An Innovative Assist Device for Intravenous Infusion

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Abstract—This study proposed a portable intravenous infusion assist device that uses a peristaltic pump for continuous intravenous infusion. The innovative assist device uses a micro computer-controlled peristaltic pump which controls the infusion rate at between 60-140ml/hr with an infusion rate error within 0.5%. Results have shown that the peristaltic pump is adopted in IV infusions, the infusion rate and the needle number used are completely unrelated. This assist device can be used continuously for 8.1 hours. After 5 hours of actual use, the total voltage remains at 15V and a stable output voltage of 12V can be maintained. By using this device, patients are relieved of the difficulties involved with using an intravenous drip stand while achieving an accurate infusion rate and can reduce their use of infusion sets. In addition, the total weight of the intravenous infusion assist device and power bank is no more than 723g. The intravenous infusion assist device is a novel medical aid that attends to patients’ dignity and also effectively ensures treatment safety.

Keywords—Intravenous infusion, peristaltic pump, portable assist device, infusion rate, rotational speed.

I. INTRODUCTION

Continuous intravenous infusion (IV infusion) is commonly known as “drip feed”. Since Scottish medical pioneer Thomas Latta introduced IV therapy in 1832, the lives of countless patients suffering from cholera have been saved [1]. More than one hundred years later, IV infusion has become an effective method of treatment commonly used in nearly all medical and nursing institutions and has contributed greatly to patient treatment. When administering IV infusions, family members and nursing personnel should frequently monitor the fluid level. During IV infusion, the catheter may become blocked, so they should also check to ensure the fluid level is decreasing. The intangible stress caused by this monitoring, however, can become a serious physical and psychological burden for families and nurses.

Intravenous drip stands (IV stands) are inconvenient and unsafe, and the drip rate cannot be accurately adjusted, thus affecting the effectiveness of medication.

In addition, traditional IV infusions use infusion bags suspended from an IV stand, a set-up which applies potential energy (gravity) to infuse fluids into the patient’s veins. In other words, the principle of static pressure is used to inject fluids into the patient’s body. Due to venous pressure, low fluid levels often cause blood to flow backward into the catheter; that is, the fluid meniscus height in the infusion bag must be hung higher than the outflow point of injection site (60-120cm) [2]. When getting out of bed, patients must bring the IV stand with them while keeping the infusion bag higher than the injection site, which is very inconvenient for patients. Patients also often accidently pull the catheter, removing the tubing or causing the IV stand to fall, or sometimes injure their feet on the bottom of the IV stand.

Due to the inconvenience of traditional IV infusion, several patents have been submitted in Taiwan for possible improvements [3]. However, the majority of innovation patents focus on the monitoring of and warnings related to fluid levels; to this day there has yet to be a portable IV infusion assist device that can control the flow itself. Some hospitals have already begun using IV infusion instruments which may provide accurate IV infusion speed and flow. However, due to the large sizes and weights of these machines and their use of alternating current, they are not suitable for use in wards.

Nowadays, the microminiaturization of electronic components[4-6], the actuator of the micro peristaltic pump developed by Koch et al. [7] is only 2cm×2cm×1cm, and the size of the miniature motor used is 2.1cm×2.1cm×1.2cm. With the change of the motor rotation, the linear flow rate of the fluid that is being delivered is between 0.5 and 27μl/min. If a catheter is used to deliver the fluid, then the flow rate is 0.65-41μl/min. However, the flow rate provided by this type of micro peristaltic pump is not enough to be used in the 1000-2400μl/min range required for IV infusions.
The IV infusion assist device proposed in this study does not require the use of an IV stand. A small peristaltic pump is used for continuous, steady infusion. This device is an innovative and creative method which is both portable and completely removes the need for traditional IV stands that require infusion bags to be suspended high.

II. EXPERIMENTAL FACILITY & METHODS

A. Development of the Devices

As shown in Figures 1 and 2, this IV infusion assist device includes a case unit (#1) and infusion unit (#2). The case unit includes a case cover (#11) and case body (#12). Screws are used to attach the case cover to the case body for easy assembly and maintenance of the infusion unit. The front of the case cover is a transparent window that allows patients to observe the operation of the infusion unit. The case body is single-piece plastic component. The case cover and case body can be accurately positioned and tightly fixed together to protect the infusion unit installed inside the case body. The infusion unit includes a switch (#21), operation panel (#22), display panel of flow rate (#23), controller (#24), fan (#25), peristaltic pump (#26), and peristaltic pump head (#27). Patients use the touch panel as the operation interface and the flow rate monitor to obtain the IV infusion flow rate. The fan is used to disperse the heat produced by the controller. Screws and nuts are used to install the fan at the side of the case body. The controller is the core of this unit and is mainly the control board of a printed circuit. Its three main functions are pulse wave generation, microcomputer control, and driver amplification.

B. Theoretical Background

In order to verify that this device conforms to conventional medical effectiveness, we produced a set of experiments to simulate a real-life IV infusion situation (as shown in Figure 3). Since the infusion liquid was inserted into the measuring cup via a needle, the ambient pressure was the atmosphere; thus the gauge pressure was zero. However, during actual fluid infusion, the needle is inserted into the vein. Although the venous pressure is below 35mmHg [9], in order to consider the effect of venous pressure on the use of peristaltic pump, the water cycle system in Figure 3 used a simulated blood circulatory system.
The submersible pump acted as the heart and the plastic tubing acted as a vein. Because there is liquid flowing in the plastic tube of the water cycle unit, a Bernoulli equation [10] shows that the pressure at any point in the plastic tube (refer to point ② in the figure) simulates real-life intravenous pressure. Thus the effect of the intravenous pressure on this device can be further estimated.

The injection needles normally used in medical practice use G as the standard unit for the outer diameter (d₀) and the tip of the IV catheter (abbreviated as IC needle) is 12G-25G. In order to carry out a simulated intravenous infusion experiment, this study adopted the commonly used 19G, 21G, and 23G needles with an outer diameter of 1.1, 0.8, and 0.6mm, respectively. A #4 catheter with an inner diameter of d₁=3.2mm, thickness of t₁=1.6mm, a range of flow rate of 3.6-84.2cc/min (where 1ml=15drops) was used to infuse fluids.

In Figure 3, along the streamline between point ① and point ②, assuming that the fluid is uniform flow, steady flow, and incompressible flow and considering the input power and friction loss of the submersible pump, the flow situation can therefore be shown below using the extended Bernoulli equation below:

$$\frac{v_1^2}{2g} + z_1 + \frac{P_1}{\gamma} + h_p = \frac{v_2^2}{2g} + z_2 + \frac{P_2}{\gamma} + h_L$$  (1)

The above equation can also be called the mechanical energy equation, where v is velocity, g is gravitational acceleration, z is elevation, p is pressure, and γ is the specific weight of fluid. h₀ and hₚ represent pump head and loss head (in meters). The definition of pump head hₚ is shown below:

$$h_p = \frac{W}{\gamma \Omega}$$  (2)

Where W is the power of the submersible pump and Ω is the water flow volume inside the plastic tube. To simplify equation (1), the following rational assumptions were added:

- The change in the liquid level of point ① is extremely small and can be ignored; therefore it was calculated as v₁=0.
- The height difference between points ① and ② can be ignored; therefore, z₁=z₂.
- Point ① is the atmosphere, so the gauge pressure is 0 (P₁=0), and the corresponding pressure P₂ of point ② is the gauge pressure.
- The interior of the plastic tube was smooth, so friction loss is not considered; therefore, h₁=0.

After substitution of all the physical parameters that are zero in the aforementioned hypotheses into equation (1) and the equation can be simplified as follow:

$$h_p = \frac{v_2^2}{2g} + \frac{P_2}{\gamma}$$  (3)

In addition to the aforementioned hypothetical conditions, we obtained the parameters from the simulated blood circulatory system through the experimental setup shown in Figure 3:

- The water flow volume of the submersible pump: Ω=410ml/min=6.83×10⁻⁶m³/s.
- The pump head of the submersible pump: hₚ=1.8m.
- The specific weight of water at 15°C: γ=9800N/m³.
- Gravitational acceleration: g=9.81m/s².

According to the data listed above, we first obtained the water flow velocity in the plastic tube. Among which the definition of the water flow velocity in the tube is water flow volume (Ω) divided by cross-sectional area:

$$\frac{v_2}{A} = \frac{\Omega}{\pi d_1^2 / 4} = \frac{6.83 \times 10^{-6}}{\pi (0.0032)^2 / 4} = 0.85 \frac{m}{s}$$

Accordingly, the water flow velocity (v₂) and pump head (hₚ) are substituted into equation 3, resulting in the only unknown number, the pressure (P₂) in the tube:

$$\frac{P_2}{\gamma} = h_p - \frac{v_2^2}{2g} = 1.8 - (0.85)^2 \div 2 \times 9.81 = 1.763m$$
Thus the pressure (P₂) in the tube can be obtained as:

\[ P₂ = 17.3kPa = 129.8mmHg \]

It is important to realize the pressures produced by infusion set. The intravenous infusion assist device have alarms that detect unacceptable rises in infusion pressure at the time of occlusion. Infusion pressure drop (ΔP) mainly with small bore cannula, higher infusion rates and viscous solutions. These factors are brought together in the Hagen-Poiseuille equation for laminar flow [10]:

\[ \Delta P = \frac{128 \mu \text{g}L}{\pi d t^4} \]  (4)

Where \( \mu \) is the viscosity of infusion liquid, \( q \) is the infusion rate; \( L \) and \( d \) are the length and diameter of infusion tube, respectively. Equation (4) is commonly referred to as Poiseuille’s law [10].

Normally, with regards to the venous pressure, the infusion bag should be hung high enough that the infusion pressure is at least 150mmHg for adults receiving traditional IV infusions and 50mmHg for neonates [11]. The experiment results of the device developed by this study showed that under the conditions of an empty needle (\( P₂=0\)mmHg) and simulated IV infusion (\( P₂=129.8\)mmHg), the difference between infusion volumes (Q) for the two was less than 0.26% [3]. Therefore, it can be inferred that even if there was venous pressure, its effect on the accuracy of the flow of this device would be very little.

III. RESULTS AND DISCUSSION

Figure 4 shows the infusion volume (Q) and infusion rate (q) measured during 10, 20, and 30 minutes of peristaltic pump rotation at different rotational speeds of peristaltic pump (n) and needle numbers. The needles were 19G, 21G, and 23G and the y-coordinate is the infusion volume (Q) and x-coordinate is the rotational speed (n). The statistics in the figure show a linear relation between infusion volume (Q) and rotational speed (n) and that the longer the infusion time (t) the greater the infusion volume (Q). Quantitative analysis was used to obtain the linear equation shown in equation (5) shown below:

\[ Q = C₁ \cdot n \cdot t \]  (5)

Where \( C₁ \) represents the slope of the line. The figure shows that the needle number used for infusion has little effect on the infusion volume (Q). Correspondingly, the rotational speed (n) and infusion time (t) are important parameters related to changes in infusion volume (Q).

Statistics show that infusion volume (Q), rotational speed (n), and infusion time (t) all show a direct proportional trend. Further comparison and analysis from Figure 4 show that regardless of whether the needle number was 19G, 21G, or 23G, the straight lines corresponding to the infusion time (t) were completely identical. Therefore it can be shown that if the peristaltic pump is adopted in IV infusions, the infusion volume (Q) and the needle number used are completely unrelated. The linear equation for the infusion time (Q, ml), rotational speed (n, rpm), and infusion time (t, min) is shown below:

\[ Q = 0.386 \cdot n \cdot t \]

We emphasize here that due to the strong correlation between the infusion volume (Q), rotational speed (n), and time (t) of the peristaltic pump, if infusion volume (i.e., infusion rate (q)) is used to present the test results (Figure 5), then the y-coordinate will be infusion rate (q) and x-coordinate will be rotational speed (n). The results in the figure show a linear relationship. Quantitative analysis was used to obtain the linear equation shown in equation (6) below:

\[ q = C₂ \cdot n \]  (6)

Where q is the infusion rate (ml/hr), n is the rotational speed (rpm), and \( C₂ \) is the slope of the straight line and the derived unit is ml/rpm-hr. According to the statistical results of the experiment, constant \( C₂=23.2 \). Equation (6) can be changed into the following:

\[ q = 23.2n \]
Although IV infusion needs to consider the age and disease of patients, doctors usually set the infusion rate ($q$) at 60, 80, 100, 120, and 140ml/hr. According to the results where $q=23.2n$, the required infusion rate ($q$) can be converted into an accurate rotational speed ($n$) of the peristaltic pump. The accuracy of the infusion rate can also be obtained.

This main novelty of this device is portability. Therefore, a 5,000mA-h power bank is required. Not only is this device easy to carry, it also conforms with the operation time IV infusion required for peristaltic pump. The power bank used with this new device was a rechargeable lithium-polymer (Li-Po) battery. The experiment results show that although usage time reached 300 minutes, output voltage was still above 14.8V (Figure 6).

The DC12V voltage stabilizer circuit designed in this study outputs the electric energy of the charged battery to the selected peristaltic pump. Its rotational speed does not change and is fixed. The specifications for the circuit is DC12V voltage stabilizer circuit, the battery used must be higher than 2.5V, and have a maximum circuit output of 1A. The Li-Po battery volume was 5000mA-h and the average load current of the peristaltic pump design was 620mA, so that $t=(5,000\text{mA-h}/620\text{mA})= 8.1$ hours was calculated using the equation.

It can be known that the combination of the selected peristaltic pump and Li-Po battery can theoretically be continuously used for 8.1 hours, which according to the results has exceeded the required design time (over 4 hours). After 5 hours, the total voltage remained at 15V, and a stable output voltage of 12V was maintained (as shown in Figure 6). Therefore, this portable device can continuously administer 2 to 4 bags of fluids as long as the rechargeable battery is properly used and fully charged.

### IV. CONCLUSIONS

The completed IV infusion assist device developed in this study is shown in Figure 7. The case unit size was 115mm×70mm×90mm and weight was 623g. If the weight of the power bank (113g) and 500cc fluid bag (500g) is added, the total weight was 1236g. By using this device for drip feed, an accurate infusion rate can be achieved, and the use of the infusion set can be reduced. More importantly, patients are able to move around freely without being limited by traditional IV stands.

This device uses a peristaltic pump to rotate the pump head and achieves continuous drip feed by compressing the catheter. This device is small and portable, unlike traditional IV infusions which require an infusion set and are inconvenient and dangerous. Patients can easily carry this device and avoid the inconvenience and difficulty of using an IV stand.
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