correct electrolyte abnormalities, and nutritional support. The flow rate accuracy of the infusion is defined for each drug, and ensuring appropriate management of this accuracy during administration is a critical in intravenous therapy. Precise management of infusion requires correct understanding and proper handling of the entire infusion system. Small-scale facilities frequently apply the natural dripping method to administer infusion. In this approach, the flow rate is adjusted using a clamp. The drops are counted either visually or mechanically, and the flow rate is calculated by multiplying the volume of the droplets. The drop volume influences the flow rate, while being influenced by the density and surface tension [4]. A possible reason for the infusion temperature not lasting for 60 min is the small contact area between the hot water bottle and the infusion bag. Expanding the contact area by covering the entire infusion bag is presumed to facilitate temperature management [10,11].

The large dispersion of the measured flow rate in PTM is attributed to the inability to control the temperature of the hot water bottle, generating variations in flow rates within the drop chamber. TM showed a significantly lower actual flow rate than RTM, consistent with the findings of Yamashita et al. [12]. A possible reason is that the infusion temperature declined after the measurements were commenced, resulting in an enhancement of the surface tension owing to increased viscosity, eventually decreasing the flow rate. In contrast to RTM, the actual flow rates for TM and PTM showed greater dispersions, presumably because of the variation in droplet volumes. This consideration is supported by the results that a larger variation in infusion temperature was observed for the TM and PTM methods, whereas RTM indicated a small dispersion in infusion temperature. A comparison between the actual and measured flow rates showed that the actual flow rate exceeded the measured flow rate under all conditions, which was assumed to be associated with the drop volume. The measured flow rate, obtained using drip infusion management tools, was determined based on the drop count. The flow rate was calculated, assuming that 20 drops was equivalent to 1 mL; therefore, the volume of each droplet was 0.05 mL.

The actual flow rate exceeded the measured flow rate because the individual droplet volume in the actual flow rate exceeded 0.05 mL. The drop volume was determined by opening the drip chamber of the infusion set. Accuracy of the infusion set was 20 drops = 1±0.1 mL, suggesting that the discrepancy between the measured and actual flow rates was attributed to differences in the infusion sets. The error rates between the actual and measured flow rates were probably caused by the elevated temperatures of the infusion in the TM and PTM, which resulted in decreased drop volume and surface tension. The error rates decreased because the drop volume of the actual flow rate approached that of the measured flow rate calculated at one drop = 0.05 mL. The increase or decrease in error rate was determined by the opening of the drop chamber in the infusion set. The infusion set used in this study was designed with a drop opening that released a large volume of droplets at room temperature. Consequently, when the infusion was heated, the drop volume decreased, resulting in small error rates. Based on ISO 8536-4, these errors are acceptable because of the application of the natural dripping method and the fact that all error rates were within a 10% margin.

Conclusion

Regarding infusion using the natural dripping method, this study demonstrated that heating the infusion decreased the actual flow rate. When a heated infusion is administered, it is essential to consider the effect of temperature variations and recognize that elevated infusion temperatures can compromise the accuracy of the flow rate.

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