

Comparison of the effectiveness of the piston-pump method versus the pressure-infusor method for rapid infusion of fluids

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Abstract

Background The piston-pump method is a simple method for rapid administration of fluids. However, some problems regarding effectiveness in increasing the flow rate of fluid administration, occurrence of excessive pressure in the infusion circuit and vessel, and bacterial contamination of fluids are unsolved. We compared the effectiveness of using the piston-pump method with that of the pressure-infusor method.

Methods Twelve anesthesiologists were classified randomly into the piston-pump and pressure-infusor groups. They were asked to infuse 500 ml of 0.9% saline three times successively through a 16-G intravenous cannula as rapidly as possible using a pump with a 50-ml syringe or a pressure-infusor at 300 mmHg. The time taken for infusion, the pressure in the infusion circuit and substitute vessel, and bacterial contamination were examined.

Results The infusion time (mean \pm SD) in the pressure-infusor and piston-pump groups was 233 ± 19 s and 301 ± 48 s, respectively ($P < 0.01$). There was a significant difference in the infusion time at the first and third attempts of infusion only in the piston-pump group ($P < 0.05$). The pressure (in mmHg) in the circuit was 131 ± 9 and > 200 ($P < 0.01$) and in the substitute vessel was 5 ± 1 and 17 ± 7 ($P < 0.01$) in the pressure-infusor and piston-pump groups, respectively. A pressure of -200 mmHg or less occurred at all infusion attempts in the piston-pump group. Bacterial infection was not observed in either group.

Conclusions If fluids must be administered rapidly, use of the pressure-infusor is more efficient than the piston-pump method because the latter is less effective in infusing fluids rapidly and associated with excessive positive and negative pressure in the infusion circuit. However, this method should be considered as first aid until a commercially available rapid transfusion and infusion system has been prepared.

Background

Fluid and blood need to be administered rapidly when unexpected blood loss has occurred. In this situation, manual syringing of fluid is often forced to increase the effect of a fluid load (piston-pump method) because this is a simple method and special preparation is not required [1, 2]. However, several problems have been pointed out in the piston-pump method. First, attempting a rapid push of the piston generates the excessive positive intravenous pressure, which is difficult to regulate and can lead to barotrauma [3–6]. Second, negative pressure occurs when withdrawing the syringe plunger before refilling, which may hemolyse red blood cells [1, 7]. Third, the effectiveness of increasing the flow rate of fluid administration has been reported to be variable [1, 2]. Finally, repeated pumping of the piston can cause bacterial contamination of fluids [8].

To increase the flow rate when rapid administration of fluids is necessary, use of a pressure infusor (pressure-infusor method) is simple alternative to the piston-pump method [1, 9]. Although time for attaching the fluid bag to a pressure infusor and inflating the infusor is required, the pressure-infusor

method enables to save labor during infusion. The excessive positive intravenous pressure occurs such as the piston-pump method but can be controlled in the pressure-infusor method. Therefore, we examined the effectiveness of increasing the flow rate of saline administration through an intravenous cannula, the circuit pressure and substitute-vessel pressure, and bacterial contamination using the piston-pump and pressure-infusor methods.

Methods

Ethical approval of the study protocol

The requirement for ethical approval was waived by the Ethics Committee of our hospital because no patients were involved in our study. Written informed consent to participate in the study was obtained from all participants.

Infusion circuit (Figure)

The infusion circuit consisted of a sterile 180-cm Sure-Plug® infusion set (content 10.7 ml; Terumo, Tokyo, Japan), including three-way taps for connecting a syringe and measuring circuit pressure, together with a 32-mm 16-G intravenous cannula (B.Braun, Melsungen, Germany). A 50-cm polyvinyl-chloride extension tube (ID 3.1 mm; Terumo, Tokyo, Japan), including a three-way tap for measuring the pressure, was used as a substitute vessel, and a 16-G intravenous cannula was spiked to it in a sterile manner. The infusion circuit and substitute vessel were primed with sterile 0.9% saline (Terumo, Tokyo, Japan). Then, a new 500-ml bag of 0.9% saline was spiked to the infusion circuit, and the total drop in height from the lowest part of the infusion bag to the intravenous cannula was 100 cm. Thirty-six infusion circuits were created. We took, in a sterile manner, 1 ml of 500 ml of saline and cultured the bacteria within it.

Bacterial culture

The samples were inoculated into the plates prepared with Standard Methods agar using aseptic techniques and mixed thoroughly. The plates were incubated at 36 ± 1 °C (mean \pm SD) for 7 days. During the incubation period, the plates were evaluated for bacterial growth every day and mixed daily. Final bacterial growth identification was carried out by standard reference methods.

Infusion time

Six male and six female anesthesiologists [age 37 ± 13 years] were classified randomly using a sealed-envelope method into two groups: piston-pump group (M:F = 3:3) and pressure-infusor group (M:F = 3:3). Anesthesiologists washed their hands with alcohol gel (Saraya, Osaka, Japan) before experimentation. Experiments were carried out in an operating room at room temperature (25 °C). Anesthesiologists In the piston-pump group pumped the piston with a 50-ml syringe (Terumo, Tokyo, Japan) as quickly as possible, and infused the remaining 499 ml of saline into a sterile 1-L beaker. In the pressure-infusor

group, anesthesiologists attached a pressure infusor (C-fusor®; Smiths Medical, Dublin, OH) to the fluid bag, inflated the infusor as quickly as possible to 300 mmHg, and infused the remaining 499 ml of saline into the beaker. They maintained 300 mmHg by intermittent insufflation of air throughout infusion. The time required to administer 499 ml of saline in each group was recorded. Each anesthesiologist in each group infused the saline successively thrice in the same fashion. The saline collected in the beaker was taken and bacterial culture was carried out. Other anesthesiologists blinded to the study aims infused 499 ml of saline by gravity from a height of 100 cm (gravity-fed infusion) with the same infusion circuit used in the present study and repeated it 10 times. The infusion time was measured.

Pressure in the circuit and substitute vessel

The pressure in each group was measured immediately upstream of the cannula and the distal end of the substitute vessel using pressure transducers (Edwards, Irvine, CA, USA) connected to the side port of the three-way tap. In addition, in the piston-pump group, the pressure was measured immediately upstream of the syringe because a negative circuit pressure was generated while pumping the piston. The pressure measurements (range, 0 to 200 or - 200 to 0 mmHg) were recorded by an Infinity Delta® monitor (Draeger, Telford, PA, USA) every 10 s until the end of each infusion. The anesthesiologists blinded to the study aims selected the maximum (or minimum) value of the circuit and substitute-vessel pressure from these records. If the maximum pressure was > 200 mmHg and < - 200 mmHg, these were calculated as 201 mmHg and - 201 mmHg, respectively.

Statistical analyses

The primary endpoint of our study was the time required to infuse 499 ml of saline. A minimum sample size was estimated on the basis of the time required for infusion. The time under gravity-fed infusion was 438 ± 10 s. A “clinically important change” was defined as an absolute change of 20%. Hence, minimum sample size of five was required to detect such a change with $\alpha = 0.05$ and $\beta = 0.2$. The infusion time and maximum circuit and substitute-vessel pressures were compared using the unpaired t-test. Also, we compared the infusion times at the first and third attempts of infusion in each group with a paired t-test. The result of bacterial culture was compared with the chi-square test. $P < 0.05$ was considered significant. Statistical analyses were carried out using StatView 5.0 (SAS Institute, Cary, NC, USA).

Results

It took 438 ± 10 s to infuse 499 ml of saline using gravity-fed infusion. The pressure-infusor group led to faster infusion of 499 ml of saline (233 ± 19 s) than the piston-pump group (301 ± 48 s) ($P < 0.01$). There was no significant difference in the infusion time between the first and third attempts in the pressure-infusor group (242 ± 24 s and 236 ± 12 s, respectively). However, in the piston-pump group, the infusion time at the third attempt was significantly longer than that at the first attempt (316 ± 43 s and 285 ± 53 s, respectively) ($P < 0.05$).

The maximum pressure in the infusion circuit was 131 ± 9 mmHg in the pressure-infusor group and > 200 mmHg in the piston-pump group: the latter was significantly higher than the former ($P < 0.01$). A

pressure of -200 mmHg or less occurred at all infusion attempts in the piston-pump group. Despite a high circuit pressure, the maximum pressure in the substitute vessel was 5 ± 1 mmHg and 17 ± 7 mmHg in the pressure-infusor and piston-pump groups, respectively. A significant difference in the substitute-vessel pressure was found between both groups ($P < 0.01$) but the clinical change was small. There was not bacterial infection of the saline solution before and after infusion attempts in both groups.

Discussion

The flow rate of saline through a 16-G intravenous cannula was most rapid with the pressure infusor, followed by the piston pump, and gravity-fed infusion. The approximate mean flow rate (in ml min^{-1}) in the pressure-infusor group and piston-pump group was 130 and 100, respectively. Use of the pressure infusor doubled the flow compared with that using gravity-fed infusion. However, a commercially available rapid-infusion system, such as the Level 1® H-1000 (Smiths Medical, Dublin, OH), can infuse more than 400 ml min^{-1} of fluids rapidly when used in conjunction with a 16-G intravenous cannula [10]. Anesthesiologists should change to this system if it can be prepared.

Smart et al. [1] and Stoneham [9] reported that the flow rate of saline through a 16-G intravenous cannula was 240 ml min^{-1} and 340 ml min^{-1} using a pressure infusor at 300 mmHg, respectively, which are not in accordance with our results. They used an infusion circuit that was similar to the one that we employed, but they did not use a substitute vessel. The substitute-vessel pressure was remarkably lower than the circuit pressure because it was downstream of the resistance of a thin intravenous cannula. We considered that the combination of lower substitute-vessel pressure and the resistance of a substitute vessel could have affected considerably the flow rate. In the Stoneham's study, the flow rate by gravity from a height of 100 cm (which was the same height used in our study) was 190 ml min^{-1} , compared with 70 ml min^{-1} in our study. A difference in the flow rate by gravity may support our opinion. We believe that the result in the present study is close to the flow rate seen in the clinical setting.

Regarding the piston-pump method, previous investigators have demonstrated that a modification of the standard method by placing a one-way valve both upstream and downstream of the three-way tap can increase a flow rate of fluids because of no necessity for turning the three-way tap during syringing of fluid [1, 2]. O'Callaghan et al. [2] have clarified that the modified method allows administration of 500 ml saline an average of one minute more quickly, compared with the standard method. As for rapid infusion of fluids, this method may be a useful alternative if the pressure infusor is not available.

Among the piston-pump groups, the infusion time at the third attempt of infusion was significantly longer than that at the first attempt. A possible reason for the variation in infusion time is the fatigue elicited by infusing 500 mL of saline three times successively because this task was hard work. Also, increased friction due to repeat pumping of the piston may cause the variation because of use of the same syringe when infusing 500 mL of saline thrice. Further studies are needed. The effort devoted to pumping by the anesthesiologist when unexpected massive bleeding, which is a life-threatening emergency situation, occurs is another cause for concern in this method. Conversely, in the pressure-infusor method, the

variation in the infusion time was not observed when infusing 1500 mL of saline, which was an obvious advantage of the pressure-infusor method.

The circuit pressure in the pressure-infusor group was significantly lower than that in the piston-pump group. The maximum pressure was ~ 150 mmHg in the pressure-infusor group, which was approximately identical to the systolic arterial pressure. The pressure of the substitute-vessel, which was a polyvinyl-chloride extension tube, was as low as 5 mmHg in the pressure-infusor group. Venous pressure will be lower than it because the vein wall is much more flexible than the polyvinyl-chloride substitute-vessel. In the piston-pump group, the maximum circuit pressure was too high to measure in this study. Smart et al. [1] have demonstrated that the piston-pump method generates more than 600 mmHg when attempting rapid push of the piston, which can cause barotrauma. In contrast, the substitute-vessel pressure was less than 20 mmHg. Thus, neither the piston-pump method nor the pressure-infusor method will cause barotrauma. However, there have been some case reports of extravasation and compartment syndrome resulting from pressurized infusion [3–6]. Moreover, even if the cannula is placed appropriately in a vein and the proximal run-off from the vein is occluded, the venous pressure can increase markedly [11]. Thus, intravenous sites should be checked closely if using both the piston-pump and pressure-infusor methods.

A unique problem in the piston-pump method was excessive negative pressure (< -200 mmHg) when withdrawing the syringe plunger before refilling. Use of the pressure infusor can avoid this problem. Negative pressure can hemolyze red blood cells. Studies have shown that hemolysis is not caused by negative pressure alone [1, 7]. However, Pohlmann et al. [7] demonstrated a combination of negative pressure and an air-blood interface to be associated with hemolysis. Thus, anesthesiologists should be careful not to mix air in blood when using the piston-pump method.

Although anesthesiologists undertook repeat pumping of the piston in a 50-ml syringe more than 10 times to infuse 499 ml of saline, bacterial contamination of the infused saline was not observed in this study. Huey et al. [12] showed that bacteria were not detected in the drainage after five reciprocations by grasping the protruding part of a disposable-syringe plunger with dry hands that were not disinfected; their data are consistent with our results. Conversely, Blogg et al. [8] demonstrated bacterial contamination of syringe contents after repeated refilling. Bacterial contamination of a syringe may not always result in bacterial contamination of fluids. In addition, we used a Terumo 50-ml syringe but the risk of bacterial contamination may differ if other types of syringes are employed.

Conclusions

If fluids must be administered rapidly, use of the pressure-infusor method is more efficient than that of the piston-pump method because the latter is less effective in infusing fluids rapidly and associated with excessive positive and negative pressure in the infusion circuit. However, this method should be considered as first aid until a commercially available rapid transfusion and infusion system has been prepared.

Abbreviations

Standard deviation
SD.

Declarations

Ethics approval and consent to participate

The need for ethical approval was waived by the Institutional Ethical Committee because no patients were involved in this study. Informed consent to participate in the study was obtained from all participants.

Consent for publish

Not applicable.

Availability of data and materials

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

We have declared that we have no competing interests.

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Authors' Contributions

Wataru Hashimoto performed the experiments, analyzed the data, and drafted the manuscript.

Ichiro Takenaka conceived, designed, performed the experiments, analyzed the data, and drafted the manuscript.

Keisuke Yasunami performed the experiments and contributed materials and analysis tools.

Tomoko Minami performed the experiments and contributed materials and analysis tools.

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Tables

Due to technical limitations, the table is only available as a download in the supplemental files section.

Figures

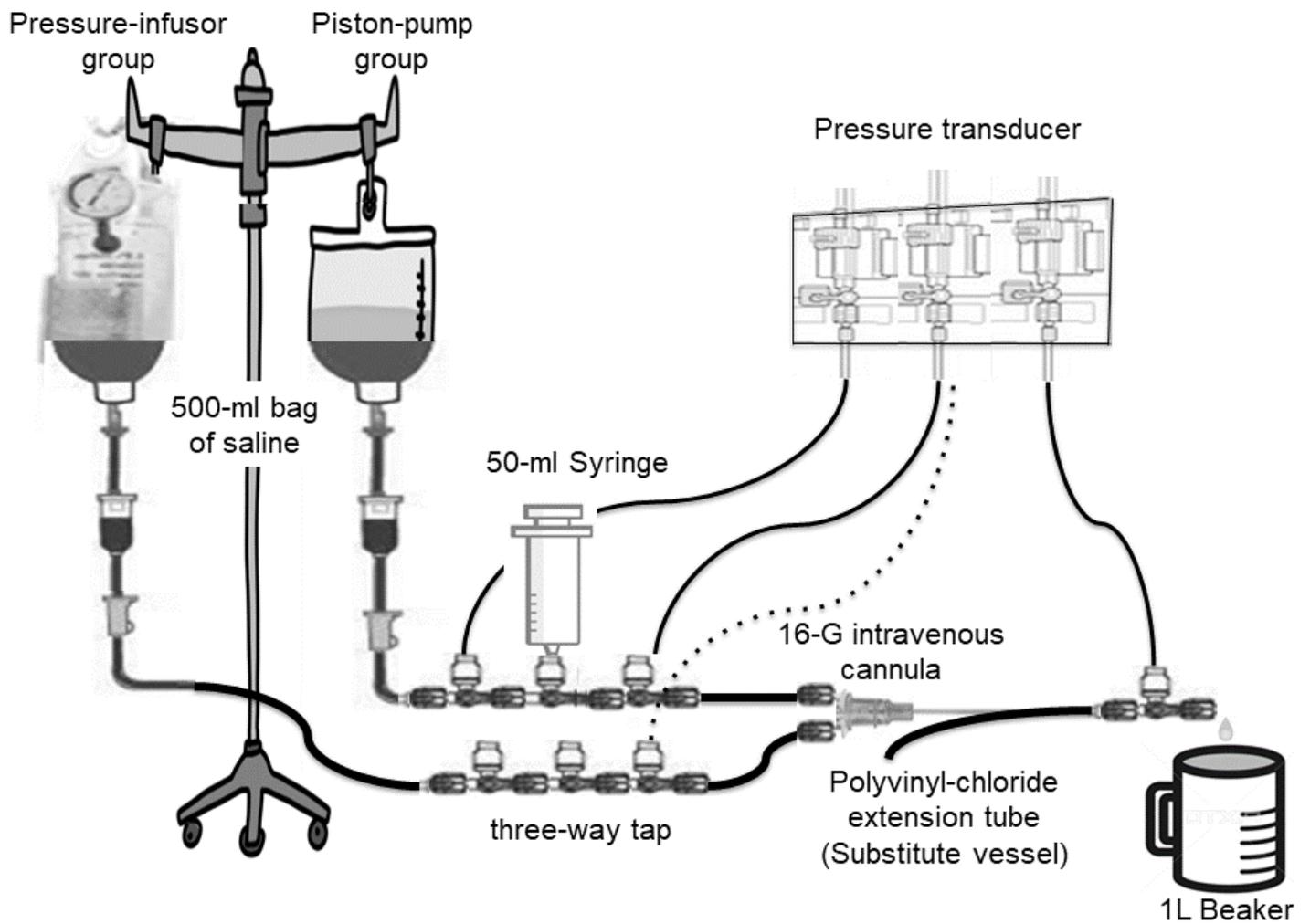


Figure 1

Diagram of infusion circuit and substitute vessel in the piston-pump and pressure-infusor groups

Supplementary Files

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