Managing Gravity Infusion Using a Mobile App

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ABSTRACT

Gravity infusion is a common and basic method for delivering fluids to a patient without the use of any complex medical device, such as an infusion pump or a syringe driver. Nevertheless there are many quite complex and error-prone steps involved in the setting up a gravity infusion for the correct dose, and since there is no technology involved to assist with the procedure, it can be difficult to guarantee the accuracy and consistency of the fluid delivery.

We present a new method for accurately setting the drug delivery, based on a handheld mobile application that includes a novel approach to help estimate flow rates and double-checking the steps involved in setting it up. This new method can reduce errors and slips with gravity drug infusions, as well as making each step simpler and less stressful for nurses to carry out correctly.

Categories and Subject Descriptors

H.5.2 [**Information interfaces and presentation**]: Miscellaneous; H.5.2 [**Information interfaces and presentation (e.g.,HCI**]: ????

General Terms

Design, Human Factors

Keywords

Human Computer Interaction, Medical Systems, Mobile Applications, Healthcare Technologies

1. INTRODUCTION

Infusion therapy, relating to administering medication fluids to a patient intravenously, is one of the most frequent practices within the healthcare domain. In the UK National Health Service (the NHS) around 15 million infusions are

Figure 1: App to help nurses carry out intravenous drip-rate infusions.

carried out every year. Unfortunately, there are approximately 700 unsafe incidents reported annually, and many more going unreported [?].

According to two major studies in the USA, between 44,000 to 98,000 people die each year as a result of preventable medical errors [?]. These rates are higher than those of deaths from motor-vehicle accidents, breast cancer and AIDS per year in the USA [?] and no doubt in any other country with western healthcare standards (or roads). The problem of drug dose calculation error has been identified in the literature [?]; there have been numerous incidents where calculating or entering the wrong dose — and administering it — has led to patient harm or death (e.g., [?,?,?] etc).

A professional case study by Lee [?] carried out in a large NHS hospital on the mathematical confidence levels of nurses, identified the lack of confidence when carrying out basic infusion rate calculations as an area for concern. In their day-to-day work nurses regularly need to carry out different types of mathematical calculations when administering fluids and drugs to patients. Calculators can be used as a way of double-checking their calculations, however calculators have been criticized for their design in regard to human error [?,?,?]. Another issue is that similar calculators (sometimes even from the same manufacturer) can work differently to each other, and can produce different answers when using the same key sequences [?]. Calculators also

have a tendency to display math equations differently to how we would usually write them out and this can sometimes lead to confusion, especially when performing a long calculation [**?**]. Calculators cannot be depended upon for correctly calculating an equation.

The use of a modern pump such as an infusion pump assists the safe delivery of IV (intravenous) medication. Around 90% of hospitalized patients receive IV medication through an infusion pump. Some "smart pumps" have a pre-installed drug libraries with fixed thresholds set for each drug. This, in effect, can warn the nurse of potentially inappropriate doses that they may try to administer; typically smart pumps have "hard" and "soft" limits, and while they avoid some types of error, they are complex to use and are often circumvented — it is easier to set a smart pump to a harmless drug like "saline" so it does not interfere with what the nurse does. However, whether smart pumps are used or not this still does not guarantee the calculation is right.

Modern electronic infusion pumps provide many features and are generally recommended to be used for delivering drugs to patients, but there are situations where nurses are faced with having to carry out infusions by gravity drips. Gravity drips are simpler and they do not suffer from battery failure: Lee *et al.* [**?**] review some of the problems.

In this paper we present a novel mobile application for the training and checking of gravity infusions. Our aim is to explore new ways of supporting healthcare tasks through the use of our everyday mobile devices. The application includes features for assisting healthcare staff through each of the tasks involved when carrying out gravity infusions — the initial medication calculation, setting up the drip and checking and monitoring the drip.

2. GRAVITY INFUSION
Gravity infusion is the most basic form of delivering fluids to a patient. It is delivered intravenously (into the vein) and is used for fluids that do not require a high level of accuracy, or in cases where drug delivery pumps are not available. Since there is no device to control the delivery, the infusion rate depends entirely on gravity. The flow rate is measured by counting the drops per minute. Gravity infusion is a popular method of infusion due to its low cost. However as there is no assistance from a device, there are more steps involved with the calculation relating to the delivery of any drugs to be administered in this fashion. Getting each of the steps right in calculating and delivering the drug is important to guarantee the safety and well being of a patient.

2.1 Mathematical Calculation
The first step in carrying out a gravity infusion is to calculate the correct dosage based on the patient's prescription. Each patient's prescription is delivered from a fluid bag that can vary in size from 50 mL to 2 litres and is delivered through an IV "administration set" (flexible tubing to deliver the drug). Each administration set will have a "drop factor" size. These sizes can be 10 drops per mL, 15 drops per mL, 20 drops per mL and 60 drops per mL.

To calculate the intended drip-rate of a gravity infusion you need to divide the total volume of fluid (in milliliters) by the total time required for the delivery (in hours) and then multiply by the drop factor (number of drops per mL). This gives you the total number of drops required per hour. To convert this to drops per minute, you need to divide by 60.

The full formula is:

$$\text{Drops per minute} = \frac{\text{Total volume, mL}}{\text{Total time, hr}} \times \frac{\text{Drip factor}}{60}$$

Although this type of calculation is not particularly difficult to calculate, there are many steps involved before the final answer can be obtained, also each variable in the calculation needs to be carefully converted to the correct unit of measurement. Nurses that do not regularly carry out this calculation can easily forget some of the steps involved in carrying out this in practice. One should remember that remembering and correctly performing the calculation under clinical conditions is very much harder than reading the explicit calculation above while reading a research paper!

Another calculation is also required. The nurse has adjust the actual drip rate to be equal to the calculated drip rate. This involves counting the drips in one minute and making appropriate adjustments. This is a lengthy process, and fortunately it suffices to count drips in 15 seconds and then multiply by 4. The advantage of having a shorter time and counting fewer drops (and therefore missing fewer drops and having less time to be interrupted by other tasks) is finely balanced against the additional step of multiplying in by 4.

Nurses often write down common calculations on anything handy, such as tongue depressors. This workaround is an indication of the difficulty of the task for the nurses in real clinical environments.

2.2 Setting the Drip-Rate
Once the drip-rate has been calculated, the nurse can then begin to set up the gravity infusion. This involves hanging the bag of fluid on a steady drip stand and connecting the correct administration set from the bag to the patient. The administration set has a "drip chamber" (shown in figures **??** and **??**) built on to it, which is used by the nurse to measure the flow rate of the fluid (that is, watch the drips and time them against their watch) and adjust a roller clamp to make the flow rate correct. The flow rate is measured in drops per minute.

One of the problems with this is that it can be time consuming; adjusting the roller clamp, looking at your pocket watch, counting the drops, and trying to adjust the clamp to achieve the precise drip-rate. Gravity infusion rates are often therefore approximated.

2.3 Checking and Monitoring the Drip-Rate
Even after completing the process you still need to check that the rate has not changed of a period of time. Many factors can influence the drip-rate of a gravity infusion, from the patient moving their position, changes in temperature, through to change in the position/height of the fluid bag. As this is gravity infusion there are no devices used to monitor a drip's activity or alarms to notify staff of changes. It is up to the nurse to do regular checks by manually counting the falling drops against the second hand on their watch. They

will usually count the drops and estimate the drip-rate; that is, they count drops for approximately 15 seconds on their watch and then multiply by 4 to get an estimated number of drops per minutes.

3. A MOBILE APP FOR TRAINING AND CHECKING GRAVITY INFUSIONS

We worked directly with experts in healthcare (in the National Health Service, the NHS) and carried out user-centred design approaches with agile methodologies to allow users to feed into the design process to develop a system that would suit their needs. We followed the recommendations of ISO Standard 14971, *Medical devices – Application of risk management to medical devices* and ISO Standard 62366 *Medical devices – Application of usability engineering to medical devices.*

We developed a mobile solution (see figure **??**), which can be used for training purposes and also as a "checker" for nurses when carrying out gravity infusions. The app has features for calculating, setting and checking infusions.

We will now discuss how each of the implemented features in the mobile solution can be used to carry out gravity infusions safer and briefly describe the usability techniques that were used in the development of the system.

3.1 Calculating the Right Dose

Infusion calculations are carried out in a hospital on a daily basis. It is crucial that the dose is calculated correctly to ensure the safety and well-being of a patient.

Figure **??** shows the design of the interface for calculating drip-rates. There are three main steps to the calculation:

1. Total volume of the drug to be infused (in milliliters),

2. Total time of infusion (hours/minutes), and

3. The drop factor (which is written on the administration set).

One of the key problems with many software systems is that they do not always check for human error. As humans, we make mistakes, which is why it is critical that we design safety mechanisms into healthcare systems to detect input errors from the user. Some of the problems with modern calculators and how they ignore human error are raised in [**?**], and there are many reports (both individual cases in the media and in research) of calculation errors being a leading cause of medication errors [**?, ?, ?**].

4. USABILITY ENGINEERING

We followed Nielsen's [**?**] usability heuristics for user interface design.

We now summarize some of the error-prevention methods we engineered into the design to help carry out safer calculations for infusion drip-rates:
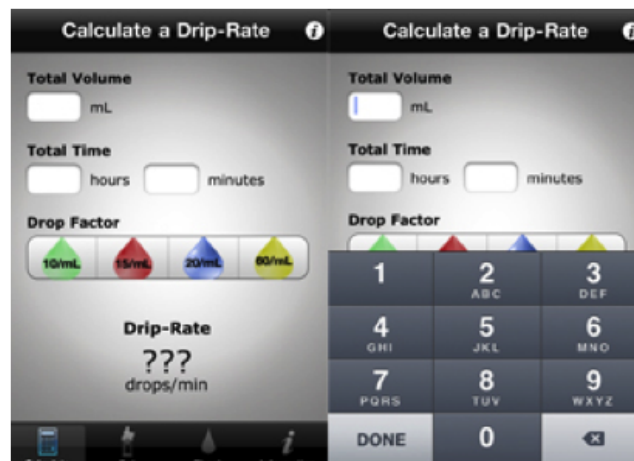

Figure 2: User interface for calculating drip-rates.

4.1 Minimize the User's Memory Load

All steps of the calculation appear on the same screen. This reduces the memory load and allows users to see previous steps in the calculation, which lead to the answer.

4.2 Aesthetic and Minimal Design

Calculations are very clear to read by breaking down each step in the calculation and using a larger font for answers. The user interface contains only what is needed for the calculation.

4.3 Help Guides

Located in the corner of the interface, the "information" icon pulls up the help features, which explain each calculation step to the user in case they get stuck or confused. It also includes the formula used by the app for the drip-rate calculation.

4.4 Error Prevention

Units and conversions are automatically calculated. Correct symbols and abbreviations have been used. In particular, we adhere to the Institute for Safe Medication Practices guidelines [**?**]. For example "100mL" is correctly represented as "100 mL" with a space between the dose and unit of measure, and a capital L is used for litres, since l (the letter) is too easily confused with 1 (the digit). The space helps prevent the "m" from being mistaken as a zero or two zeros (e.g., when written badly by hand), risking a 10- to 100-fold overdose.

Each input field has been capped with a threshold to prevent any accidental lethal doses. "Total volume" cannot be bigger than 4 dgits and the "hours" and "minutes" fields cannot be greater than 2 digits each. The "drop factor" can only be a value of 10 mL, 15 mL, 20 mL or 60 mL corresponding to the value on the administration set. For this we used graphical icons to represent the values, where only one can be selected at a time. By default, no value is selected. When a value becomes selected, its button will change its state and display as highlighted. This eliminated the chances of a user entering an invalid value and saves time key pressing.

Decimal points have been removed from the number pad, as they are not needed in this type of calculation, eliminating

Figure 3: Interface for setting a drip-rate. The user adjusts the clamp to synchronize the real drip chamber (shown on the left) with the visual animation on the app.

the chances of decimal point errors [**?**].

4.5 Visibility of System Status

The interface keeps the user informed about the state of the calculation by revealing an answer when all three parts of the calculation have been correctly entered.

4.6 Recognition Rather Than Recall

Each step in the calculation is visible and nothing is hidden. The user is not required to remember any information from one step to the next.

4.7 Visual, Audio and Vibration Output for Better Guidance

Once the drip-rate to an infusion has been calculated, the next step for the nurse to do is set this rate. This involves adjusting a roller clamp and counting the drops in the drip chamber against the seconds-hand on their watch. Carrying out this process and getting the right rate can be tricky and therefore the rate is usually approximated. One of the ways that we thought could help this procedure was through using some of the affordances that a mobile device offers — namely visual, audio and vibrations.

Figure **??** shows the user interface for supporting the setting of a drip-rate. Users first enter the drip-rate value, which may or may not have been calculated using the calculate feature. Once a drip-rate value has been entered, checks are made to ensure the value is not over the threshold limit. Once the value has been validated and approved, the visualization can start. The visualization mimics the design and characteristics of a real drip chamber. Drops will fall from the top and down into the chamber, repeatedly at the speed of the dripping rate that was entered by the user. When this visualization begins, a timer and counter also begins. The timer starts from zero and counts the time the drips. The counter counts the number of drops that have fallen for each second. This visualization feature is further supported by the use of sound ("drip falling" sound) and vibration feedback when a drip falls into the chamber, to guide the user

Figure 4: Interface for checking drip-rate. The user taps the screen each time a drop falls.

if they are unable to view the screen continually — which is likely, as they are also watching the actual drip chamber.

The idea behind this feature was to guide nurses better when setting up a drip. A nurse can hold the visualization up against the real drip chamber and try to synchronize the accurate on-screen representation against the real one, which they try to achieve by increasing/decreasing the wheel of the roller clamp on the administration set. We suggest that it can reduce nurse workload by not having to count the drops and time manually, instead matching the rate of the app's visualization. It may also be quicker and could even help achieve the precise rate that needs to be set. See Further Work, below, in section **??**.

4.8 Touch Input for Counting Drops

Infusions that are administered by a medical pump (such as an infusion or syringe pump) have the advantage of monitoring the infusion over the infusion's total time set. With gravity infusion there is pumping mechanism to deliver the medication or any tools to monitor the infusion. The nurse is required to regularly check that the drip-rate has not changed and that the patient receives the total specified amount of medication.

In figure **??** we show a feature developed for checking the drip-rate of a set infusion. The approach should be compared to current methods for counting the rate of drips, which involves a nurse holding out a pocket watch, simulaneously counting the number of drops that fall against the time elapsed, and performing the appropriate calculations.

As we earlier said, counting how many drops that fall in 15 seconds, then multiplying this value by 4 to get an average total number of drops per minute (of course 4×15 s $= 1$ m). The feature that we have developed works by touching the large "drop" icon displayed on the interface, each time a drop falls. When the user first touches the screen, it will begin a timer and count the number of drops against the time.

The user continues to tap the interface whenever a drip falls in the chamber. The software measures the intervals be-

tween each screen press and looks for a consistent, steady pattern in the rate. When a steady pattern has been made, the software prints an alert to the screen, informing the user what the drip-rate value is. Instructions and previous recordings are displayed on the interface to avoid confusion and reduce memory load. The idea behind this feature is that nurses might be able to perform these regular infusion rate checks quicker and also remember what previous recorded rates were. As this feature relies on the user's reactions as input, it is only safe to say that the final figure is an approximation. Some initial testing, which has been carried out on a fake infusion, using a bag of saline showed that this feature achieved drip-rate values that were within a ± 3 range. Although it might not be possible to achieve the exact figure every time, it has shown new ways of carrying out infusion checks, which can act as a useful training tool for trainee staff. We aim to carry out further in-depth studies and focus groups on the evaluation of this feature with qualified staff nurses.

5. FUTURE WORK

When we designed this system we used focus groups and expert users to inform the design, and this allowed us to fine tune the initial design. This has now been downloaded over 20,000 times in over 25 countries worldwide.

We are now carrying out user studies with nurses and related healthcare professionals. We are also collating feedback from people who have downloaded it from the app store and using it. We are interested in knowing how practitioners are using the app and how we can build on from its current features. Technically, we are examining the use of Augmented Reality interfaces that would allow the user to capture drip-rates using the phone's camera. We are also examining the use of the system in a training environment and the way that as part of training the system could be adapted to have more social elements

6. CONCLUSIONS

This paper has addressed some of the issues and difficulties with carrying out gravity infusions. We have presented a mobile solution, which can help nurses and practitioners in carrying out drug infusions safely and accurately. Although we still need to carry out user studies to evaluate the efficiency and usefulness of these features, our development has shown new ways of thinking about how we can develop simple, accessible mobile solutions that improve the quality of safety when carrying out important drug infusions.

Acknowledgements

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