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ORIGINAL RESEARCH

Control Volume Analysis of the Infusion Rate in Cephalic and Median Cubital Veins Based on Infusion Bag Height and Peripheral Venous Catheter Inner Diameter: Application of Bernoulli's Equation and Consideration of Frictional Forces

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Purpose: This pilot study aimed to provide basic data on intravenous infusion nursing by analyzing the infusion rate in the cephalic and median cubital veins depending on the height of the infusion bag and inner diameter of the peripheral venous catheter (PVC).
Methods: While infusing 0.9% normal saline at 22 °C (room temperature) into elbow cephalic and median cubital veins, the infusion rate may be controlled by adjusting the fluid height and PVC diameter. To assess the validity of the laminar flow assumption, the study estimated the Reynolds number (Re) using the velocity obtained by applying Bernoulli's equation considering the friction coefficient.
Results: At a constant fluid height, the infusion rate increased with increasing PVC diameter. At a constant PVC diameter, the infusion rate increased with increasing fluid height. In a comparison between the cephalic and median cubital veins at constant fluid height and PVC diameter, the solution was infused at a higher rate into the cephalic vein, which was under lower venous pressure.
Conclusion: The analysis of the infusion rate according to fluid height and PVC diameter provided basic data on intravenous infusion nursing. The results are expected to provide evidence for the standardization of intravenous infusion nursing.
Keywords: catheterization, infusions, intravenous, nursing, patients

Introduction

With the rapid advancements in medicine and development of new treatments, the use of intravenous therapy has expanded in recent years. Intravenous therapy, which directly supplies blood and fluid intravenously, has such advantages as complete drug absorption, maintenance of fluid and electrolyte balance, and supply of nutrients, leading to its administration in various forms in more than 80% of inpatients.[1] Indeed, more than 85% of direct nursing activities are associated with drug administration, measurement, and observation,[2] with intravenous therapy accounting for the greatest proportion of clinical nursing tasks and time. The nursing practice guidelines for intravenous therapy recommend the 20- to 24-gauge peripheral venous catheter (PVC) in general, the 22- to 24-gauge PVC in older adults to minimize insertion-related injuries, and the 16- to 18-gauge PVC when rapid fluid replacement is required.[1] For the provision of an optimal amount of fluid, emphasis is also placed on the assessment of the location of the peripheral vein, gauge of the catheter, condition of the vein, and blood flow rate.[3]

According to data reported in the United States, approximately 55% of patient safety incidents in medical facilities are related to medication errors, with errors in infusion rates accounting for about 29.8% of medication incidents.[4] In this regard, many healthcare institutions and guidelines recommend that nurses increase their patient rounds and regularly check infusion rates to ensure accurate fluid administration. They also suggest using infusion controllers or pumps to prevent medication

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errors when adjusting fluid rates.[5] Furthermore, in clinical practice, flow regulators for controlling fluid rates were introduced in the 1970s to regulate the infusion rates for patients. However, the displayed rates on these regulators often do not match the actual infusion rates, leading to a lack of trust among medical professionals who use them in real-world situations. Previous studies have reported that flow regulators can be influenced by various factors, potentially leading to inaccurate flow rates.[6] Previous studies have also reported that the infusion rates of fluids can vary due to physical characteristics such as the unspecified fixed height of fluids,[7] concentration of the solution,[5] and temperature of the fluids,[8] factors that have not been specifically outlined in practical guidelines. Ultimately, peripheral intravenous fluid therapy requires consideration not only of the physical attributes of fluids but also evidence-based factors such as the regional venous pressure for maintaining smooth fluid administration and patient safety.

In existing nursing practice guidelines, only PVC size and vein selection are presented as important factors to consider; in practice, however, considering only these factors would limit clinical nurses' ability to predict and adjust the exact amount of infusion. To maintain an optimal infusion rate, nurses should consider various factors, including the height of the infusion bag, connection type, frictional force, and intravascular pressure.[9] Therefore, the height of the infusion bag and inner diameter of the PVC must be considered when estimating the flow rate of the fluid infused into the cephalic and median cubital veins. A fluid dynamics approach is considered an effective way to accurately predict the infusion rate when planning infusion. From the perspective of fluid dynamics, all materials are classified into fluids and solids. Fluids can be described as materials whose stress can be measured numerically or quantitatively according to shear stress under the assumption that fluids are continuum materials in mechanical engineering.[10] As such, this study used Bernoulli's equation considering friction force in the estimation of flow rate.

Materials and Methods

Study Design

This pilot study is designed by analyzing the infusion rate in the cephalic and median cubital veins depending on the height of the infusion bag and inner diameter of the PVC. To this end, we set the following objectives:

1) to set the control volume for the analysis of the flow rate of the fluid infused into the cephalic and median cubital veins depending on the height of the infusion bag and inner diameter of the PVC;
2) to formulate the Bernoulli equation considering frictional force under the assumption of laminar flow;
3) to determine the infusion rate depending on the PVC inner diameter at a fixed fluid height when 0.9% normal saline is infused into the elbow cephalic and median cubital veins at 22 °C (room temperature);
4) to assess the validity of the laminar flow assumption by determining the Reynolds number (Re) at the flow rate derived using the Bernoulli equation considering the friction coefficient.

Composition of the Control Volume Analysis

The Composition of the control volume analysis of this study is shown in Figure 1, and the specific details are as follows.

(1) Fluid

For fluid analysis, we used 0.9% normal saline. Considering that the density and viscosity of a fluid change with temperature,[10] the results may vary depending on the temperature set for the analysis. In this study, the temperature for 0.9% normal saline was set at room temperature (22 °C), which is commonly used in clinical practice.

(2) Height of the infusion bag

We set the height (h) of the infusion bag as the value from the patient's bed to the midpoint of the drip chamber, which ranges from 0.8 to 1.5 m, increasing by increments of 0.1 m. The infusion bag changes its shape over time, and a decrease in the fluid volume per hour leads to a decrease in the flow rate. However, considering that the spike of the

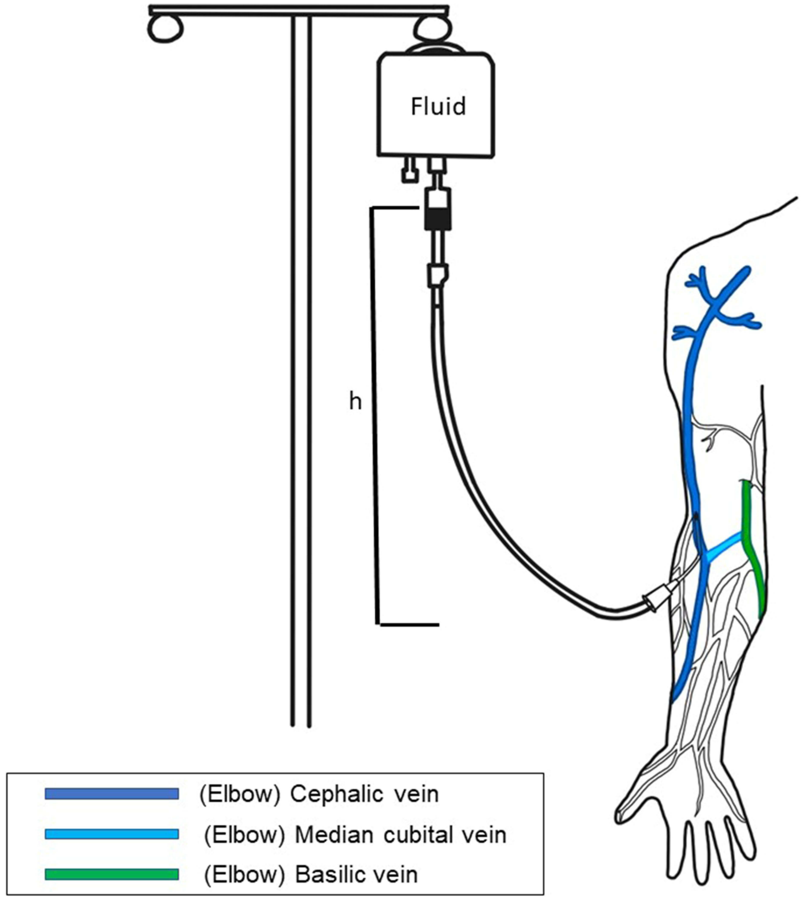

Figure 1 Composition of the control volume analysis.

standard infusion set is designed to pass a constant flow rate, a constant flow rate is supplied to the drip chamber regardless of the amount of remaining solution in the bag (KSCI, 2022). However, approaching the flow analysis of the fluid flowing into the drip chamber with the Bernoulli equation has limitations. Moreover, we focused on the flow characteristics according to the height of the infusion bag. Thus, we defined the 1/2 height of the drip chamber as point 1 of the Bernoulli equation, which can be considered the steady state.

(3) Infusion set

The length of the drip chamber was set to 4 cm, the maximum length of the standard infusion set (length: 150 cm) specified in the Korean Standard (KS P 8004). We set the drip chamber and tube inner diameters, which are not specified in either the Korean standard or manufacturer's specifications, to 1.81 and 1.30 mm, respectively.

(4) Peripheral venous catheter

We used 14G, 16G, 18G, 20G, 22G, 24G, and 26G PVCs (GST Corporation Limited); we used the inner diameter and length of each catheter for analysis. Although the catheter inner diameter through which the fluid flows is important for pipe flow analysis, most manufacturers provide only the outer diameter without specifying the inner diameter. Therefore, we referred to the range of the inner diameter (0.45 to 1.74 mm) presented by the manufacturer (GST Corporation Limited) of PVCs that meet the ISO standard (EN ISO 13485:2012), with the length of the catheter ranging from 19 to 45 mm.

(5) Peripheral vein

The elbow cephalic and median cubital veins, which are frequently used for intravenous fluid administration, were chosen as the veins through which the infusion enters the body, and the venous pressures at rest in the supine position in healthy adults were applied: cephalic vein, 951.2 Pa; median cubital vein, 1010 Pa.[11]

(6) Connection between standard infusion set and PVC

The system we used comprised three points, as indicated by circled numbers in Figure 1: Point 1, the level of the fluid within the drip chamber (mid-length of the drip chamber); Point 2, the end of the standard infusion set connected to the PVC; Point 3, the end of the PVC. The standard infusion set and PVC are connected in series. Points 1 to 3 are used as subscripts 1 to 3 in the upcoming equations.

Governing Equations

For the application of the Bernoulli equation, we assumed that the prior conditions of steady state, incompressibility, and absence of external heat transfer were satisfied. In this study, the working fluid was liquid saline, which has a negligible change in density within the velocity range we set. As such, the assumption of incompressibility stands to reason. The amount of external heat transfer is also negligible in the nurses' work environment. Although the droplet flow in the drip chamber is associated with a non-steady state element, the affected area has a locally limited influence relative to the entire system. Thus, the assumptions made for the application of Bernoulli's equation considering frictional force were considered applicable to the nurses' work environment. ()Subscript 1 of (Equation 1) represents the mid-length of the drip chamber; subscript 2, the end of the tube of the infusion set; and subscript 3, the end of the PVC. In the continuity equation, (Equation 1), A_1V_1, A_2V_2 and A_3V_3 denote the volume flow rates at the 1/2 point of the drip chamber point, end of the drip tube, and end of the PVC, respectively. Here, A represents the cross-sectional area of drip chamber, and V is the mean velocity in the direction perpendicular to the cross-section. By determining the inner diameter at each point, we could calculate the velocity of the fluid passing through each point.

$$A_1V_1 = A_2V_2 = A_3V_3 \tag{1}$$

$$\frac{P_1}{\rho g} + \frac{\alpha {V_1}^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{\alpha {V_2}^2}{2g} + z_2 + h_{f,1\sim2} \tag{2}$$

$$\frac{P_2}{\rho g} + \frac{\alpha {V_2}^2}{2g} + z_2 = \frac{P_3}{\rho g} + \frac{\alpha {V_3}^2}{2g} + z_3 + h_{f,2\sim3} \tag{3}$$

$$\frac{P_1}{\rho g} + \frac{\alpha {V_1}^2}{2g} + z_1 = \frac{P_3}{\rho g} + \frac{\alpha {V_3}^2}{2g} + z_3 + h_{f,1\sim3} \tag{4}$$

(Equations 2 and 3) are the Bernoulli equation applied between points 1 and 2 and points 2 and 3, respectively, of the system. (Equations 2 and 3) can be combined to derive (Equation 4), which expressed the Bernoulli equation applied between points 1 and 3. Here, P represents pressure, ρ is density, g is the acceleration due to gravity, z is the position in the opposite direction of gravity, α is the kinetic energy correction factor, and h_f is the head loss. The sum of the head losses of the peripheral venous infusion set and catheter is the total head loss of the system, as expressed by (Equation 5).

$$h_{f,1\sim3} = h_{f,1\sim2} + h_{f,2\sim3} = f_i \frac{L_i}{d_i}\frac{{V_i}^2}{2g} + f_c \frac{L_c}{d_c}\frac{{V_c}^2}{2g} \tag{5}$$

(Equation 5) expresses the relationship between flow in the pipe and head loss and is called the Darcy–Weisbach equation, where subscript i denotes the infusion set; f_i, the Darcy friction factor of the infusion set; L_i, the length of the infusion set tube; d_i, the diameter of the infusion set tube; V_i, the area averaged velocity of the flow through the infusion set tube; subscript c, the catheter, with f_c, L_c, and d_c, denoting the Darcy friction factor, length, and diameter of the catheter, respectively; and V_c, the area averaged velocity of the normal saline flowing through the catheter.

Additional head loss occurs in the segments where the intraluminal diameter changes between points 1 and 3 (between the drip chamber and infusion set tube and between the infusion set tube and PVC) across the study system. However, as the lengths occupied by the segments where the inner diameter changes were negligibly short relative to the entire system, we did not consider the head loss in these segments. Therefore, in Equation 5, V_i can be expressed as V_2 and V_c as V_3. In addition, d_i can be expressed as d_2 and V_c can be expressed as d_3. In this study, the flow is assumed to be laminar. In case of laminar flow, the Darcy friction factors f_i and f_c in (Equation 5) can be expressed as in (Equation 6).

$$f_i = \frac{64}{Re_i} = \frac{64}{\frac{\rho V_2 d_2}{\mu}},\ f_c = \frac{64}{Re_c} = \frac{64}{\frac{\rho V_3 d_3}{\mu}} \tag{6}$$

Here μ represents dynamic viscosity, Re is the Reynolds number and is used as a criterion for distinguishing laminar flow from turbulent flow. In general, in the case of flow in a duct, the flow transitions from laminar flow to turbulent flow at Re~2300, and if the Reynolds number is less than 2300, the flow is laminar flow.

Equation 5 can be expressed in the same form as Equation 7 using Equation 6.

$$h_{f,1\sim3} = h_{f,1\sim2} + h_{f,2\sim3} = \frac{64\mu}{\rho V_2 d_2}\frac{L_i}{d_2}\frac{V_2^2}{2g} + \frac{64\mu}{\rho V_3 d_3}\frac{L_c}{d_3}\frac{V_3^2}{2g} \tag{7}$$

From the law of conservation of mass in (Equation 1 and 8) can be derived as a function of V_2 and V_3:

$$V_2 = \frac{{d_3}^2}{{d_2}^2} V_3 \tag{8}$$

By plugging (Equation 8) into (Equation 7), $h_{f,1\sim3}$ can be expressed as a function of V_3:

$$h_{f,1\sim3} = kV_3 \tag{9}$$

In (Equation 10), k is a constant and is expressed as follows from the geometrical information of the drip chamber, infusion set, and PVC:

$$k = \frac{32\mu L_i}{\rho {d_2}^2 g}\frac{{d_3}^2}{{d_2}^2} + \frac{32\mu L_c}{\rho {d_3}^2 g} \tag{10}$$

Equation (4), which represents the Bernoulli equation applied from Point 1 (drip chamber) to Point 3 (end of the PVC), can be expressed as (Equation 11):

$$\frac{P_1}{\rho g} + \frac{\alpha {V_1}^2}{2g} + z_1 = \frac{P_3}{\rho g} + \frac{\alpha {V_3}^2}{2g} + z_3 + kV_3 \tag{11}$$

The pressure at Point 1 is the pressure at the center of the drip chamber, which is $P_1 \approx 0$ because the drip chamber is isolated from ambient air and is close to a vacuum state in which only vapor pressure exists. If Point 3 is used as the reference point for measuring the height, then $z_3 = 0$ and z_3=h. We set the kinetic energy correction factor α to 2.0, which corresponds to laminar flow, in the analysis range. The height of the mid-length of the drip chamber h is the height in the opposite direction of gravity measured from the PVC. It can be also expressed as ${V_1}^2 = \left({d_3}^4/{d_1}^4\right){V_3}^2$ from (Equation 5), which observes the law of conservation of mass.

(Equation 11) can be rewritten as (Equation 12) in the form of a quadratic equation of V_3:

$$\frac{1}{g}\left(\frac{{d_3}^4}{{d_1}^4} - 1\right){V_3}^2 - kV_3 + \left(h - \frac{P_3}{pg}\right) = 0 \tag{12}$$

By solving (Equation 11), a quadratic equation, the relation between P_3 (intravenous pressure), h (point from the patient's bed to the mid-length of the drip chamber), d_3 (diameter of the PVC), and the infusion rate can be analyzed.

Data Analysis

The density of 0.9% normal saline at room temperature (22 °C) was 1004.6 kg/m^3, and the viscosity was measured at 0.00102 Pa/s. The length of the drip chamber of a standard infusion set (Sewoon Medical Co., Ltd.) was measured at 4 cm and the set length (L_i), 150 cm. The inner diameters of the drip chamber (d_1) and drip tube (d_2), unspecified by the manufacturer, were measured with a digital caliper (Guilin Guanglu Measuring Instrument Co. Ltd.), a micrometer, and recorded as 0.130 and 0.181 cm, respectively. The height (h) of the infusion bag was set as the value from the patient's bed to the midpoint of the drip chamber, thus ranging from 0.8 to 1.5 m and increasing in increments of 0.1 m. The inner diameter (d_3) and length (L_c) of the 14G, 16G, 18G, 20G, 22G, 24G, and 26G PVCs (GST Corporation Limited) were used, applying the inner diameter ranging from 0.45 to 1.74 mm and the length ranging from 19 to 45 mm as specified by the manufacturer. Lastly, we chose the elbow cephalic and median cubital veins as the veins through which the infusion flows, and the venous pressures (P_3) at rest in the supine position in healthy adults were applied: cephalic vein, 951.2 Pa; median cubital vein, 1010 Pa.

Data analysis was performed using Microsoft Excel, considering the friction loss with the Darcy–Weisbach equation (Equation 5), and calculating the infusion rate flowing into the designated vein using the Bernoulli equation and law of conservation of mass, with the flow assumed to be laminar. To assess the validity of the laminar flow assumption for the flow analysis, we calculated Re ($= \rho Vd/\mu$). In this study, Re confirmed as 143–1540 in the elbow cephalic vein and median cubital vein, which satisfies the assumption of laminar flow.

Ethical Considerations

This study was conducted after obtaining an exemption from the Kyung Hee University institutional review board of the institute (KHSIRB-22-556(EA)) with which the research is affiliated, as a study based on literature review and control volume analysis.

Results

Infusion Rate via the Cephalic Vein According to Fluid Height and Catheter Inner Diameter

Table 1 and Figure 2 present the infusion rate via the cephalic vein according to the fluid height and catheter inner diameter. In all gauges, the lowest and highest flow rates were observed at the fluid heights of 0.8 and 1.5 m, respectively, demonstrating that the infusion rate increases with increasing fluid height. The ranges of the infusion rates for each PVC size were as follows: 14G, 1.102 cc/s (66.12 cc/min) to 2.137 cc/s (128.22 cc/min); 16G, 1.007 cc/s (60.42 cc/min) to 1.895 cc/s (113.70 cc/min); 17G, 0.876 cc/s (52.56 cc/min) to 1.601 cc/s (96.06 cc/min); 18G (45 mm), 0.769 cc/s (46.14 cc/min) to 1.381 cc/s (82.86 cc/min); 18G (32 mm), 0.811 cc/s (48.66 cc/min) to 1.445 cc/s (86.70 cc/min); 20G, 0.601 cc/s (36.06 cc/min) to 1.041 cc/s (62.46 cc/min); 22G, 0.440 cc/s (26.40 cc/min) to 0.746 cc/s (44.76 cc/min); 24G, 0.270 cc/s (16.20 cc/min) to 0.455 cc/s (27.30 cc/min); and 26G, 0.207 cc/s (12.42 cc/min) to 0.353 cc/s (21.18 cc/min).

Table 1 Infusion Rate via the Cephalic Vein According to Fluid Height and Catheter Inner Diameter (Flow Rate Unit: mL/sec)

Height \ Gauge	14G	16G	17G	18G (L=45mm)	18G (L=32mm)	20G	22G	24G	26G
0.8m	1.102	1.007	0.876	0.769	0.811	0.601	0.440	0.270	0.207
0.9m	1.254	1.140	0.987	0.863	0.910	0.670	0.489	0.300	0.230
1.0m	1.404	1.270	1.095	0.955	1.005	0.737	0.536	0.328	0.252
1.1m	1.553	1.399	1.200	1.045	1.098	0.802	0.581	0.355	0.274
1.2m	1.700	1.526	1.304	1.132	1.188	0.864	0.624	0.381	0.294
1.3m	1.847	1.651	1.405	1.217	1.275	0.925	0.666	0.407	0.314
1.4m	1.992	1.774	1.504	1.300	1.361	0.984	0.707	0.431	0.334
1.5m	2.137	1.895	1.601	1.381	1.445	1.041	0.746	0.455	0.353

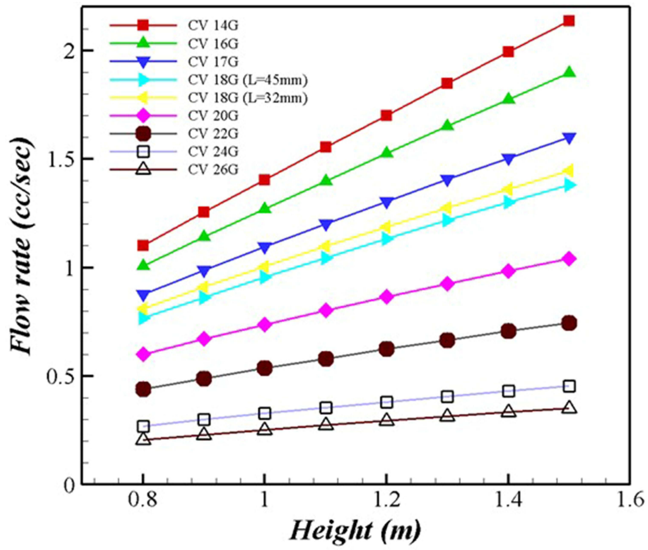

Figure 2 Infusion rate via the cephalic vein according to fluid height and catheter inner diameter.

Infusion Rate via the Median Cubital Vein According to Fluid Height and Catheter Inner Diameter

Table 2 and Figure 3 present the infusion rate via the median cubital vein according to the fluid height and catheter inner diameter. In all gauges, the lowest and highest flow rates were observed at the fluid heights of 0.8 and 1.5 m, respectively, demonstrating that the infusion rate increases with increasing fluid height. The ranges of the infusion rates for each PVC size were as follows: 14G, 1.093 cc/s (65.58 cc/min) to 2.128 cc/s (127.68 cc/min); 16G, 0.999 cc/s (59.94 cc/min) to 1.888 cc/s (113.28cc/min); 17G, 0.869 cc/s (52.14 cc/min) to 1.596 cc/s (95.76 cc/min); 18G (45 mm), 0.763 cc/s (45.78 cc/min) to 1.377 cc/s (82.62 cc/min); 18G (32 mm), 0.805 cc/s (48.30 cc/min) to 1.440 cc/s (86.40 cc/min); 20G, 0.597 cc/s (35.82 cc/min) to 1.038 cc/s (62.28 cc/min); 22G, 0.437 cc/s (26.22 cc/min) to 0.744 cc/s (44.64 cc/min); 24G, 0.269 cc/s (16.14 cc/min) to 0.453 cc/s (27.18 cc/min); and 26G, 0.206 cc/s (12.36 cc/min) to 0.351 cc/s (21.06 cc/min).

Characteristics of the Infusion Rate According to Fluid Height and Catheter Inner Diameter

At a constant fluid height, the velocity of the fluid infused into the catheter decreases with increasing PVC diameter. According to the law of conservation of mass, the velocity of the fluid infused into the catheter is inversely proportional to the square of the diameter of the catheter. At a constant PVC diameter, the velocity of the fluid infused into the catheter

Table 2 Infusion Rate via the Median Cubital Vein According to Fluid Height and Catheter Inner Diameter (Flow Rate Unit: mL/sec)

Gauge / Height	14G	16G	17G	18G (L=45mm)	18G (L=32mm)	20G	22G	24G	26G
0.8m	1.093	0.999	0.869	0.763	0.805	0.597	0.437	0.269	0.206
0.9m	1.245	1.132	0.980	0.858	0.904	0.666	0.486	0.298	0.229
1.0m	1.395	1.263	1.088	0.950	0.999	0.733	0.533	0.326	0.251
1.1m	1.544	1.391	1.194	1.039	1.092	0.798	0.578	0.354	0.273
1.2m	1.692	1.518	1.298	1.127	1.182	0.861	0.622	0.380	0.293
1.3m	1.838	1.643	1.399	1.212	1.270	0.921	0.664	0.405	0.313
1.4m	1.984	1.767	1.498	1.295	1.356	0.980	0.704	0.430	0.333
1.5m	2.128	1.888	1.596	1.377	1.440	1.038	0.744	0.453	0.351

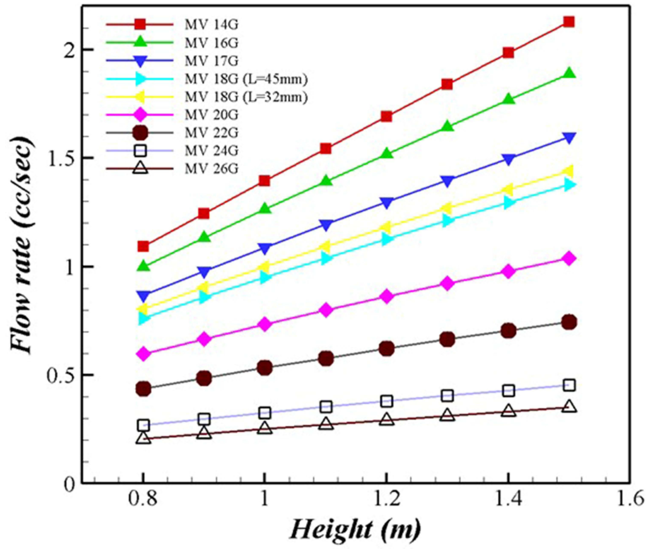

Figure 3 Infusion rate via the median cubital vein according to fluid height and catheter inner diameter.

increases with increasing infusion rate. According to the law of conservation of mass, the velocity of the irrigation solution infused into the catheter has a linear relation with the infusion rate. That is, when the flow rate doubles, the velocity of the fluid infused into the catheter also doubles. Moreover, the flow rate of the fluid infused into the catheter increases with increasing fluid height, and at a constant fluid height, the flow rate of the fluid infused into the catheter increases with increasing PVC diameter. At constant fluid height and PVC diameter, the flow rate of the fluid infused through the catheter increases with decreasing pressure in the peripheral vein into which the fluid is infused.

Discussion

This study aimed to provide nurses with a standard for infusion rate while maintaining the height of the infusion bag and inner diameter of PVC using fluid dynamics. The implications of our results are discussed below.

In this study, the infusion rate through the cerebral and median cubital vein based on the infusion height and catheter inner diameter was investigated. The results revealed that for all gauges, the lowest and highest flow rates were observed at infusion heights of 0.8m and 1.5m, respectively, indicating that the infusion rate increased with an increase in infusion height. These results are in line with findings from an experimental study conducted by Stoneham,[12] which examined intravenous flow rates. The study concluded that using a 14-gauge catheter is more effective than a 16-gauge catheter for increasing the flow rate of clear fluid at room temperature. Likewise, in the present study, when the fluid height was fixed at 100 cm, the 14G and 16G catheters yielded 84.24 and 76.20 mL/min, respectively, presenting an increase in flow rate of about 10%. Likewise, at a constant fluid height of 100 cm, the 26G and 14G, the catheters with the smallest and largest diameters, respectively, yielded the infusion volumes of 907 and 4514 mL, respectively, indicating about a five-fold increase. Therefore, to increase the infusion rate, nursing staff should select a catheter with a large diameter. If a catheter with a large diameter cannot be selected, an additional infusion path should be secured.

Second, in the flow characteristics identified through the equations applied in this study, at a constant PVC diameter, the velocity of the fluid infused into the catheter increases with increasing infusion rate. According to the law of conservation of mass, the velocity of the irrigation solution infused into the catheter has a linear relation with the infusion rate, which suggests that the higher the infusion rate, the greater the pressure on the vein. Considering previous reports that excessive intravenous infusion pressure can cause trauma, and pressure-induced trauma can cause compartment syndrome[13–16] nursing staff should select a catheter with a large diameter when the fluid volume must be increased to maintain an optimal velocity.

Moreover, the results in this study indicated that, even with the same catheter inner diameter, the infusion rate of the fluid increased with higher infusion heights. This result is consistent with the flow characteristics interpreted through the equations employed in this study, at a constant PVC diameter, the flow rate of the fluid infused into the catheter increases with increasing fluid height. Calculation of the difference in fluid volume per hour between the minimum (0.8 m) and maximum (1.5 m) fluid heights for each catheter diameter yielded the following results: 14G = 3726 mL, 16G = 3196.8 mL, 17G = 2610 mL, 18G (L = 45 mm) = 2203.2 mL, 18G (L = 32 mm) = 2282.4 mL, 20G = 1584 mL, 22 G = 1101.6 mL, 24G = 666 mL, and 26G = 525.6 mL. Thus, at a constant PVC diameter, the fluid volume infused may vary by approximately 50% depending on the fluid height. However, the "intravenous tubing" chapter in evidence-based clinical nursing practice guidelines covers only the site of intravenous tubing and catheter size; guidelines specifying fluid height are virtually non-existent. Fluid height should be measured not from the floor but from the patient's infusion site. However, most manufacturers of infusion poles indicate the top-to-ground height, and nurses are left to ascertain the fluid height from the patient's infusion site by themselves. Therefore, considering the difference in the infusion rate according to fluid height, a practical manual will have to be prepared to provide relevant information.

At constant fluid height and PVC diameter, the flow rate of the fluid infused through the catheter increases with decreasing pressure in the peripheral vein into which the fluid is infused. This supports the research finding of a randomized controlled trial[17] that the most effective intervention for reducing pain during propofol injection in adults is by utilizing an antecubital vein with low venous pressure. An antecubital vein also known as a large upper limb vessel that flows from the forearm during elbow bending is also considered an antecubital fossa. It is a preferred vein for intravenous injection for its safe and easy access. Selecting such a blood vessel can contribute to smooth flow and vascular pain reduction. In this study, we selected only the cephalic and median cubital veins for the purpose of comparing results. Future research should assess the infusion rate at different tubing sites under different venous pressures.

Lastly, in an experimental study investigating the flow rate of saline using a 16G intravenous cannula,[18] when the fluid height was fixed at 100 cm, the flow rate under gravity was 70 mL/min, which is similar to our result (76.20 mL/min), with a difference of only 6.20 mL/min under the same conditions (16G, 100 cm). Moreover, a previous study[19] reported that while experiments tend to be cost-intensive and time-consuming in terms of creating a perfect experimental environment, fluid engineering allows for calculations without the need to create an experimental environment and yields excellent results because they are not affected by experimental errors. Fluid mechanics has rarely been applied in the field of nursing. However, continuing multidisciplinary research including fluid mechanics, as in this study will contribute to producing evidence for practical guidelines in the field of nursing.

Conclusion

This study demonstrated that nurses should consider both the diameter of the needle and height of the infusion bag to maintain the infusion rate when performing intravenous infusion therapy. This study is significant as an attempt to provide basic data for the development of the standard for practical nursing to improve the quality of intravenous infusion therapy. The standard derived from the results of this study is expected to be used in the education of nurses, nursing students, and patients. Moreover, our findings are expected to contribute to improving nursing quality by offering practical solutions to intravenous infusion in nursing practice. The following proposals may be useful for future research. As demonstrated in this study, further research must be conducted to confirm the intravenous infusion volume depending on the choice of vein. For promoting the application of the work standards for intravenous infusion therapy, follow-up studies should involve various experts, such as national guideline development organizations, pertinent societies, and expert groups. However, this study has limitations in not accounting for both the material and roughness of the infusion set. In future research, we aim to conduct computational fluid dynamics simulation studies that take these factors into consideration.

Data Sharing Statement

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

Disclosure

The authors report no conflicts of interest in this work.

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