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EDITED BY
Juan Victor Lorente,
Hospital Juan Ramón Jiménez, Spain

REVIEWED BY
Dalia Perkumiene,
Vytautas Magnus University, Lithuania
Hongwei Ning,
Anhui Science and Technology University, China

*CORRESPONDENCE
Jerome Belford,
jeromebelford2@gmail.com

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Innovative efficient approaches to (IV) fluid administration: the role of multiple (IV) lines in enhancing flow rates

Slawomir Oleszak, Jerome Belford*, Daryn Moller, Ralph Epstein, Jason Lee and Sergio Bergese

Department of Anesthesiology, Stony Brook University Medical Center, Stony Brook, NY, United States

Fluid therapy is essential for maintaining circulatory homeostasis and ensuring adequate oxygen delivery to tissues during surgery and certain traumatic conditions. According to Poiseuille's Law, flow rate is influenced by pressure gradient, tubing radius, tubing length, and fluid viscosity; however, clinical situations often necessitate the use of smaller gauge catheters (for example, 20-gauge) due to poor vein quality or limited access, which significantly reduces flow. The main goal of this study was to develop a means of improving rates of fluid resuscitation in such situations. Conventional strategies, such as high-pressure infusion devices, can increase flow but also carry risks including venous rupture and air embolism. In this laboratory-based study, we investigated whether connecting multiple IV systems to a single catheter could improve flow rates in scenarios where catheter gauge size is limited. We hypothesized that adding IV systems would improve flow rates in accordance with Poiseuille's law. Using 16-gauge, 18-gauge, and 20-gauge catheters (internal diameter 16G (gauge) ≈1.7 mm; 18G, ≈1.3 mm; 20G, ≈1.0 mm) at three different heights (110 cm, 140 cm, 170 cm), we compared flow achieved with one, two, or three IV systems to that produced by a pressure bag set at 250 mm of mercury (millimeters of mercury (mmHg)). Our findings demonstrated that multiple IV systems significantly increased flow rates; for example, with a 20-gauge catheter at 110 cm, the flow rate increased from 38.87 mL per minute (mL/min) with a single pressured system to 45.25 mL/min using three gravity-fed systems—an improvement of approximately 16.4%. Similar enhancements were observed across other catheter sizes and heights. These results suggest that using multiple IV systems can provide a practical, lower-risk alternative to pressurized infusion for situations requiring rapid resuscitation, especially in patients with difficult access or fragile veins. Further clinical trials are warranted to validate these findings and assess their applicability in real-world settings.

KEYWORDS

intravenous fluid therapy, fluid resuscitation, rapid fluid administration, Poiseuille's law, multiple IV systems

Introduction

Perioperative fluid therapy entails the replacement of preexisting fluid deficits, administration of maintenance fluids, and replacement of surgical losses. [1]. Compensatory intravascular volume expansion (CVE) counteracts venodilation and cardiac depression from anesthesia as well as the hemodynamic effects of positive-pressure ventilation. Current vascular access options for rapid fluid administration include large-bore peripheral IV catheters (14G, 16-gauge (16G)), central venous catheters (central venous catheters (CVCs)), intraosseous (IO) access, and specialized rapid infusers. These options may not always be feasible due to poor venous access, patient condition or availability [2, 3]. CVCs and introducer sheaths offer higher flow rates but involve more invasive procedures and higher risk of complications such as venous thromboembolism and other major complications [4]. IO access provides an alternative in emergency situations but is typically a temporary measure [5].

Additional limitations to intravenous access for patients are due to factors such as poor vein quality, limited number of veins, patient positioning, and surgical coverings, making it difficult to gain access [6]. These challenges are particularly acute in emergency situations involving unexpected bleeding or when rapid fluid resuscitation is required due to acute trauma. [7]. There exist devices such as the power infuser which provide rapid fluid administration and have been associated with a reduction in length of patient Emergency Department (ED) stay, morbidity and cost accrued by both the hospital and patient [8]. Despite its utility, power infusers are not typically found in small ambulatory units and the associated tubing system can be very costly [9].

The objective of this study was to determine whether connecting multiple intravenous (IV) systems to a single catheter can enhance flow compared to both single gravity-fed and pressure-infused systems. We hypothesized that adding IV systems would improve flow rates in accordance with Poiseuille's law.

Poiseuille's Law, which governs the flow of fluids through cylindrical tubes, describes how factors such as the radius of the tube, fluid viscosity, and tube length influence flow rate. The flow rate is directly proportional to the pressure gradient, the fourth power of the tube's radius and inversely proportional to its length and the fluid's viscosity [10]. While many studies have examined the impact of variables like gravity, angiocath diameter, and length on flow rates, no research has yet explored the effect of adding multiple IV systems to a single angiocath [11]. Our study aims to fill this gap by comparing the flow rates from multiple IV systems to those from a single IV column, as well as comparing these to the flow rate achieved by a single IV column under pressure from a pressure bag. We hypothesize that increasing the number of IV systems connected to a single angiocath by 3 stopcocks will result in a higher flow rate. This hypothesis is grounded in the understanding that adding more IV systems increases the effective cross-sectional area for fluid flow and pressure gradient, thereby reducing resistance and enhancing flow rate as predicted by Poiseuille's Law (Equation 1). To test this, we first compared the flow rates of multiple IV systems with those of standard gravity-fed IV lines.

$$Q = (\pi \Delta P r^4)/(8 \eta L) \tag{1}$$

where Q is flow rate, ΔP is the pressure difference, r is the internal radius of the tube, η is the viscosity of the fluid, and L is the length of the tube.

Our study will measure the flow rate at increasing number of IV systems and compare this to the flow from a single system with a pressure of 250 mmHg given by pressure bag. This study will have several different scenarios serving as controls, with fixed angiocath diameter and height. The variable that will be changed will be the number of IV systems and this will be measured in different scenarios and compared to the flow given by pressure bag in each scenario. Additionally, we measured the pressure generated from each specific scenario at the level of the angiocath to determine how increasing the number of systems impacts pressure generated. This study is being done without patient involvement; flow will be measured through an open canister.

Methods

Study design

This study is a laboratory-based experimental design aimed at comparing the flow rates of IV saline fluid delivered through different numbers of IV systems connected to a single angiocath, with the flow rate increased by height and compared to that delivered by a pressure bag set to 250 mmHg. The study will use a controlled environment to simulate the conditions under which fluids are administered to patients in clinical settings.

The equipment and materials used in this study included an angiocath (16-gauge [G], internal diameter ≈1.7 mm; 18G, ≈1.3 mm; 20G, ≈1.0 mm; gauge refers to the external diameter of the catheter, with smaller gauge numbers corresponding to larger internal diameters), standard IV tubing (60 drops/mL, 2.9 m), 500 mL 0.9% saline solution bags, a pressure bag set to 250 mmHg, a manifold port with 2–6 stopcocks (Discofix 4-way stopcock), a plastic canister for fluid collection, and a stopwatch. We first set up the manifold and connected multiple IV systems to it. Two tube extensions were connected from the manifold. We hung 500 mL saline solutions from an IV pole and measured the height from the end of the chamber to the end of the angiocath in the plastic cannister. We then chose a single angiocath diameter and kept both height and diameter constant while we changed the number of IV systems. For the second component of the study, we used a pressure bag to infuse the 500 mL saline bag under 250 mmHg of pressure and held it. We allowed this system to flow completely and measured the time it took and from this calculated the flow rate.

Additional experimental details: Tubing length was fixed at 2.9 m with an internal diameter of approximately 3 mm (manufacturer specification). The viscosity of 0.9% saline at room temperature (22 °C–24 °C) is approximately 0.89 centipoise (cP). Stopcocks used were Discofix 4-way stopcocks with an internal bore of ~2.5 mm. All experiments were performed at room temperature to ensure consistent fluid properties.

We then repeated the same measurement without the pressure bag. We then connected to three open IV systems flowing through a single angiocath. The above process was repeated in different scenarios with different heights and angiocath diameters being kept constant while the number of IV systems were varied. The

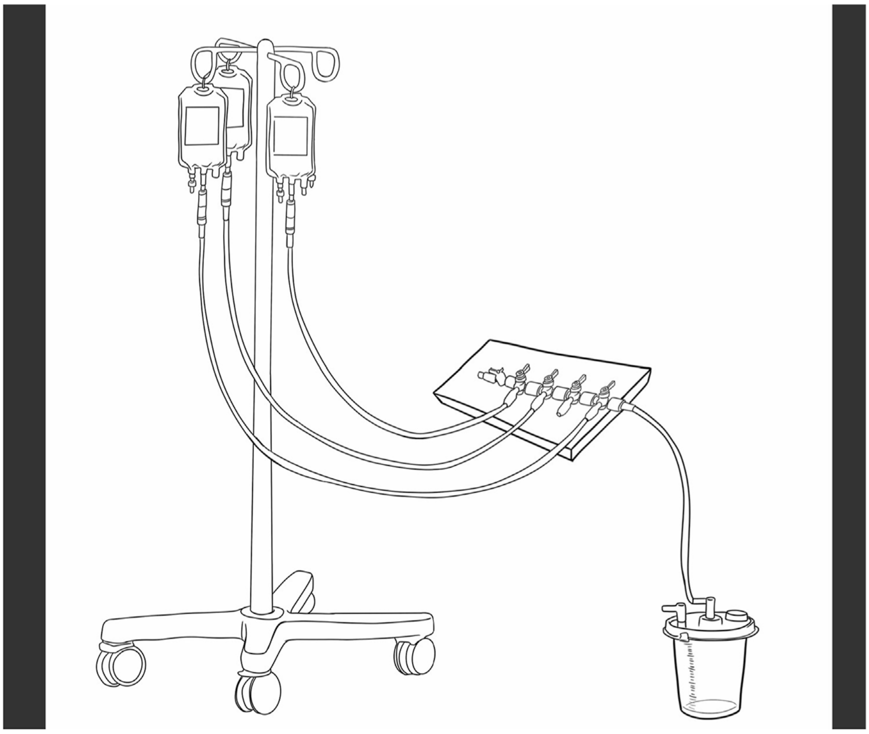

FIGURE 1
Experimental setup demonstrating the use of multiple IV systems connected via a manifold to a single angiocath, delivering fluid to a plastic cannister. Illustrated by Taka Nah Jelah.

experimental setup is depicted in Figure 1. Finally, we measured the pressure generated at the level just before endpoint of the angiocath in each specific scenario. This was done by vertically connecting two arterial line extensions to the stopcock and measuring the pressure generated in cm H_2O (centimeters of water pressure).

Results

Across all catheter gauges and heights, flow rate increased systematically with the addition of each IV system. Results are therefore presented by catheter size to allow for clear comparison with the 250 mmHg pressure-bag control.

We first analyzed the results from the condition of the 20 gauge (G) angiocath at a height of 110 cm. The flow rate of the single 500 mL saline solution with 250 mmHg pressure added from a pressure bag revealed a rate of 38.87 mL/min (Figure 2). Flow rates for 1,2 and 3 systems were as follows 26.65 mL/min, 39.02 mL/min and 45.25 mL/min (Figure 2). We next looked at the condition of the 20G angiocath at a height of 140 cm. The flow rate of a single 500 mL saline solution with 250 mmHg added from a pressure bag was 48.83 mL/min (Figure 2). Flow rates for 1,2 and 3 systems were as follows 32.95 mL/min, 47.23 mL/min and 54.03 mL/min (Figure 2). With the 20G angiocath we last looked at the results from the height of 170 cm. The flow rate of a single system with 250 mmHg added from a pressure bag was 62.53 mL/min (Figure 2). Flow rates for 1,2 and 3 systems were as follows 39.58 mL/min, 54.91 mL/min and 62.90 mL/min (Figure 2).

We next analyzed the results of the 18-gauge (18G) angiocath in various conditions. We first started with the 18-gauge (18G) angiocath with a height of 110 cm. The flow rate of the 500 mL saline solution with 250 mmHg via pressure bag was 46.87 mL/min (Figure 3). The flow rates for 1,2 and 3 systems were as follows 29.32 mL/min, 47.09 mL/min and 55.97 mL/min (Figure 3). We next looked at the results from the height of 140 cm. The flow rate of a single system with 250 mmHg added via pressure bag was 63.32 mL/min (Figure 3). The flow rates for 1,2 and 3 systems were as follows 36.76 mL/min, 59.06 mL/min and 71.89 mL/min (Figure 3). Finally we looked at the results at 170 cm. The flow rate of a single system with 250 mmHg added via pressure bag was 67.39 mL/min (Figure 3). The flow rates for 1,2 and 3 systems were as follows 40.22 mL/min, 65.53 mL/min and 78.66 mL/min (Figure 3).

The last angiocath analyzed was the 16G, results were obtained in various conditions. We first started with a height of 110 cm. The flow rate of the single 500 mL saline solution with 250 mmHg added via pressure bag was 58.07 mL/min (Figure 4). Flow rates for 1,2 and 3 systems were as follows 31.88 mL/min, 56.58 mL/min and 67.66 mL/min (Figure 4). We next looked at the results from 140 cm. The flow rate of a single 500 mL saline solution with 250 mmHg via pressure bag was 72.19 mL/min (Figure 4). Flow rate for 1, 2 and 3 systems were 37.36 mL/min, 65.74 mL/min and 87.00 mL/min (Figure 4). Finally we looked at the 16G at a height of 170 cm. Flow rate of a single system with 250 mmHg added via pressure bag was 73.11 mL/min (Figure 4). The flow rates for 1, 2 and 3 systems was 40.57 mL/min, 71.92 mL/min and 92.12 mL/min (Figure 4).

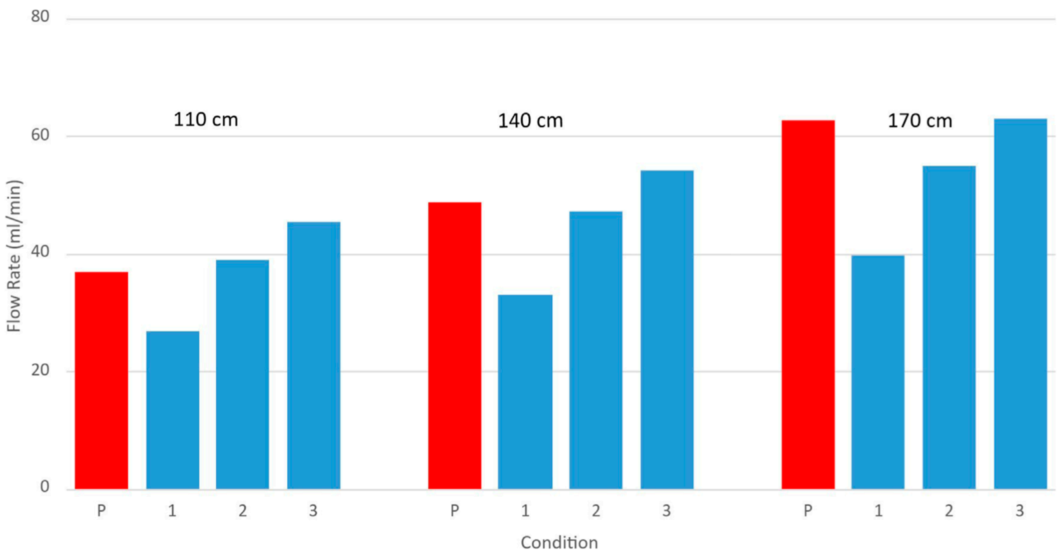

FIGURE 2
Flow rates (cc/min) through a 20-gauge (20G) angiocath at three different heights (110 cm, 140 cm, and 170 cm), comparing a pressure bag at 250 mmHg (P) to one, two, and three IV systems.

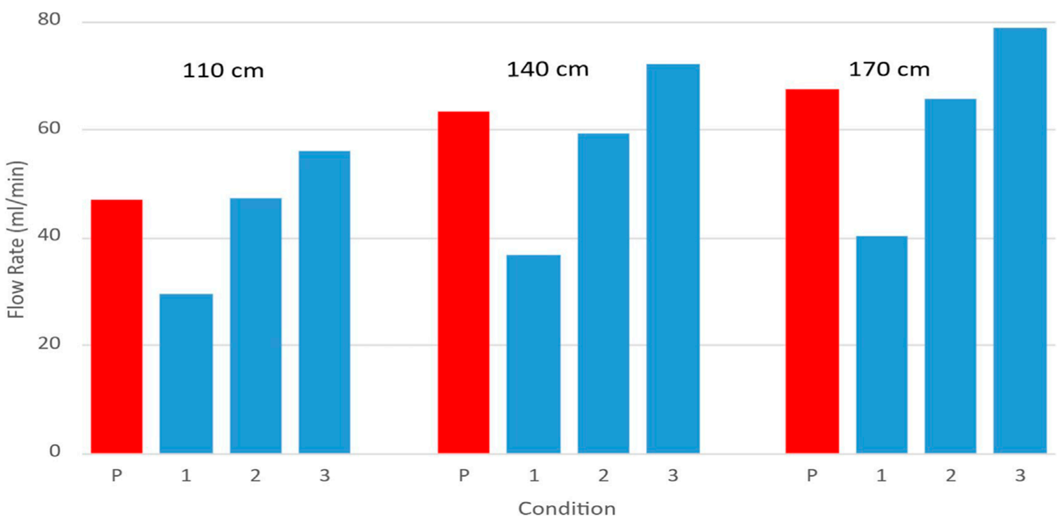

FIGURE 3
Flow rates (cc/min) through a 18-gauge (18G) angiocath at three different heights (110 cm, 140 cm, and 170 cm), comparing a pressure bag at 250 mmHg (P) to one, two, and three IV systems.

Overall, multiple gravity-fed IV systems achieved flow rates comparable to, and in some cases exceeding, those produced by pressurized infusion. This trend was consistent across all catheter sizes and heights tested.

Discussion

Our study aimed to investigate the effect of using multiple IV systems connected to a single manifold had on fluid flow rates, compared to the flow rate achieved by a pressure bag set at 250 mmHg. We found that increasing the number of IV systems can achieve flow rates that are similar or surpass those provided by a pressure bag, with the highest flow rates observed when three IV systems were used. Specifically, with a 20G angiocath at a height of 110 cm, the flow rate increased from 38.87 mL/min with one IV system under pressure to 45.25 mL/min with three IV systems without pressure. This pattern was consistent across different heights and angiocath sizes. For instance, with an 18G angiocath at a height of 140 cm, the flow rate increased from 63.32 mL/min with one pressured IV system to 71.89 mL/min with three IV systems without pressure. Similarly, with a 16G angiocath at 170 cm, the flow rate increased from 68.60 mL/min with one pressured IV system to 92.12 mL/min with three IV systems without pressure.

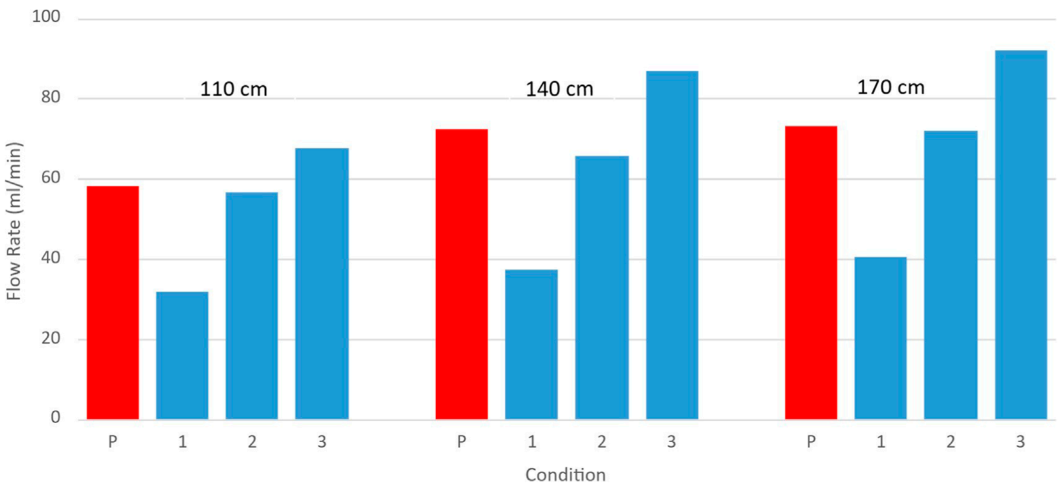

FIGURE 4
Flow rates (cc/min) through a 16-gauge (16G) angiocath at three different heights (110 cm, 140 cm, and 170 cm), comparing a pressure bag at 250 mmHg (P) to one, two, and three IV systems.

While previous studies [12, 13] have quantified the effects of catheter diameter and height on flow, none have evaluated whether increasing the number of IV systems connected to a single catheter can overcome the limitations imposed by smaller gauges. Addressing this gap formed the basis of the present study. Our findings provide new insights into fluid resuscitation methods, suggesting that using multiple IV systems can be an effective alternative to pressure infusers. This is particularly relevant in clinical situations where high pressure might pose risks, such as in patients with fragile veins or certain medical conditions [14]. The clinical implications of our findings are significant. In scenarios requiring rapid fluid resuscitation, such as massive hemorrhage or trauma, the use of multiple IV systems can potentially enhance fluid delivery rates while minimizing the risks associated with high-pressure infusers This method could be particularly beneficial in situations where IV access is limited or when it is critical to avoid the complications associated with high infusion pressures. Complications associated with high infusion pressure can include air emboli and vein rupture [15]. Venous air embolism due to pressurized IV fluid administration has been reported in specific case reports [16].

This method of increasing flow rates is also notable for its accessibility. Pressure infusers require specialized equipment and constant monitoring [17]. Multiple IV systems can be implemented using standard equipment found in most clinical settings. This makes the approach particularly suitable for mild-to-moderate fluid resuscitation in settings with limited resources or barriers to IV access, such as poor vein quality or a limited number of available IV lines.

Interestingly, our findings challenge common assumptions about fluid administration. Prior to this study, it was not intuitive to think that increasing the number of systems connected to a single IV line would improve flow rates. Conventional wisdom would suggest that such an arrangement might introduce additional resistance or inefficiencies. However, our results demonstrate that adding more IV systems can effectively increase the pressure gradient which increases fluid flow and reduces resistance, as predicted by Poiseuille's Law (Equation 1).

The principles of viscosity and laminar flow, as described by Poiseuille's Law, are fundamental to understanding fluid movement through intravenous catheters [18]. The law states that the flow rate Q of an incompressible and Newtonian fluid in a long cylindrical pipe (such as an IV catheter) is directly proportional to the fourth power of the radius (r) of the tube and the pressure difference (P1 – P2) and inversely proportional to the fluid's viscosity (η) and the length of the tube (L). (Equation 1) [10] our findings align with Poiseuille's Law by both the concepts of increasing pressure gradient and reducing resistance. By increasing the number of IV systems this will increase the pressure gradient through which the fluid flows. This increase in pressure gradient explains the boost in flow rate. Additionally, the use of multiple IV systems reduces the overall resistance by providing parallel pathways for fluid to flow. The fact that multiple IVs system can achieve flow rates similar to those produced by a pressure bag at 250 mmHg with much lower measured pressure cannot be fully explained by Poiseuille's Law, we postulate that other factors are contributing to this increased flow, possibly explained by Bernoulli's equation and requires further investigation.

This study was conducted in a controlled laboratory environment, which does not fully replicate clinical variability in venous compliance, patient movement, or fluid viscosity. Although we used saline to model flow, fluids with different viscosities may yield varying results. The setup also did not simulate patient anatomy or external resistance from soft tissue. These factors should be addressed in future *in-vivo* studies. We were concerned that our system, especially three systems, could generate higher pressures than 250 mmHg pressure bag. To address these concerns, we measured the pressure in various conditions, and found for the 20G catheter at 170 cm, the pressure generated for three IV systems (the highest-pressure gradient situation in all our experiments without pressure bag) was much lower than the pressure generated from the 250-mmHg pressure bag (Figure 5).

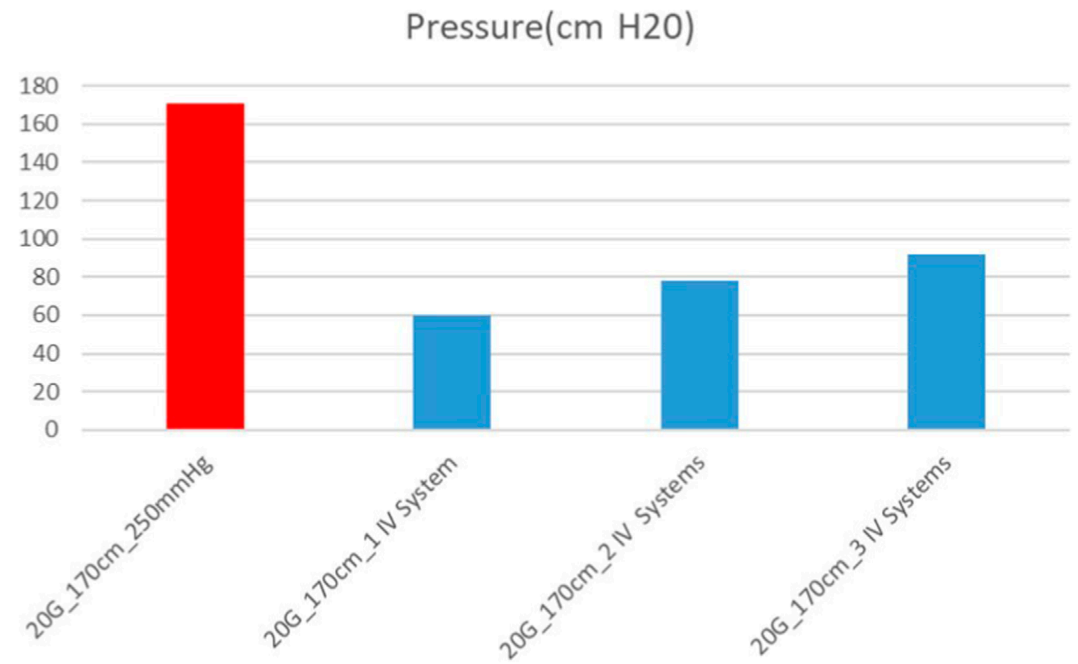

FIGURE 5
Pressure Measurements for 20-gauge (20G) catheter at 170 cm, comparing pressure generated from 250 mmHg pressure bag, to one, two and three IV systems.

Future research should include clinical trials to validate our findings in real-world settings. It would be valuable to explore the use of multiple IV systems in different patient populations and surgical scenarios to determine their effectiveness and safety in clinical practice. Additionally, studies could investigate the optimal configurations and combinations of IV systems to maximize fluid delivery rates without compromising patient safety and adding undue complexity.

In conclusion, this study demonstrates that connecting multiple IV systems to a single catheter can substantially increase flow while maintaining safe pressure levels. This approach offers a practical, low-cost alternative to pressure infusers, particularly useful in settings where catheter gauge or equipment availability limits flow. Broader clinical validation is warranted to confirm its effectiveness across patient populations and care environments.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

SO: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Writing – review and editing. JB: Data curation, Investigation, Writing – original draft, Writing – review and editing. DM: Writing – review and editing. RE: Writing – review and editing. JL: Writing – review and editing. SB: Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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