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Investigating Drip Infusion Speed Control: A Study of Weight and Pinch Methods Concerning Subject Variations

Lanny Agustine[1] | Made Indra Ayu Astarini[2] | Maria Manungkalit[3] | Hartono Pranjoto[4]

[1,4] Department of Electrical Engineering, Widya Mandala Surabaya Catholic University
Kalijudan 37 Street, Surabaya, East Java, Indonesia
[2]Nursing Study Program, Faculty of Nursing, Widya Mandala Surabaya Catholic University
Kalisari Selatan 1 Street, Pakuwon City, Surabaya, East Java, Indonesia
[3]List all distinct addresses in the same way

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Abstract:

An infusion drip system that utilizes a clamp method to control the drip rate has not yet achieved a consistent drip rate across different subjects. The condition was that each movement of the pinch valve did not consistently stimulate the release of one drop of liquid. In this study, tests were conducted with variations in the pinch-release period (3 seconds, 2.5 seconds, 2 seconds, and 1.5 seconds) and variations in the release pinch valve duration (55 milliseconds, 60 milliseconds, 65 milliseconds, 70 milliseconds, and 75 milliseconds). The testing involved 15 participants, including 100 cc of NaCl infusion fluid for 1-2 hours. The results indicated two variations in drip speed among all test subjects: it required either two ticks to produce one drop of infusion (the dominant outcome) or just one tick. Based on tests with healthy participants and their responses to questionnaires, it was concluded that the device was quite comfortable to use with the release pinch valve duration of 60-70 milliseconds and a pinch-release period of 2 seconds, 2.5 seconds, or 3 seconds.

Keywords: Infusion, Drip, Rate, Pinch, Duration

Introduction:

Fluid therapy through infusion, as guided by medical professionals, is essential for ensuring that patients maintain proper fluid balance. This therapy is commonly delivered through two main methods: infusion pumps and drip intravenous systems [1-2]. Nurses play a key role in administering these therapies accurately to optimize their therapeutic benefits [3-5].

Although infusion pumps allow for precise control over fluid delivery and can be programmed to stop at specific intervals, their high costs often limit their application to select cases, resulting in an extra charge for the patients. In contrast, drip infusion therapy is commonly used [6-7]. Still, it depends significantly on the attentiveness of the nursing staff, the patient, and the waiting family, particularly when the fluid level is running low [4-5].

Recent advancements by the authors have led to a device that utilizes a pinch mechanism on the infusion line to regulate fluid flow in drip infusion systems. The introduced method is less invasive than the pumping method because the pinch mechanism simply clamps the line to halt the flow, imitating the function of the roller clamp. This

innovative device incorporates a load cell to monitor outflow [8-12], and a pinch valve to do the pinch mechanism [13].

The pinch method significantly improves nursing efficiency by minimizing the need for constant monitoring, it allows nurses to focus on other critical tasks, thereby enhancing overall patient care. Moreover, it contributes to patient safety and comfort; automatically stopping fluid flow when levels are low. This method decreases the risk of over-infusion and its complications. Patients and their waiting families also benefit from feeling less anxious about monitoring when fluid levels are low.

However, previous research highlights that individual patient factors can lead to variations in flow rates, requiring tailored adjustments for optimal therapy. These differences may stem especially from patient physiology for the same infusion fluid administered. The previous study concluded an important finding that the pinch valve release duration longer than 70 milliseconds may cause the patient to feel a tingling or even sore sensation.

The recent study discussed in this article examined two key areas: the connection between the patient's specific physiological parameters and the adjustments needed for optimal timings for the pinch valve's operation to achieve one drop of liquid per second. This study aims to verify the precision of drop counts at specific time intervals with different patient body parameters.

Method for regulating the drip rate of infusion fluid

The manual adjustment of the drip rate is performed by regulating the tightness of the roller clamp on the infusion set, thereby controlling the number of drops over time according to the physician's instructions, as shown in Fig. 1.a) [1]. The developed system applies control of the pinch-release period of the infusion tube using a pinch valve (Fig. 1.b) to stimulate the infusion fluid drops naturally based on gravitational force. Results from previous research indicate that drop control can be achieved using this method; however, the drip rate varies among individuals even with the same control duration. Therefore, further investigation is needed to optimize the pinch-release period of the pinch valve to achieve the desired drip-rate. [13]

(a) (b)

Figure 1. Method for regulating the drip rate of infusion fluid: a) adjusting the roller clamp [1], b) using a pinch valve and roller clamp in the fully open position [13].

Research Design:

The drip infusion control system with the pinch method incorporates notable features, including integrating a load cell and a pinch valve. The load cell weight sensor accurately determines the volume of infusion fluid by measuring the weight of the infusion bag and its contents. Meanwhile, the pinch valve regulates the drip rate and can halt the flow of the infusion fluid as necessary.

A controller will oversee all operational aspects, including drip calculations and fluid cessation. The design carefully considers various factors to accommodate the conditions of a patient’s room, such as minimizing noise generated by the pinch

valve operation, monitoring ambient light levels, and ensuring ease of use for nursing staff.

It is important to note that this research study focuses solely on the features outlined above within a highly controlled laboratory environment and with healthy subjects to test the device's performance [11-13]. The automated drip infusion control system comprises several key components, including a load cell sensor, a pinch valve, and a single-board computer.

Load cell and signal conditioning module

The load cell will measure the weight of the infusion fluid, including the infusion bag. The resistance difference of a load cell is only 2 Ω (full scale) within a total resistance of 860 Ω, resulting in a difference of only 0.23% of the full scale for a 1 kg load cell. Load cells are typically connected to an HX711 module to achieve precise measurements. It utilizes a 24-bit analog-to-digital converter (ADC) for accurate weight measurement in electronic scales via a Wheatstone bridge configuration. The HX711 provides serial output.

Pinch valve

A 5V pinch valve controls the drip rate of infusion flow. It is a control valve used to regulate fluid flow with pinch-release mechanism. It compresses the flexible infusion line, effectively stopping or restricting fluid flow. The advantages of a pinch valve are low-pressure drop and ease of maintenance. In previous research, it was observed that the duration of the pinch valve release affects the size of the infusion fluid drops. Additionally, if the release duration exceeds 70 msec, it can cause discomfort for the patient in the area of the infusion needle. The current required for the pinch valve exceeds the controller's capability; therefore, a relay interfaces the controller to the pinch valve.

Controller

The controller's minimum specifications include six digital I/O pins and I2C LCD communication. The controller operates when the measured weight from the load cell exceeds 100 mL, with the total weight encompassing both the infusion fluid and the tubing. It collects this total weight data for four seconds, averaging the measurements taken during this interval.

The controller activates the valve to pinch and release the infusion line as illustrated in Fig. 2, thereby stopping and resuming the flow of infusion fluid. This mechanism is used to regulate the drip rate. The controller manages both the duration of the pinch and the cycle period for pinching and releasing. Drip rates are observed for varying cycle durations across different test subjects to ensure that the drip rate aligns with the target of emptying 100 mL of fluid in 100 minutes. The study utilizes a Terumo infusion set with 20 drops per mL drip factor [14-15], resulting in a target drip rate of 1 drop every 3 seconds. The controller will generate a tick timer to manage the pinch valve. The period between each tick is 3 seconds theoretically. However, the period required may change when connected to the patient.

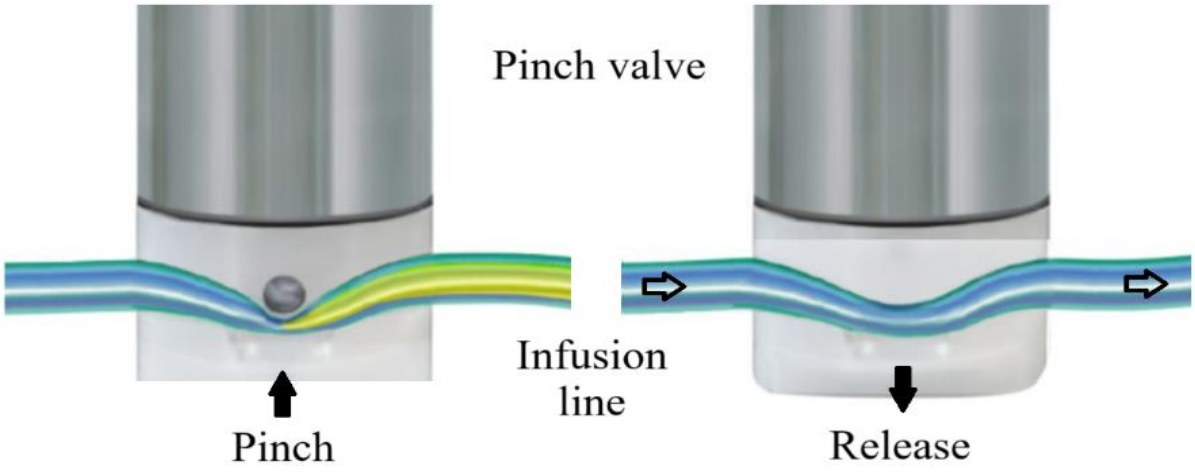

Figure 2. Pinch-release mechanism

Experiment

Earlier experiments were conducted in which the device was not connected to a patient. These experiments indicated that a longer valve release period increases volume per fluid drop [13]. However, once the device is connected to a subject, the volume of each drop and drip rate might change [13]. The aspects monitored in this experiment are the duration of one cycle of pinch and the release of the pinch valve concerning the drip rate of the fluid when infused into the subjects [13]. This observation aims to conclude the variations in the duration of one cycle of pinch-release of the pinch valve needed for different subjects to achieve a rate of 20 drops per minute.

The device was tested on a cohort of 15 healthy participants. The test subjects comprised male and female individuals aged between 18 and 21 years with a weight range of 47 kg to 80 kg, and blood pressure within the normal range, specifically between 90/60 mmHg and 130/80 mmHg. Each subject will undergo testing with four variations of the pinch-release period: 3 milliseconds, 2.5 milliseconds, 2 milliseconds, and 1.5 milliseconds. Each variation of the pinch-release duration will be tested across several different release durations. Table 1 illustrates that for the 3 milliseconds pinch-release period, tests were conducted under two pinch valve release durations of 70 milliseconds and 75 milliseconds, while the other periods were tested with five variations of pinch valve release durations: 55 milliseconds, 60 milliseconds, 65 milliseconds, 70 milliseconds, and 75 milliseconds. Testing has been conducted for 100 pinch-release cycles for each release duration setting, Thus, there will be a total of 17 tests for each subject involving variations in the pinch-release period and the duration of the pinch valve release. This procedure requires one hour for each subject to be completed, an additional 30 minutes for the infusion insertion and removal, and personal data collection. Observations were conducted to monitor which timing settings would yield one drop per pinch-release cycle

.Table 1. Variations in the duration of the pinch and release of the pinch valve

Test sequence	Pinch-release period (milliseconds)	Release duration (milliseconds)
1	3000	70; 75
2	2500	55; 60; 65; 70; 75
3	2000	55; 60; 65; 70; 75
4	1500	55; 60; 65; 70; 75

Discussion:

Successful evaluations were conducted for all participants with the planned duration settings for pinch valve performance. Fig. 3 presents a bar graph depicting the weight, systolic, and diastolic blood pressure of the test subjects, compared to the pinch-release period settings required for each subject to achieve a rate of 20 drops per minute represented in a line graph. The results indicated that 80% of the participants required an adjustment of the pinch valve to a pinch-release period of 1500 msec and the release duration set at 60-70 milliseconds, as it took two pinch-release cycles of the pinch valve to produce one drop of liquid. Conversely, 20% of participants necessitated a performance setting of 2500-3000 milliseconds, with only one pinch-release cycle of the pinch valve producing one drop of liquid at a release pinch valve duration of 70 milliseconds as shown in Fig. 3 for subjects 3 and 5.

The graph indicates that subjects 4 to 6 and 12 to 14 have higher systolic pressures than the others. The diastolic pressure appears to follow the fluctuations of the systolic pressure. There is no evident correlation between the blood pressure and the pinch-release period, as only subjects 3 and 5 require a longer pinch-release period compared to subjects 12 to 14, who have relatively similar high blood pressures. Additionally, the weight parameter shows no significant differences for subjects 3 and 5 when compared to the other subjects, despite requiring lower pinch-release period settings. Notably, the subjects' weight and blood pressure did not appear to influence the performance regulation of the pinch valve.

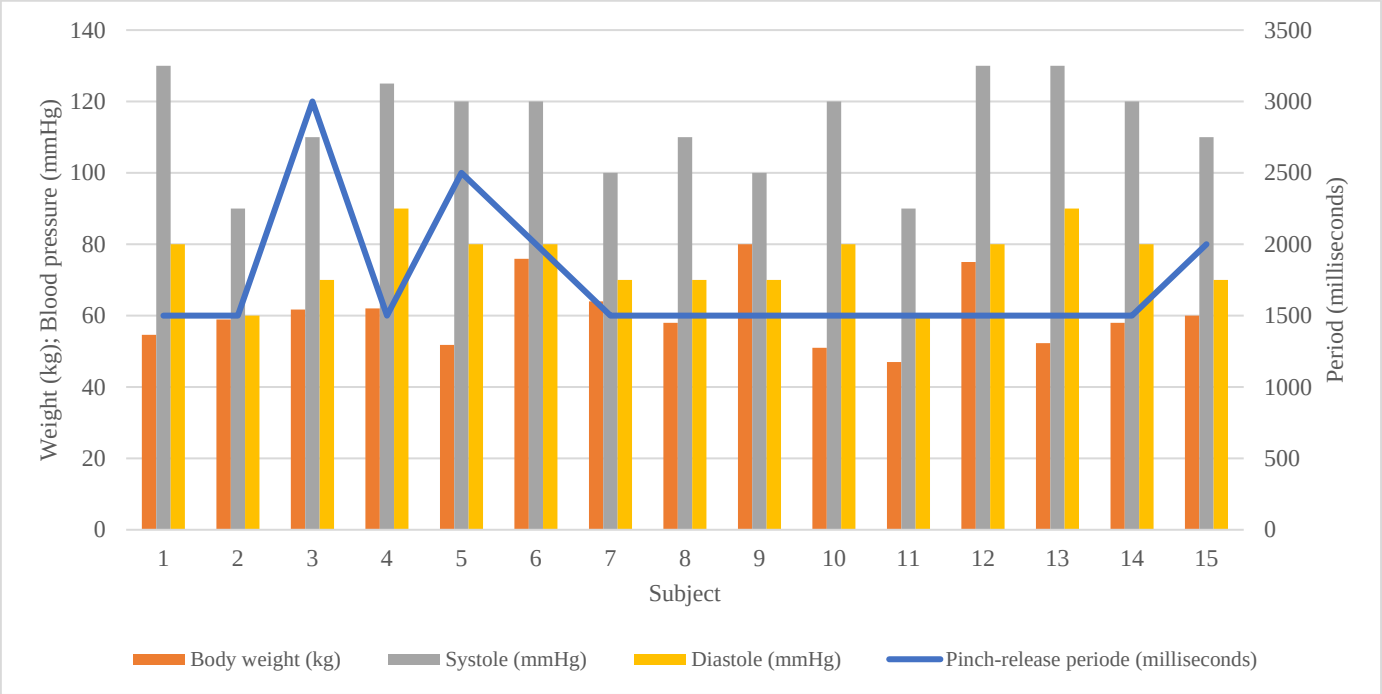

Figure 3. The comparison graph of subjects' weight, systolic, diastolic, and pinch-release period

It can be concluded that the parameters of body weight and blood pressure do not correlate with the effects of the drip rate of the infusion fluid using the pinch-release method. Therefore, based on the results of the tests, the variations in pinch-release durations that should be provided for the pinch valve are 1500 milliseconds, 2500 milliseconds, and 3000 milliseconds. Other bodily parameters not considered in this study that may impact drip rate include the narrowness of the blood vessels due to inherent structural characteristics or the psychological influence on the test subjects during the testing process.

Based on the testing results, performance time provisions for the pinch valve are outlined in Table 2. By default, the device operates using the first setting. Every 10 minutes, the weight of the liquid dispensed is monitored. The device will automatically switch to the second setting if the total weight is below the target. The device will transition to the third setting when the total weight remains below the target during the 10-minute interval.

If the device operates for 10 minutes under the default setting (first) and the measured weight of the dispensed liquid exceeds the target, it will automatically adjust to the fourth setting. The fifth through seventh settings are addressed to control high flow velocities. This high flow velocity condition was observed through 20% of the test results. This condition was reached when a single tick of the pinch valve produced a drop of liquid. This setting will be activated if the detected liquid weight approaches twice the target weight of the default condition (first setting). Consequently, for the next 10 minutes, the fifth setting will be employed.

After this 10-minute monitoring period, if the weight of the dispensed liquid is observed to decrease, the sixth setting will be implemented. The seventh setting will be activated if, after another 10 minutes, the total weight remains below the target threshold.

Table 2. Variations in pinch valve performance settings

Setting number	Pinch-release cycle period (milliseconds)	Release duration (milliseconds)	Adjustment detection limits
1	1500	60	The default
2	1500	70	If the total weight is less than the target
3	1500	75	If the total weight is still less than the target
4	2000	60	If the total weight exceeds the target
5	3000	70	The default setting if an extreme drip rate is detected
6	3000	75	If an extreme drip rate is detected but the total weight is less than the target
7	3000	60	If an extreme drip rate is detected but the total weight exceeds the target

Conclusion:

The drip rate control system using a pinch-release mechanism of the infusion line can be applied with several limitations observed in this study. Specifically, a speed of 20 drops per minute can be achieved with a cycle duration of 1500 msec, which is twice as fast as the theoretical setting. This condition was validated by 80% of participants. Conversely, only 20% of participants could achieve the targeted drip rate within the theoretical duration of 3000 msec. Therefore, it is concluded that the default setting of the device is 1500 msec. The measured weight will be monitored periodically to determine the operational period of the pinch valve over specific time intervals, ensuring the target weight of the infusion fluid delivered to the subjects is met. Otherwise, the controller will adjust the cycle period of the pinch valve to achieve the targeted weight. Additionally, testing the release duration of the pinch valve showed that 60-70 msec is effective in producing the desired drip rate while maintaining the comfort of the test subjects.

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