Rental infusion assistant

Design Process Journal

2021-2022 MSc PDE
Tutor Jon Barnes, Craig Whittet
Student Xiangyu Jin

GSoFA

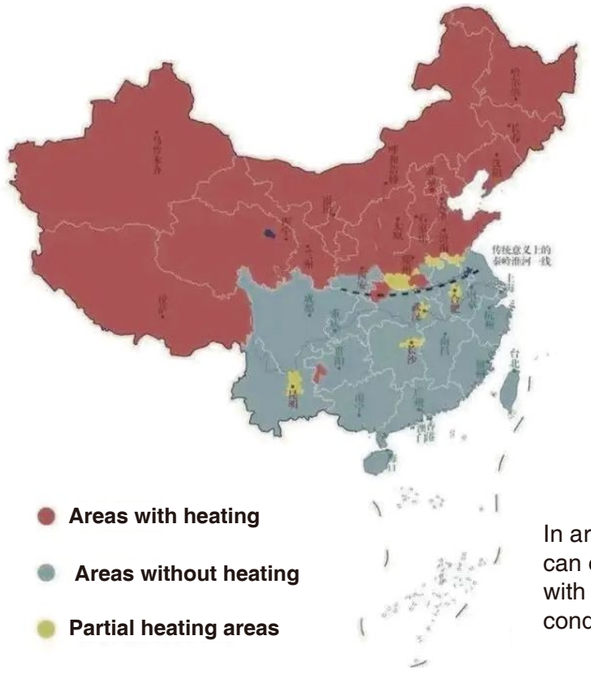
University of Glasgow

Motivation

The motivation of my Major project is from my own experience. It comes from a fever and I need go to the community hospital to get infusion. That was a winter afternoon, and the room temperature was around 10 degrees, so as the infusion liquid. After 10 minutes of infusion, my whole arm was frozen. I can still remember the feeling of my high body temperature conflicting with my cold right arm.

This problem has caused me to think about the infusion experience. Is there has not any infusion heater?

Elders using body heat to warm the infusion fluid upf or their children



In areas without heater, heating the room can only be done by an air conditioner with a heating function. This kind of air conditioner is not common.

Initial Research

Interview with patient

After discovering the problem I started to interview some people who had infusion and asked them if they had experienced the same thing. Here are a few experiences from patients who have experienced cold infusions and have had solutions:

I live in a city in northern China, but I have also experienced cold infusions, which are very uncomfortable. Because the infusion rooms are very large and out side was so cold. The room temperature is not very high even with heater. We usually just wrapped the infusion tubes around **hot water bags** and then wrapped them in clothes.

I live in central area in China, which is a rather awkward position to be in. It's not really northern so there's no heater, but it's not southern enough, so it's cold in winter. It was a long time ago that I encountered this situation. Back then we still had glass bottles for infusions and the nurses would give us **hot water in these bottles** to make hot water bottles to heat the tubes.

I live in a city in central China, and it's not very cold here in winter. What I remember is that when I went for an infusion last time when I was in col-lage, the nurse told me that it would be very cold in this temperature and she gave me a **heating patch** to wrap around the IV tube to heat it up, I don't know how much it heats up, but I really don't feel uncomfortable anymore.

Interview with Experts

After the initial interview with the patient I started to ask the people who knew the most about infusion - the nurses. They have many years of experience working with a very large number of infusion patients. Interviews with them would help me to understand the problem in more depth.

We have a heated infusion unit in our outpatient clinic which is **very complicated to operate** and is **not normally taken out for use** unless the patient has severe symptoms. Community health centres, for example, do not allocate such equipment.

She worked as an outpatient nurse in a Grade A hospital in Shenzhen

I get quite a lot of patients complaining that their infusion is too cold. As the infusion is usually given once a day for a few days, I usually ask them to bring their own hot water bag for the next infusion in this case. In the event that the infusion is really not possible at the time I will try to **reduce the flow rate** as much as possible, which will be better.

She worked as a university school nurse in Sichuan(Cities in the South West)

Insight

During my interviews with specialists and patients I gained a better understanding of infusion and gained insight :

1.The base fluid for the infusion is basically kept at room temperature, so it is normal for it to be very **cold in winter**

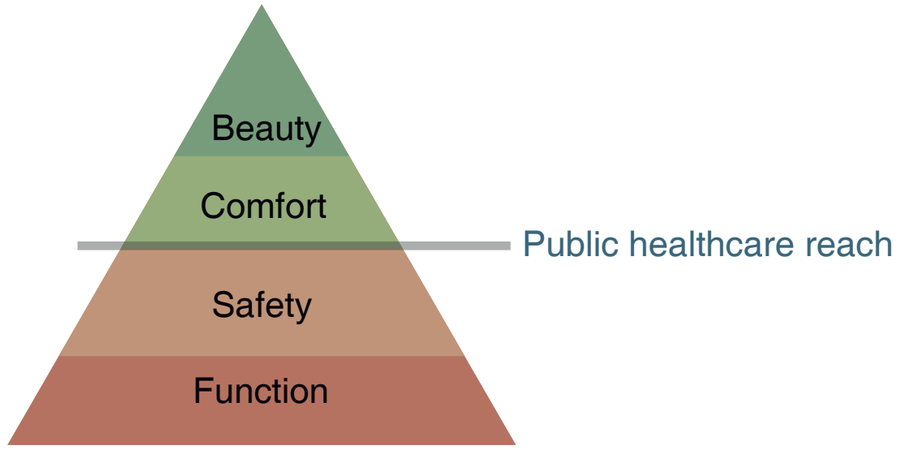
2. Because medical resources give the highest priority to the basic needs of patients, such as survival and health. Comfort is a higher level of need. This is why the hospital's infusion heating equipment is **only available for patients with very high needs**. For example, in nursing wards, operating theatres and for the very frail patients.

3. The hospital industry is not a service industry and the **user experience is not their main concern**. So for the ordinary, occasional patient who wants a better user experience, the patient has to pay for expensive infusion heating equipment or use cheap and unsafe products

4. In winter, if the patient has not experienced cold infusions, he is unaware of the problem and **cannot prepare for it in advance**.

5. Doctors and nurses are emphasising the policy that hospitals are now treating patients without infusions, so in interviewing patients I found that **infusions are becoming less frequent**.

6.An infusion temperature of **around 25 degrees is sufficient** to keep the patient from feeling very uncomfortable and is an effective "warm" fluid.The infusion temperature of around 25 degrees is sufficient to keep the patient from feeling very uncomfortable and is an effective "warm" fluid. It also reduces the amount of air that precipitates out of the fluid without the need for a high temperature.



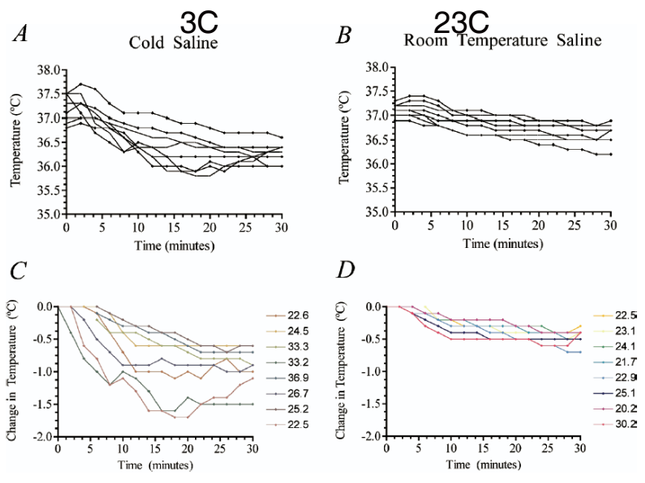


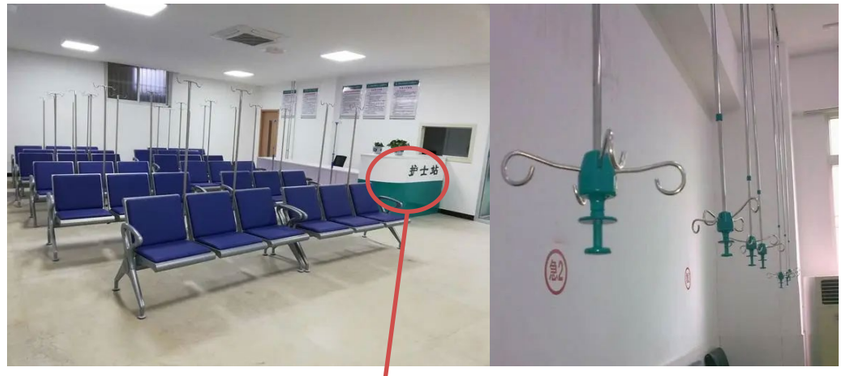
Figure 1. *A, B,* Time versus core temperature (mean [SD]) for the cold (n=8) and room temperature (n=8) groups. *C, D,* Change in core temperature over time.

Environment

In interviews with patients and specialists, and in reading the literature on infusion, my understanding of the environment and conditions of infusion has become more and more detailed.

General infusion rate: 40-60 drops/min for adults, i.e. 2-3 ml/min, except for individual fluids that require rapid infusion, e.g. mannitol. Elderly and children <40 drops/min, i.e. <2ml/min.
250-1000ml for minor cases (depending on the type of illness).

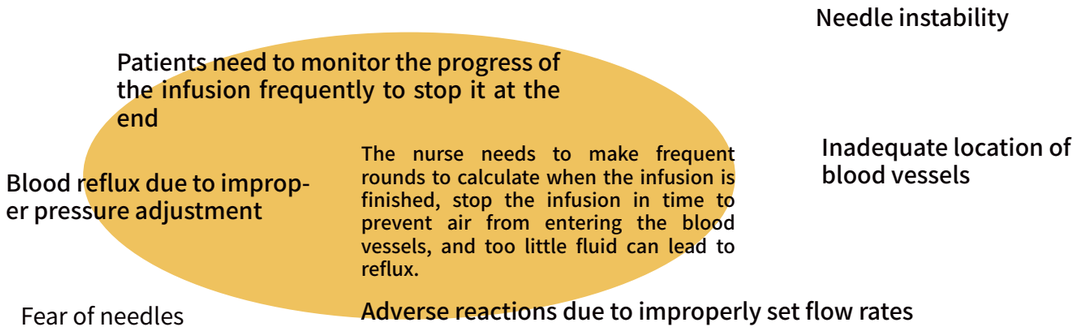
Infusion environment: From small community hospitals to provincial tertiary hospitals, infusion patients are usually clustered in the infusion hall for infusion. This makes it easier for nurses to provide timely assistance to patients. There is usually a certain amount of seating in the infusion hall and it is not guaranteed that there will be a power outlet near every seat. Hooks for hanging infusion bottles are probably divided into floor stands and ceiling-moving hooks. There must be a nurse's station or nurse's desk around the infusion area, as patients need prompt assistance from the nurse.



Floor stand hooks
infusion area with nurse desk
ceiling-moving hooks
These will affect the form in which the product is used

Expanding the scope

In interviews with patients and doctors, I don't start by asking about cold infusions. I ask them about the problems they experience with infusions, get a series of broad answers, and then ask specific questions. So during the interviews I also gathered a number of common issues that can affect the experience during an infusion.



In the initial concept, the product is closely linked to the infusion tube, so the issues associated with it that might be optimised together will hopefully be addressed together and then give patient a better infusion experience.

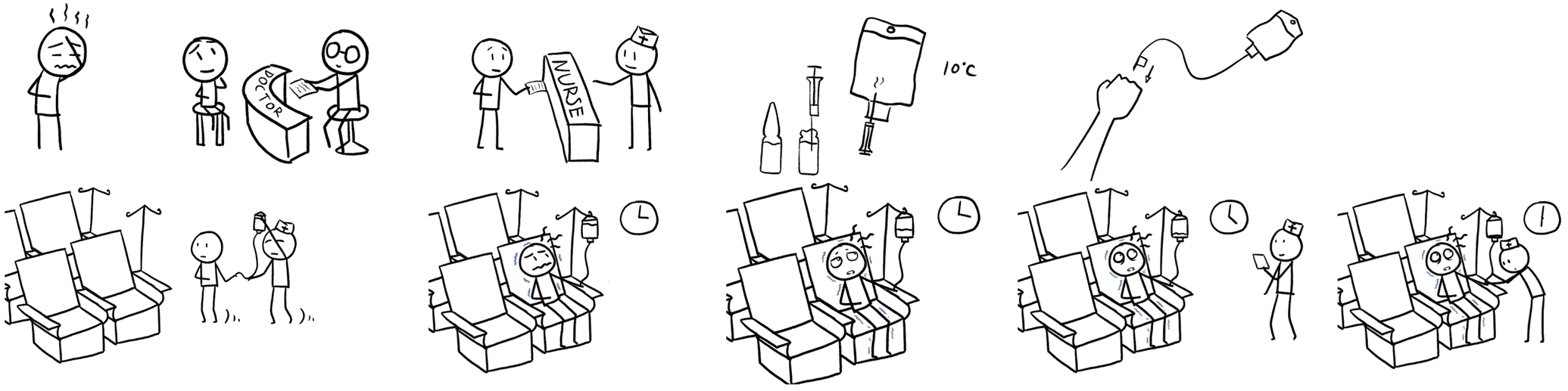
PERSONA

Wang Yihui
Age: 26
Gender: Male

Yihui lives in Sichuan, a city in southwest China. He loves to taste food and will often spend his holidays looking for different cuisines everywhere.

Just yesterday, it seems that Yihui ate some kind of unhygienic food and he vomited and had diarrhoea, a symptom of acute gastroenteritis. He needs to be seen by someone in hospital and there is a good chance that the doctor will put him on an infusion as a way of replacing the large amount of electrolytes it has lost and providing nutrition. It was a winter day, it was raining outside and Yihui was having a very hard time knowing what he was going to face next.

Current user journey



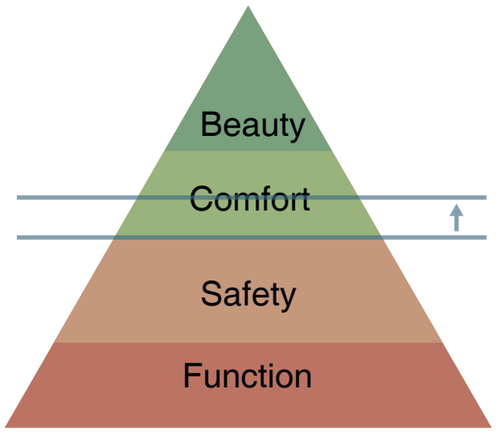
The patient will first go to the hospital to talk to the doctor about his symptoms and condition. After diagnosis, the doctor will issue a prescription for the medicine and the patient will take the prescription to the nurse at the nursing station, who will then help the patient to mix the fluids he needs for the infusion. Once the injection is completed, the nurse will take the patient to a nearby infusion room. During the infusion process, the patient feels the cold fluids entering his body, his core temperature drops and he starts to shiver and feel uncomfortable. At the same time, despite the regular rounds by the nurse, the patient needs to observe the progress of the infusion in order to stop the infusion in time for the end of the infusion. After the infusion is completed, the nurse will help the patient to remove the needle.

Market research

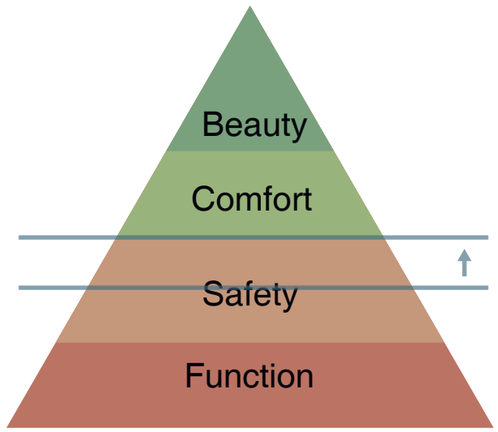
The existing infusion heating products on the market are generally at two extremes. One is highly professional, with excellent results and precise temperature control, and some are specifically designed for rapid infusion and surgical blood transfusion. One is cheap, because the frequency of infusion for ordinary patients is extremely low, and if they need infusion heating products they also need to be infused in winter. Under the constraints of multiple conditions, it is a very uneconomical thing to use high priced infusion equipment, which is often used once and then left idle, which is also a waste of resources. In this case, there is a large market for low-cost, unsafe infusion heating products.

Initial Concept

Target audience: My main target audience is the general patients who occasionally fall ill and need an infusion. This group of patients has already reached the Safety level without the aid of a heated infusion device, and their infusion experience would be enhanced and made more comfortable with the aid of a product. For the more frail patients who cannot meet the Safety requirements without infusion heating, such as the frail elderly and the critically ill who require large blood transfusions, they are not my target audience and require a more specialised infusion heating device. Hospitals will also provide these patients with the infusion heating equipment they need.



My design hope to help them reach
general patients who occasionally fall ill



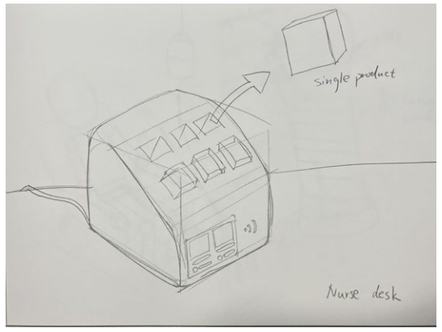
Public healthcare will help them reach
Weak patients lacking infusion heater

I wanted to design a product that would be lightweight, portable and easy to use, as opposed to traditional professional infusion heating equipment.

Storyboard

In contrast to the previous user journey, the user can rent an infusion aid from Base at the nurse's station while waiting for the nurse to dispense and can wrap the infusion aid around the infusion tube once seated. When the tube is detected to be empty it automatically rotates and snaps into place, sending a signal to Base that the infusion is complete and, on receipt of the signal, the corresponding backlight lights up to alert the nurse behind the table. The nurse then goes to help the patient to finish the infusion.

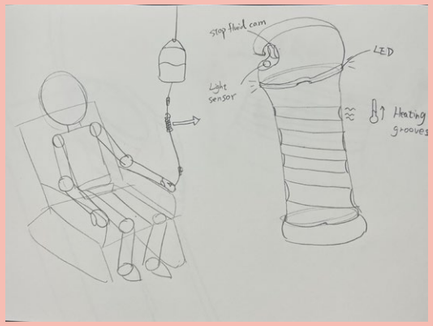
Problem: Allocation of medical resources
Aim: Low cost-Business model for renting



In the initial concept, patients can rent a single product to assist them with their infusion via a base that stores multiple individual products. This base would be placed at a nurse's station or nurse's table and linked to a power supply to charge the individual products.This Base will help manage loaned products.

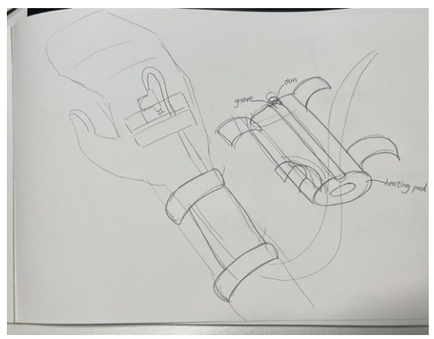
I chose to rent this product rather than sell it. This is because the frequency of infusions is decreasing and if you buy infusion aids yourself, the usage rate will be very low, which is not only more expensive but also a waste of resources. This is a costly and wasteful use of resources. The Base allows the cost of the product to be spread evenly over each loan, reducing costs and increasing usage. The rental base also serves as a reminder to the patient of what to expect during the infusion (cold infusion) so that the patient is not unprepared for cold infusions again.

Problem: Cold infusion; Patient can’t rest
Aim: Suitable liquid temperature and Stop infusion in time



Concept 1

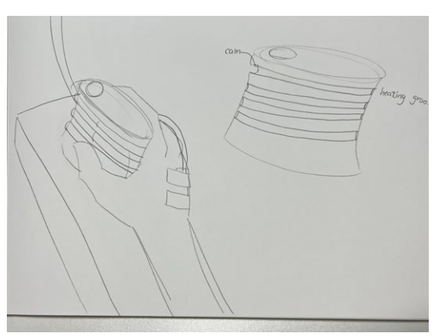
In initial concept 1, this product is used suspended from an infusion tube. The body of the product has grooves for fixing the infusion tube, which is continuously heated. The head and tail of the product have slots for fixing the infusion tube, and in the head slot there is a light sensor to sense the infusion status. The cam is responsible for stopping the infusion when it is finished and the LED alerts the patient and nurse to the status of the infusion.



Concept 2

Concept 2 was inspired by a paper entitled 'An investigation into methods of heating intravenous fluids', which referred to the concept of direct heating of the skin at the injection site. This method of heating causes the local blood vessels to dilate, increasing the rate of circulation and allowing the drug to enter the vessels to dilute quickly, thus reducing irritation to the vessel walls.
This allows the drug to be diluted quickly, thus reducing irritation to the vessel walls. At the same time, it prevents the rapid warming of the fluid and the precipitation of air bubbles.

However, Concept 2 is not very friendly to the rental model, as it has an irregular shape and is in direct contact with the skin. There are also problems with fixation, such as how to fix it, how to reduce the pressure on the patient due to fixation, and whether it will restrict the patient's hand movement.



Concept 3

Concept 3 is essentially the same principle as Concept 1, with differences in form and use. They both have heated slots, a photoelectric sensor and a cam to stop the infusion. The form is an easy to hold shape similar to that of a vertical mouse. The expectation is that the user will be able to hold it and use it to enhance the insulation of the infusion aid and to keep the user's hands warm when exposed to cold temperatures. It will also facilitate the retention of the needle. However, it is too similar to Concept 1 but not as straightforward as Concept 1, so it was not chosen.

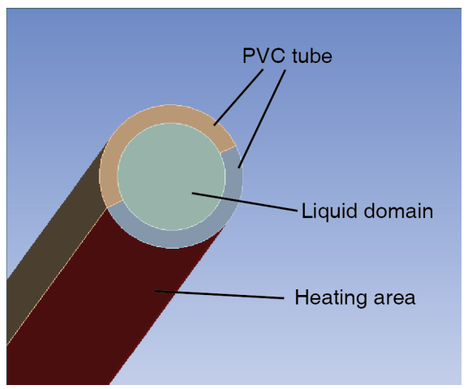
Development

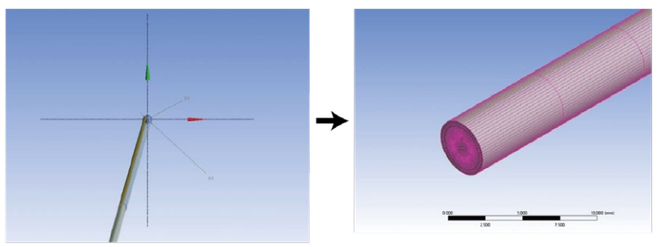
In order to reduce the size and weight as much as possible I needed to find a lower limit to the size of the product, so I first calculated the energy required to heat a standard infusion bottle of 500ml to a target temperature of 23 degrees using simple conservation of heat. I then used the heat transfer efficiency and estimated component consumption to roughly calculate the overall energy consumption and finally chose a 21mm diameter, 70mm long cylindrical battery.

Lithium polymer batteries
Model number:21700
Size: Diameter 21mm length 70mm
Volumn: 4000 mAh
Voltage: 3.7v

Safety protection:
Built-in IC protection board to prevent over-shoot, over-discharge, over-current and over-voltage

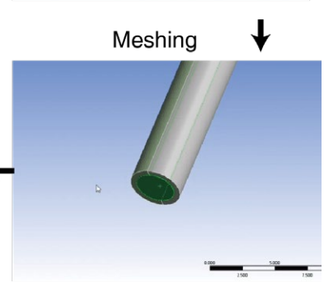
To set the appropriate heating temperature and determine the appropriate heating area, I used the fluid software in Ansys Workbench to simulate the heating in a realistic environment. First, a simple geometric model is created using Design Modeler in Ansys. The model data here is derived from the most common infusion tube specifications.



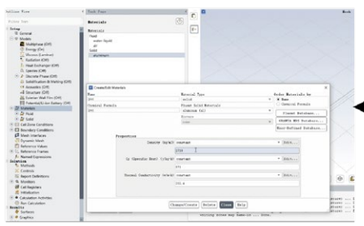


Geometry modeling

Meshing

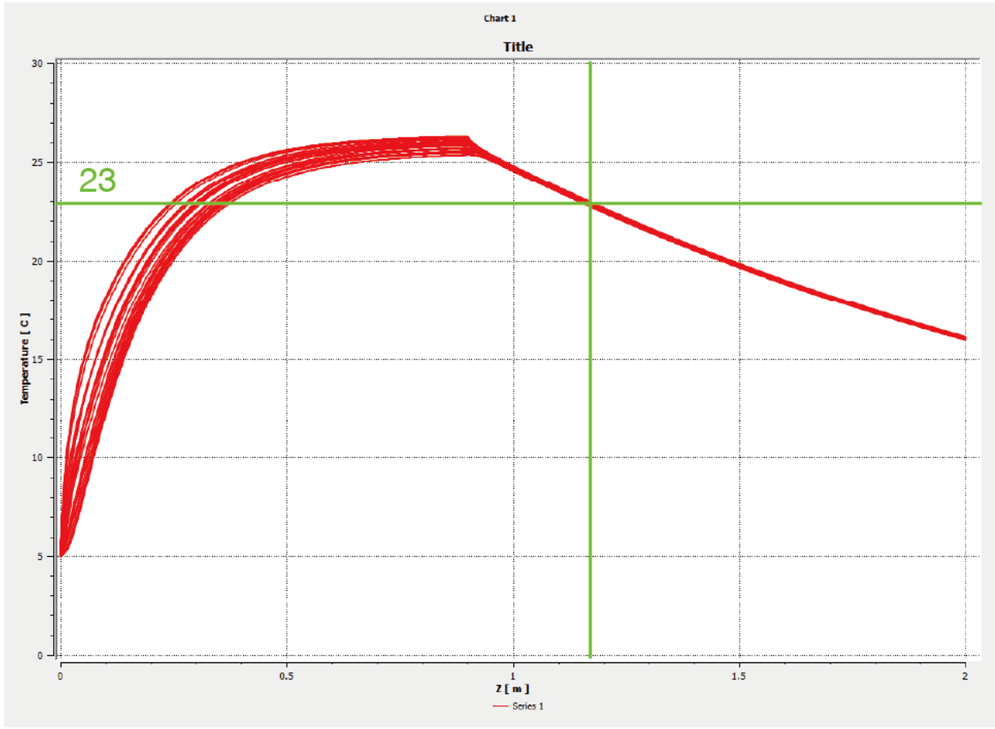


Division of fluid and solid domains



Giving materials to different domain
Set heating temperature and liquid flow rate

A standard size infusion tube is heated by a 90cm long semi-circular heating pad at a cold room temperature of 5 degrees. The following table is obtained.

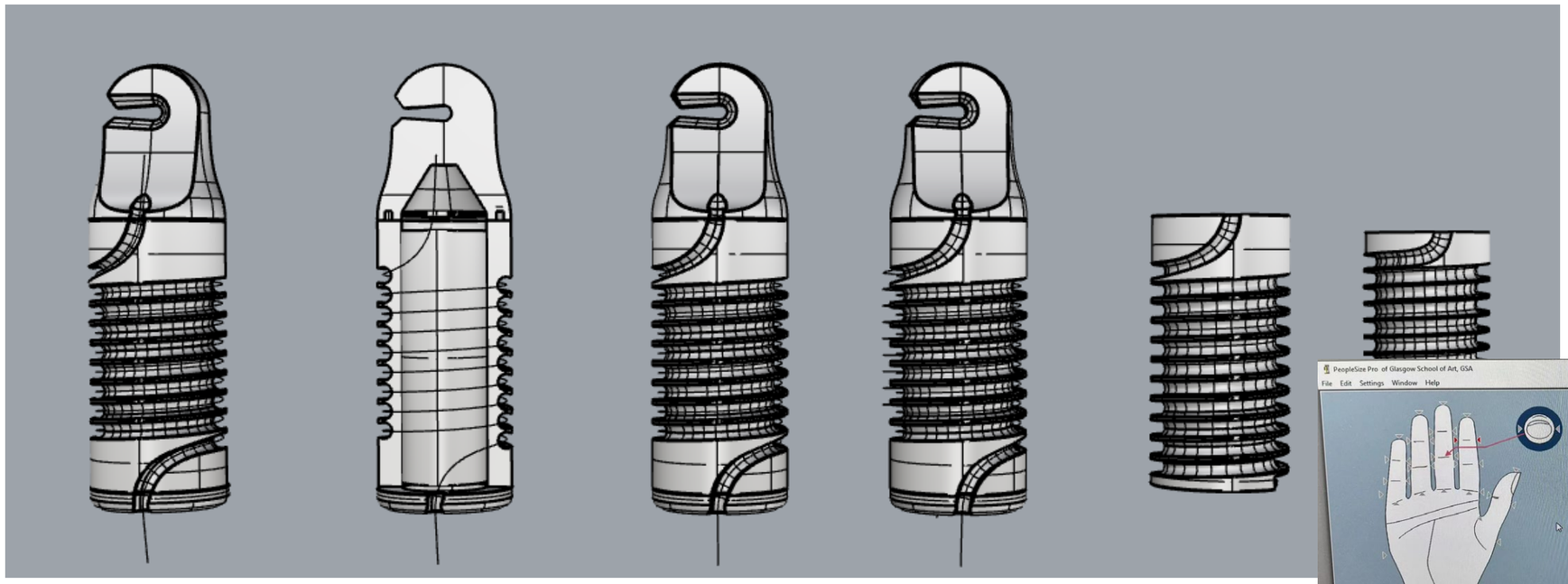


The red line in this table represents the water flow, the water flow close to the side of the heating plate will reach the target temperature faster. You can see that the heating efficiency is highest around 0-50cm, eventually approaching the target temperature. Subsequently the temperature of the fluid in the infusion tube continues to drop because of the low room temperature.

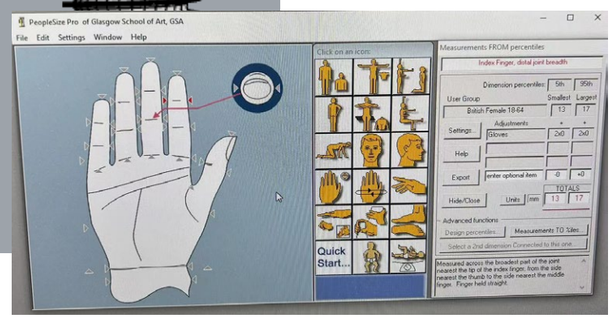
Based on the recommended static pressure of one metre for gravity infusion and the conventional 2m+ infusion tube length on the market I set the maximum heating length of the infusion aid to 85cm. This heating length is fully effective at the extreme temperature conditions and 90% of the heating effect can be achieved as long as the wound infusion tube is over 50cm. Also, according to the chart we can obtain that we cannot use the product too far from the injection, as the temperature loss will cause the fluid entering the body to fall below the target temperature. This distance is 30 cm in the extreme temperature environment. in the end, I set the output temperature at 27-23 degrees, which is adjusted according to the initial fluid temperature detected by the temperature sensor.

This simulation also changed the initial idea of using the product at the beginning of the tube, as the liquid would also lose a significant amount of heat bottom during the rest of the stroke.

Prototyping and usability testing



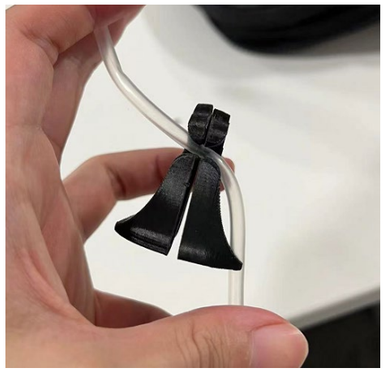
The average width of a person's index finger is also a reference for the width of the hook section of the product



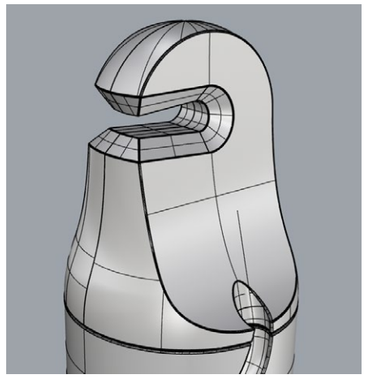
After the basic shape had been finalised it was time for some detail changes, followed by prototyping and usability testing.

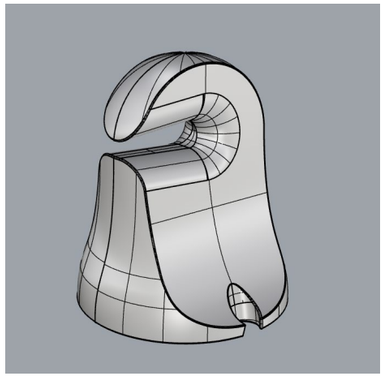
The entire model is divided into three general sections: the hook section, the middle section and the base. The first part to be printed was the middle section. The initial prototype was 3D printed and was very different from what was imagined. The size of the infusion tube was too small for a standard infusion tube, and the tolerances of 3D printing and the limitations of the printing method forced me to re-partition the parts for printing. Crucially, the turn of the infusion tube was too sharp and seriously affected the flow of fluid.

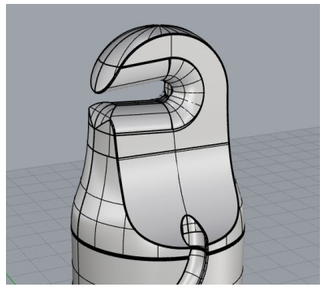
On the fourth print, I obtained a radius that was very suitable for bending and adopted this radius of curvature for the final prototype in the middle section.



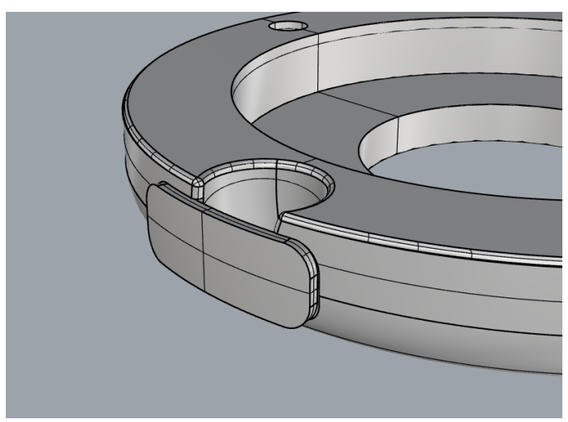
The same problem of obstructing the flow of liquid was encountered in the prototype tests on the hook section, where the cross-section of the infusion tube was significantly increased after easing the sharp angle. A curvature has also been made at the entrance to the hook that is easy to hang in.

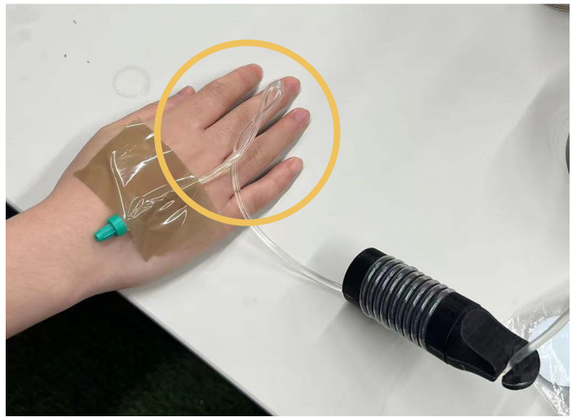


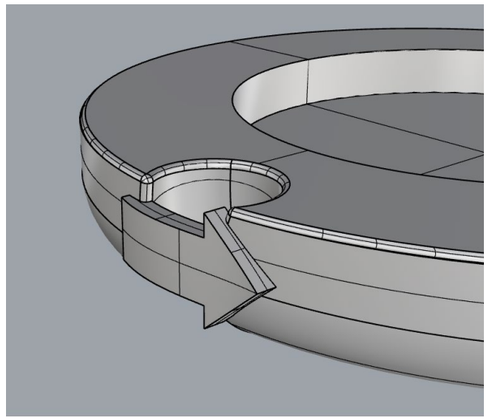




During the prototype tests on the bottom it was found that the bottom was important for the retention of the infusion tube, but the existing model was still deficient in this respect. It was therefore decided to add rubber parts to the recesses of the bottom to provide a critical fixation.







In a number of user tests in simulated environments, I have found some issues that affect the experience of using the product. The product was presented to the user without any instructions to test the user using intuitive use. A number of problems were identified: some users would start winding directly from the middle of the tubing and would encounter some obstructions such as the speed regulator. Other users would start winding from the head, resulting in too many rotations of the tube and twisting and mugging. For this type of use I have chosen to provide simple instructions for new users. A website with instructions is added via a QR code on the body, which advises the user to wrap the tube around the end of the tube and start at the bottom of the product and wrap upwards.

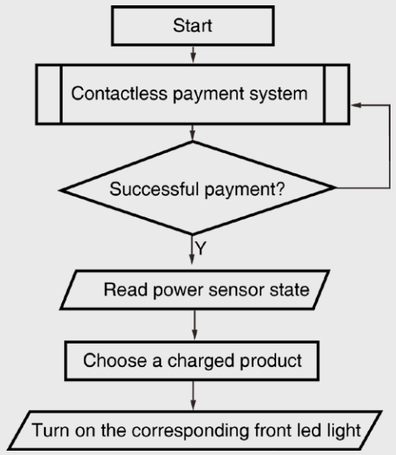
Adding signs to guide the user encourages the correct way to use the product. I have changed the rubber at the bottom that holds the tubing in place to an arrow shape that instructs the user to wrap from the bottom.

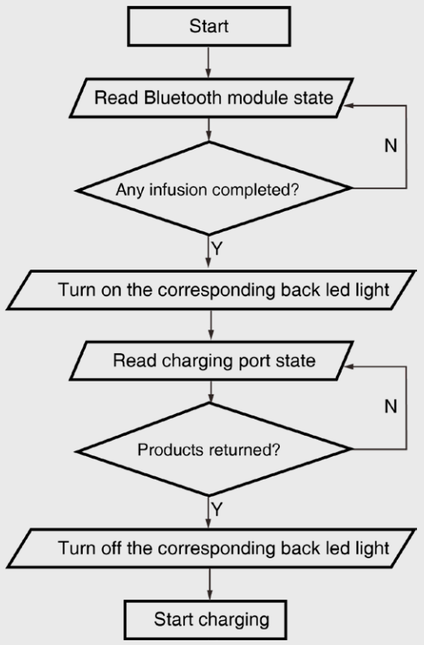
In the different user from operations, diverse and safety-compliant usage modes are also supported, such as winding the tube halfway when it is not long enough. After the winding is complete, the product is held in the hand. Because the heated output temperature is not higher than body temperature, no accidents such as burns can be caused even if the product is held.

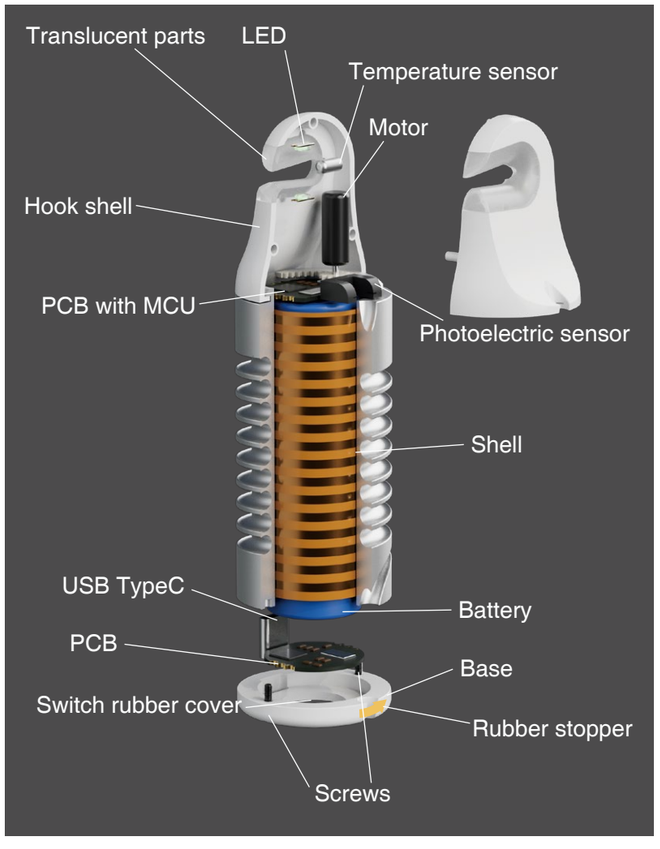
Principle of operation

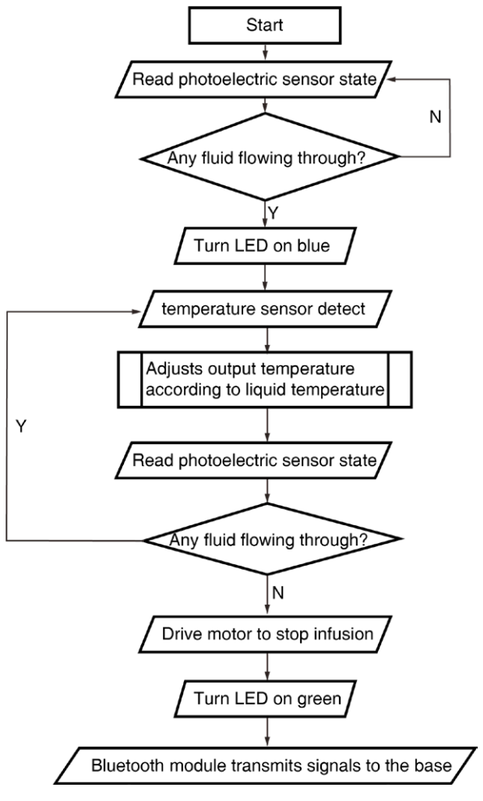
The design of the base is a relatively simple part, also because the distribution of workload is mostly divided above the infusion aids. The base was designed with two main considerations in mind: 1. to make it easy for the user to rent the product and 2. to make the reminder light on the back clearly visible to the nurse.

For the nurses' table, the user-facing side will be at an easy to reach angle and the nurse will have an angle that will not obstruct the viewing of the information.









The hook section is divided into two halves for ease of manufacturing and fixing, with a projection at the bottom that is just right for fixing to the middle section of the product. The gears on the motor fixed to the hook section fit into the teeth of the heating section, so that when the motor is activated it can drive the hook section to rotate and jam the infusion tube. The two pcb boards are connected by wires. The lower pcb is responsible for connecting the main switch and the USB power supply interface, while the upper pcb controls the LED, the motor, the photoelectric sensor and the heating membrane.

Reflection

This one project is not the longest project I have ever experienced, but it is the most completed one I have ever completed. With the engineering knowledge I have learnt over the year, I was able to push this design to a realizable level by putting the user at the centre. This project has also taught me how to think about the possibilities of refining the product from all angles and to learn more about design methods. Prototyping and user testing were the methods that I found most helpful. I was very lucky to have several 3D printers in my school's studio, as the shape of my product has a big impact on its functionality and needs to be constantly tested and optimised. Being able to produce prototypes in a timely manner helps me to update and iterate on my designs, constantly optimising them into products with a better user experience. However, I underestimated the time required for the 3D printer during the design process and I often spent a whole day in the studio waiting for a model and then making changes, which slowed down the progress of my project to some extent. User testing has also helped me to improve the project. Testing the product with multiple users from different backgrounds revealed a number of issues with the product's flow and operation that needed to be addressed. This is why I was able to address these issues in a timely manner after the testing.

Finally I would like to express my sincere thanks to Jon Barnes and Craig Whittet, two mentors who helped and encouraged me during my Major project, and to the patients, doctors, nurses, also thanks to my classmates and friends who helped me with the testing.

Future Work

I would probably take the solution to more professionals, such as doctors and senior nurses. I would ask them to experience the product and seek their advice on how to improve it. The feedback will be different from the average user, and their knowledge of the field will give suggestions that the average user might not expect. I will then probably look for companies that are willing to make this product, and I hope that a product that helps the average patient will actually be produced.

Reference

Bloria P, Luthra A, Chauhan R, Kataria K, Bloria SD. Formation of air bubbles during blood warming with Astotherm plus™. Saudi J Anaesth 2020;
MakeSafer. 2022. All Kinds of Polyimide Heating Films. [online] Available at: <https://www.makesafer.com/collections/flexible-heating-film/products/all-kinds-of-polyimide-heating-films> [Accessed 8 August 2022].
Moore, T., Callaway, C. and Hostler, D., 2008. Core Temperature Cooling in Healthy Volunteers After Rapid Intravenous Infusion of Cold and Room Temperature Saline Solution. Annals of Emergency Medicine, 51(2), pp.153-159.
Indiamart. 2022.Ranger Blood / Fluid Warming System. Available at: https://www.indiamart.com/proddetail/ranger-blood-fluid-warming-system-8674817873.html[Accessed 8 August 2022].