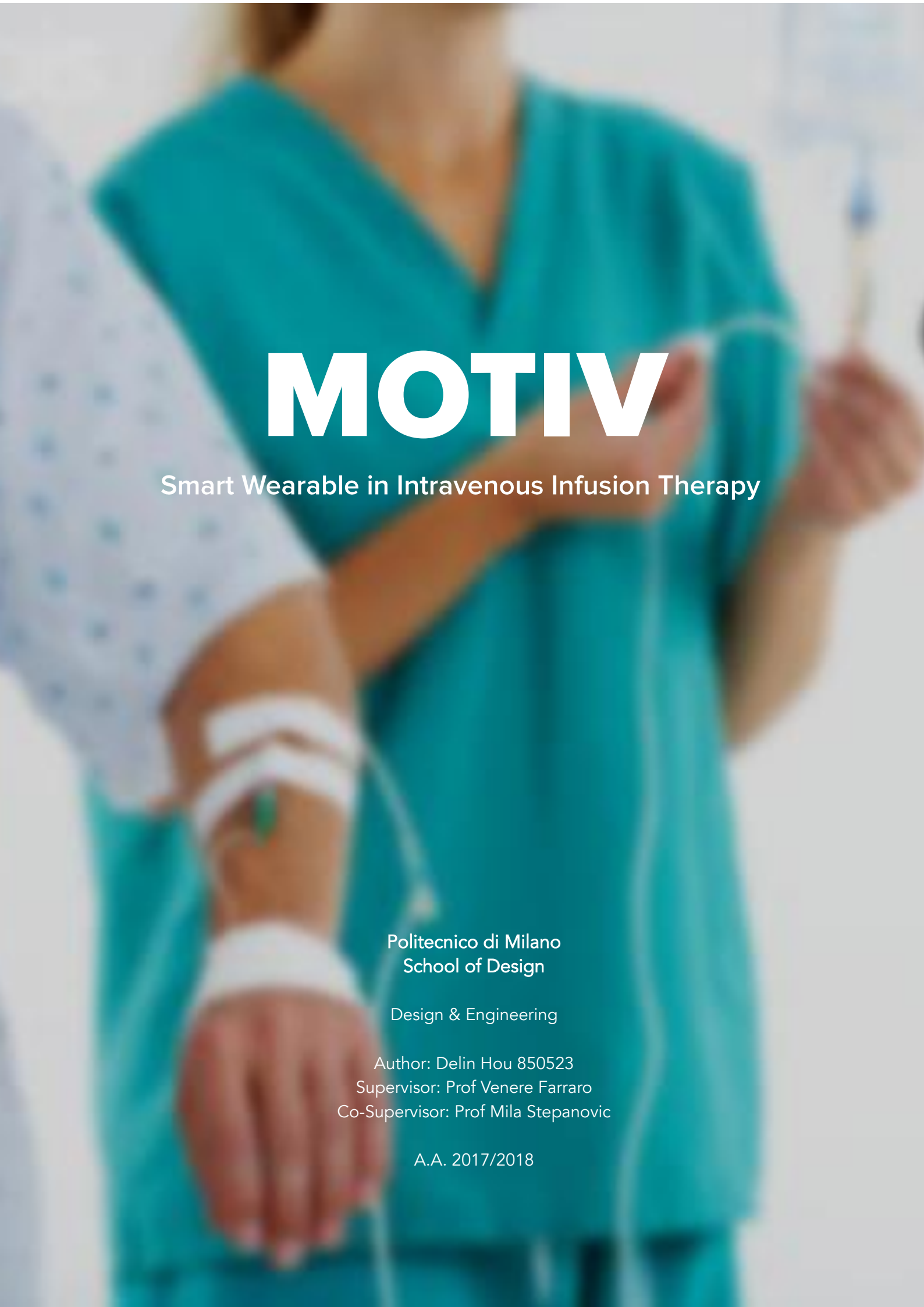

# MOTIV

## Smart Wearable in Intravenous Infusion Therapy


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# -INDEX

# -List of Figures

**Chapter 04**



**Chapter 05**

**-Fig.54 Information APP frame** *-made by author*
**-Fig.55 Concept sketches** *-made by author*
**-Fig.56 Wearable way sketches** *-made by author*
**-Fig.57 Sketches of shape concept** *-made by author*
**-Fig.58 Concept for shoulder** *-made by author*
**-Fig.59 Concept for Waist** *-made by author*
**-Fig.60 Concept for comfortable wear** *-made by author*
**-Fig.61 Concept for interface** *-made by author*
**-Fig.62 Concept for fluid protector** *-made by author*
**-Fig.63 Concept for nurse to put fluid inside it** *-made by author*
**-Fig.64 Concept for the size of fluid bags** *-made by author*
**-Fig.65 MOTIV APP design for nurse** *-made by author*
**-Fig.66 MOTIV APP design for patient** *-made by author*

**Chapter 06**

**-Fig.67 Rendering to power on/off** *-made by author*
**-Fig.68 Interface of MOTIV** *-made by author*
**-Fig.68 Interface of MOTIV** *-made by author*
**-Fig.69 IV fluid inside MOTIV** *-made by author*
**-Fig.70 Structure to change wearable method** *-made by author*
**-Fig.71 Wearable like messenger bag** *-made by author*
**-Fig.72 Wearable like waist bag** *-made by author*
**-Fig.73 Structure for groups** *-made by author*
**-Fig.74 Structure explosion view** *-made by author*
**-Fig.75 Explosion view of wearable back structure** *-made by author*
**-Fig.76 Injection modeling** *-https://en.wikipedia.org/wiki/Injection_moulding*
**-Fig.77 Die casting** *-https://www.cwmdiecast.com/blog/2016/05/24/die-casting-101-hot-chamber-vs-cold-chamber/*
**-Fig.78 Peristaltic Pump** *-http://www.kamoer.com/shop/showproduct.php?id=101&lang=en*
**-Fig.79 Peristaltic motor** *-https://www.sparkfun.com/products/10551*
**-Fig.80 Arduino board**
**-Fig.81 Temperature sensor** *-https://www.sparkfun.com/products/10988*
**-Fig.82 Fluid warmer** *-https://ems.penncare.net/p-3525-soft-sack-iv-fluid-warmer-12-volt.aspx*
**-Fig.83 Vibration module** *-https://www.precisionmicrodrives.com/vibration-motors/coin-vibration-motors*
**-Fig.84 Air bubble detector** *-https://www.sonotec.eu/products/non-invasive-fluid-monitoring/air-bubble-detection/sonocheck-abd07/*
**-Fig.85 Hidden LED Display** *-https://www.aliexpress.com/item/SAMSUNG-Original-Samsung-LED-View-Cover-Smart-Cover-Phone-Case-For-Samsung-GALAXY-S7-edge-G9350/32825930548.html*
**-Fig.86 Wifi Modular** *-https://www.lsr.com/embedded-wireless-modules/wifi-module*

# Abstract

IT

oiché il rapido sviluppo della tecnologia indossabile intelligente e la crescente attenzione delle persone nei confronti dell'assistenza sanitaria, il dispositivo di infusione indossabile intelligente è diventato una nuova tendenza per il futuro dell'assistenza sanitaria. Pertanto, al fine di progettare un nuovo dispositivo di infusione indossabile intelligente, la tesi discute le possibilità dell'infusione indossabile intelligente combinata con la ricerca sul sistema IV esistente in ospedale. La ricerca sul sistema IV esistente comprende le conoscenze di base IV, il mercato IV, le prestazioni e l'analisi dei problemi dei dispositivi IV, l'analisi dell'esperienza infusionale, il dispositivo IV indossabile esistente, le aspettative degli utenti e i requisiti dell'infusione indossabile. Inoltre, la tesi definisce e propone un nuovo dispositivo di infusione indossabile intelligente in base alla ricerca sulle aspettative degli utenti e sui requisiti di infusione per migliorare l'infusione IV corrente e l'esperienza dell'utente per paziente e infermiere.

EN

As the rapid development of smart wearable technology and people’s increasing attention to healthcare, smart wearable infusion device have become a new trend to improve infusion experience for patient and nurse, especially the movability of patient. Therefore, in order to design a new smart wearable infusion device, the thesis discuss the possibilities of smart wearable infusion combined with the research on existing IV system in hospital. The research on existing IV system includes basic IV knowledge, IV market, the performance and problem analysis of IV devices, the analysis of infusion experience, existing wearable IV device, user expectations and requirements for wearable infusion. Besides, the thesis also defines and proposes a new smart wearable infusion device according to the research on user expectations and infusion requirements to improve current IV infusion and user experience for patient and nurse.

# 01-
# Introduction

## 1.1 Objective of the thesis

The target of this thesis is to design a smart wearable IV device based on the current infusion principle and technology of wearable devices to improve patient's moving experience and communications between patient and nurse in infusion. Therefore, the thesis should investigate deeply on IV therapy, IV devices, IV market and current infusion experience of patient and nurse to understand the potential market opportunities and patient needs to IV device. The design of the wearable infusion device should be in accord with the investigation results, a reasonable structure, safe technique and simple process and suitable wearable way in order to make it mass production. In addition,

## 1.2 How to design a smart wearable IV device

In order to design a good smart wearable infusion device, the thesis researched a lot from four aspects, basic IV market, existing IV device, user experience, current wearable IV infusion.

### Basic IV knowledge

Intravenous infusion therapy is widely applied in hospital to treat a range of conditions in the fastest way to deliver medications and fluid replacement throughout the patient body. Many people maybe know more or less about infusion knowledge in their daily life. However, if I want to develop a professional infusion device, it is necessary to understand how it works, what diseases are treated by infusion and what side effects I should take into consideration when I design. Therefore, a good and deep understanding on professional infusion knowledge is necessary very much, which could contribute more to the final successful design on new infusion device.

### Existing IV devices

In recent years, with the rapid development of technology, many fields related to infusion have been explored and developed in order to establish a good infusion environment for patients and hospital. Meanwhile, a variety of devices is designed to improve patient infusion experience, like new IV pole, infusion pump, IV tubing set, infusion fluid warmer, portable infusion pressure bag, and wearable IV pole and so on. Therefore, in order to design a new device about infusion, the analysis of existing devices is helpful to clearly understand the features, performance and problems of each device. Then I can know what features and functions are necessary to create good infusion experience, what problems the devices still have and what I can design in the new device.

### User infusion experience research

By research on infusion experience, we can find more problems and new user needs in existing IV system and use them as the limitation to improve user experience. In infusion, the user includes patient and nurse. Therefore, the research will carried out to both of them, which mainly covers existing infusion process in hospital, user's behavior analysis based on infusion process, problem analysis of user's behavior, presenting an ideal experience, summarize user needs and analysis of user expectations by questionnaire to know which expectations is more important for patient and nurse respectively. In the research, interview with patient and nurse, observation to patient behaviors and questionnaire research are carried out to find user's potential needs and get user data to know the ideal infusion experience in their mind.

### Current Wearable infusion devices

Wearable infusion is a new flourished trend. It allows patients to walk around without the need for an IV stand. Patient can go anywhere they want during infusion, like corridor, shop, canteen, elevator, toilet, in-and-out of hospital. It can offer more comfort to patient to keep normal lifestyle and help patient's rapid recovery. Therefore, some new wearable infusion devices have been born to meet patient needs on movable, but their function and safety cannot be equated with conventional infusion equipment. Therefore, the research on wearable infusion is also same important with the previous analysis in order to design a good smart wearable infusion system. Besides, I can know which kind of patient prefer to use wearable infusion, what characters they have, and what wearable requirement they have.

All the result from the research on basic IV knowledge, existing IV devices, current infusion experience in hospital, and wearable infusion product can structure the new brief to develop an ideal wearable infusion system.

## 1.3 Results of the thesis

To achieve the objective, a smart wearable infusion system (based on the technology including infusion pump principle, arduino controller, bluetooth/Wifi module for remote control, peristaltic pump, temperature control module, screen and air bubble detector) was developed with the basic function of IV stand and smart performances for nurse and patient based on target patient and nurse expectations, the accessibility analysis of wearable infusion to improve the existing infusion status in hospital. The smart wearable proposal not only expand the movability and strengthen the safety for patients, but also reduces the workload from patient administration for nurse.

# 02-
# What’s IV?

*-Fig.1 a peripheral line placed on the hand*
*-https://en.wikipedia.org/wiki/Intravenous_therapy*

Intravenous infusion therapy is widely applied in hospital to treat a range of conditions in the fastest way to deliver medications and fluid replacement throughout the body. Many people maybe know more or less about infusion knowledge in their daily life. However, as for professional infusion knowledge, there are still many people who do not know it too much. Therefore, in this chapter, the basic knowledge of intravenous infusion therapy (IV) will be introduced to have a good understand on intravenous therapy in healthcare, which would contribute more to design a new infusion device. It will cover definition of IV, infusion access, basic IV principle, IV setup, types of IV, application and its side effects.

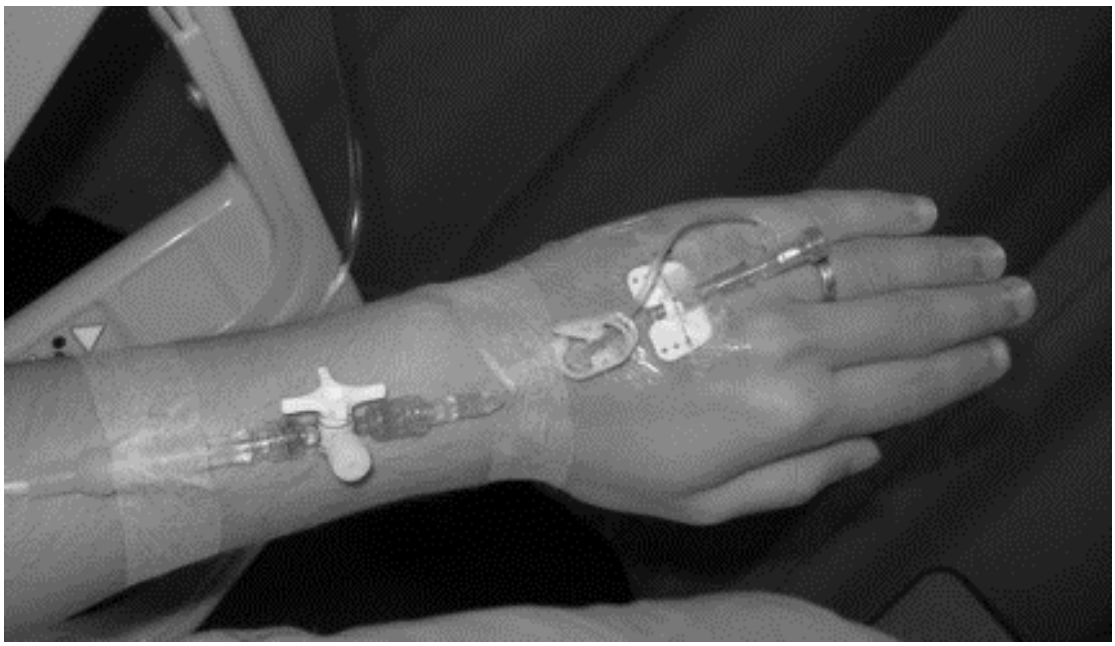
## 2.1 Definition of IV

**Intravenous therapy** is treatment that infuses intravenous solutions, medications, blood, or blood products directly into a vein.[1] The intravenous route of administration can be used for injections (with a syringe at higher pressures) or infusions (typically using only the pressure supplied by gravity). Intravenous infusions are commonly referred to as drips. The intravenous route is an effective and fast-acting way to deliver medications and fluid replacement throughout the body because the circulation carries them. Intravenous therapy is also used for patients who are unable to take medications orally.[2]

## 2.2 Intravenous infusion access basics

In healthcare, IVs are categorized by the type of vein being used because the IV tube is called a catheter and may be inserted into a number of locations across the body according to need.

**- Peripheral IVS**



*-Fig.2 a peripheral line placed on the hand*
*http://lineusmed.com/iv-basics/*

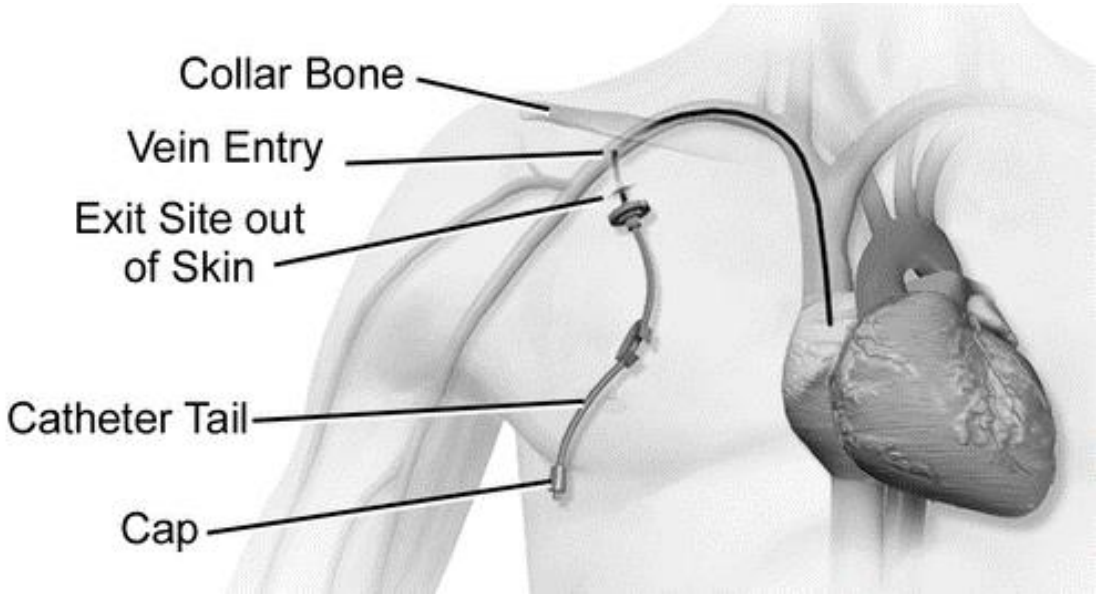
This is the most common type of IV therapy used. Peripheral intravenous lines are placed in any of the veins not included in the chest or abdomen and are normally placed in the arms, legs and sometimes the head. The first experiments with peripheral IV injections were in the 1600s using quills from bird's feathers and bladders of animals as instruments. IV access

advanced during the cholera epidemic of 1831-1832. Dr. Thomas Latta of Scotland pioneered the use of IV saline infusion in dying cholera patients and publicly reported his results in the June 1832 issue of the Lancet. Due to the waning of the cholera epidemic, general medical skepticism and Dr. Latta's death in 1833, the technique essentially disappeared for the next 70 years. IV therapy did not become a routine practice until its use in World Wars I and II.[3]

Today, up to 90% of people admitted to a hospital receive a peripheral IV, and over 1 billion peripheral IVs are placed globally each year.[4,5] Most peripheral IVs are placed by nurses in the hand, forearm or in the antecubital fossa (elbow joint area).

**- Central lines**

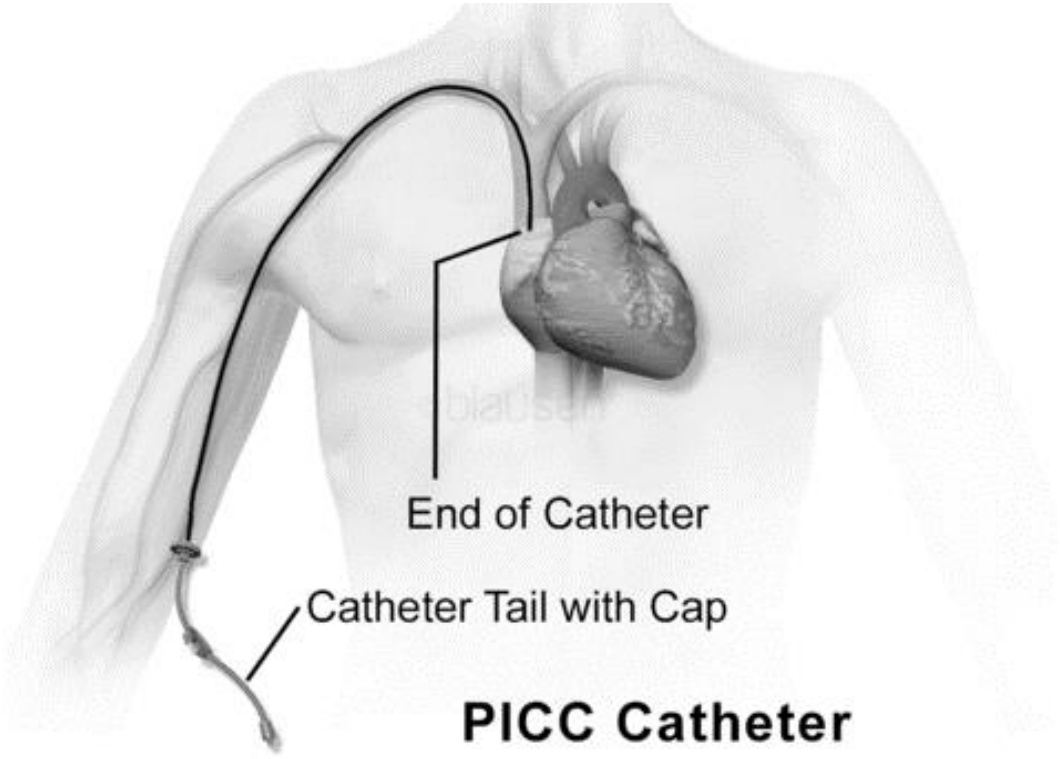
Central lines are intravenous lines designed to be placed in large veins, most commonly the large veins in the neck, chest and groin. The catheter tip is placed right above the heart, in the lower part of the superior vena cava or cavoatrial junction. Central venous catheterization was first performed in 1929 when Werner Frossmann, a German doctor, inserted a ureteric catheter into his antecubital vein. He then walked to the radiography department so that the catheter could be guided into his right ventricle using x-ray. Since then, central venous access has become a mainstay of modern clinical practice.[6]




*-Fig.3 Illustration of a non-tunneled central venous access device*
*https://commons.wikimedia.org/w/index.php?curid=29452218*

Central lines are used to administer medications that would harm smaller peripheral veins. Within North America and Europe, ultrasound is almost always used to place a hollow needle into the desired vein. A guidewire is then passed through the needle and directed to its desired location and finally a catheter is passed over the guidewire. The guidewire is then removed and thrown away.  Central lines can have multiple lumens (ports) for injecting different fluids, and can sometimes have up to five lumens.

**- Peripherally inserted central catheters (PICCs)**




*-Fig.4 PICC line placed in a vein in the arm with a catheter leading to the superior vena cava. http://creativecommons.org/licenses/by/3.0*

Peripherally inserted central catheters (PICCs) are inserted through a peripheral vein and have a catheter that varies in length from 25 to 60 cm in length and extends to the superior vena cava by the heart. PICCs are inserted most commonly by doctors, respiratory therapists, or specially trained registered nurses using ultrasound. Chest x-rays and fluoroscopy are used to aid in insertion and confirm placement. The PICC has a guide wire inside that is used to thread the catheter tip to its desired location, and then the wire is removed and thrown away. The optimal amount of time a PICC can stay in the body is not certain and is the point of many studies, but PICCs are often kept in place for weeks and sometimes for longer than a year.[7]

PICC lines are used when intravenous access is required over a prolonged period of time or when the material to be infused would cause quick damage and early failure of a peripheral IV line and when a conventional central line may be too dangerous to attempt. Typical uses for a PICC include: long chemotherapy regimens, extended antibiotic therapy, or total parenteral nutrition.

Studies estimate that between 5 and 7 million central lines/PICCs are used annually in the United States.

**Tunneled lines**

While some central lines have their catheter pass through the skin and then directly into the vein, other central lines called "tunneled catheters" insert through the skin and then pass or "tunnel" a significant distance before inserting into the vein. This reduces the risk of infection, since bacteria from the skin surface are not able to travel directly into the vein. These catheters are often made of materials that resist infection and clotting. These include the Hickman line or Broviac catheter.[8]

**Midline catheter**

A third type is a midline catheter which is inserted into a peripheral vein and advances through the vein, unlike a peripheral IV line, but falls short of emptying into a central vein.[9]

## 2.3 IV principle and Basic IV setup

### - IV principle

Infusion therapy is working by gravity. Medication is in an IV bag, and the bag is spiked with IV tubing. The infusion then drips by gravity, controlled by the roller clamp or by a Dial-a-Flo device on the tubing.[10] It is necessary for the bag to hang higher than the IV line, most often on an IV pole or an arrangement in the home such as a hook, for this to be an effective infusion method. The patient is connected to the IV administration tubing throughout the duration of their infusion.

During infusion therapy in hospital, the nurse always inserts an IV line which is attached to a bag of saline solution. The bag is then hung on the IV pole and above the patient's head to form the difference of pressure between liquid gravity pressure and patient blood pressure. The difference of pressure can carry fluid into the veins over time.


*-Fig.5 Gravity IV principle*
*https://infuserveamerica.com/pumps-and-infusion-devices/*

**-Basic IV setup**

IV stand / IV pole:

*-Fig.6 IV stand*

IV stand can provides a secure place to hang bags of medicine or fluid that with gravity, ensures an uninterrupted administration of medicine down though a hollow plastic tube and into the veins of the patient.

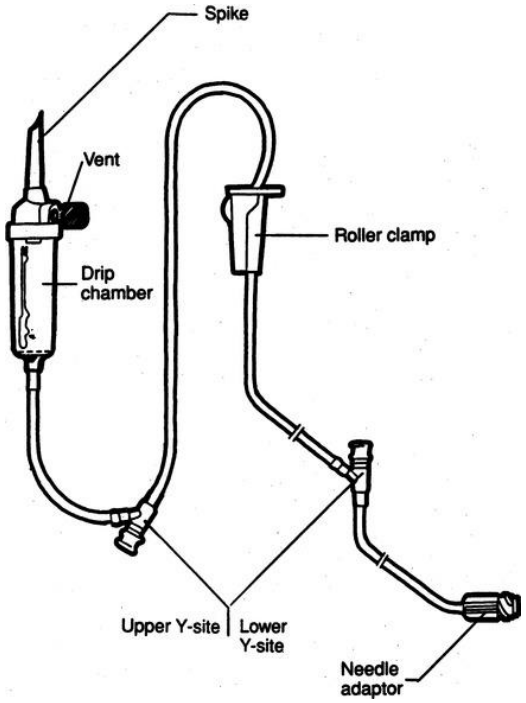
Sterile IV fluid bags:


*-Fig.7 IV fluid bag*

IVs are most often administered by bags of fluid that come premixed. The standard sizes of these bags can range from 50 ml to 1000 ml. The bag is hung from an IV pole.

IV tubing set:

IV tubing is attached to the bottom of the bag; the IV tubing contains several important parts which are drip chamber, roller clamp, slide clamp, injection port.




*-Fig.8 primary administration set. (From Hankins et al:* Infusion therapy in clinical practice*, ed 2, Philadelphia, 2001, Saunders.) https://musculoskeletalkey.com/basic-equipment-and-supplies-for-intravenous-therapy/*

The **drip chamber** is located just below the IV bag; inside this chamber we can see the fluid drip down from the bag into the IV tubing.[11] This is where we measure the speed of a manual IV setup; we look at this chamber and count the number of drops we see per minute. The **roller clamp** is what we use to control the rate at which the IV fluid infuses. If we roll it one way, it squeezes the IV tubing more tightly, making it narrower and therefore making the fluid flow through the tubing more slowly; if we roll it the other way, it loosens its pinching of the IV tubing, making the tubing less narrow, and allowing the IV fluid to flow through at a faster rate. The **slide clamp** is used when we want to completely stop the IV from flowing, without having to adjust the roller clamp. This is handy if we want to stop the IV for a moment, but we don't want to have to reset the flow rate by readjusting the roller clamp all over again once we start the IV up again. This works by pinching the tubing completely shut when we slide the tubing into the narrowest part of the clamp. The **injection port** is a place where medicine or fluids can be injected so that they will infuse into the patient's vein through the IV tubing. There is also usually an injection port close to where the needle goes into the patient's vein.

## 2.4 Types of Infusion

There are three main types of IV transfusion.

**- Continuous infusion**
A continuous infusion is primarily used to correct fluid and electrolyte imbalances. This is as opposed to intermittent infusion, when a patient requires medications only at certain times, such as secondary IV and IV push.

**- Secondary IV**
The tubing from the bag of fluid being administered that connects to directly to the patient is called the primary tubing. Any additional IVs to be administered are connected to the primary tubing and are called secondary IV, or IV piggyback; this is done instead of placing multiple catheters in the patient. When administering a secondary IV medication, the primary bag is held lower than the secondary bag so that the secondary medication can flow into the primary tubing, rather than fluid from the primary bag flowing into the secondary tubing. The fluid from the primary bag is needed to help flush any remaining medication from the secondary IV from the tubing into the patient.

**- IV push**
Some medications are also given by IV "push" or bolus. A syringe containing the medication is connected to an access port in the primary tubing and the medication is administered through the port. The syringe plunger is pressed slowly, if it might irritate the vein or cause a too-rapid effect. Certain medications, such as potassium, are never to be administered by IV push because the spike in medication in the blood from the IV push could be fatal. Once a medicine has been injected into the fluid stream of the IV tubing, there must be some means of ensuring that it gets from the tubing to the patient. Usually this is accomplished by allowing the fluid stream to flow normally and thereby carry the medicine into the bloodstream; however, a second fluid injection is sometimes used, a "flush", following the injection to push the medicine into the bloodstream more quickly.

## 2.5 What Is It Used For?

There are a number of reasons why someone might need IV treatment. Sometimes, when someone is suffering from a complex disease, they cannot eat and taking oral medication becomes impossible. Another reason is that some medications are inappropriate for oral administration because the acidic digestive system will break them down before they can be absorbed by the body to treat the disease. In acute care situations, treatment needs to be immediate, and IV delivery is much faster than oral medications. In addition, if a patient is unconscious, IV therapy means that they can still be treated.

The most common reasons for IV therapy[12] include:

1. To replace fluids and electrolytes and maintain fluid and electrolyte balance: The body's fluid balance is regulated through hormones and is affected by fluid volumes, distribution of fluids in the body, and the concentration of solutes in the fluid. If a patient is ill and has fluid loss related to decreased intake, surgery, vomiting, diarrhea, or diaphoresis, the patient may require IV therapy.
2. To administer medications, including chemotherapy, anesthetics, and diagnostic reagents: About 40% of all antibiotics are given intravenously.
3. To administer blood or blood products: The donated blood from another individual can be used in surgery, to treat medical conditions such as shock or trauma, or to treat a failure in the production of red blood cells. The infusion restores circulating volumes, improving the ability to carry oxygen and replace blood components that are deficient in the body.
4. To deliver nutrients and nutritional supplements: IV therapy can deliver some or all of the nutritional requirements for patients unable to obtain adequate amounts orally or by other routes.

## 2.6 What Are the Side Effects of IV Therapy?

Although IV therapy is safe for most people, like any type of medication, there is a risk of side effects that range from mild to life threatening.[13] This is why it is advised that anyone who is facing IV treatment should discuss this option thoroughly with their clinician so that they are fully aware of how long their IV treatment is likely to last and what their risk is of any particular side effect.

The most common side effects from IV therapy include:

**- Infection**

The injection site may become infected. To minimize this happening, the IV therapy must be administered carefully with completely sterile equipment. Many systems come with disposable components to support this practice. If the injection site becomes infected, this can also cross into the bloodstream, leading to a serious infection. Symptoms of an infection may include raised temperature, chills, redness, soreness, and inflammation at the injection site. If a patient suffers from any of these symptoms they are advised to contact their physician immediately.

**- Damage to blood vessels**

If an IV catheter is poorly inserted, this can damage veins causing infiltration. If a vein is damaged, this may result in medication leaking into the surrounding tissue instead of entering

the bloodstream as intended. Infiltration may also result in tissue damage. Other possible side effects are phlebitis (inflammation of the veins). If a patient is suffering from infiltration and/or phlebitis, they may experience warmth, pain and inflammation at the injection site. If this is the case, they should contact their doctor immediately.

**- Air embolism**

Although a small amount of air will not cause any concerns, if an air bubble gets into the syringe or medication bag or the line is allowed to run dry, air bubbles can go into the patient's vein, before traveling to the heart or lungs, blocking blood flow. In the worst case scenario, this can cause major problems, including heart attack or stroke.

**- Blood clots**

IV therapy may result in the formation of blood clots, which can then block major blood vessels, giving rise to tissue damage or even death. Deep vein thrombosis (DVT) is an example of the type of serious blood clot that may be caused by IV treatment.

# 03-

# Existing IV System in Hospital

*-Fig.9 Existing IV in hospital*

In recent years, with the rapid development of smart wearable technology and people's increasing attention to healthcare, existing IV system have been unable to meet patient and nurse needs to wearable and smart control. Therefore, in order to understand user needs clearly and to improve the existing IV system, this chapter researches existing IV system from two aspects of both existing IV devices in hospital and infusion experience of patient and nurse. Meanwhile, it will discuss the performance and problems of existing IV devices to help define what a good IV device should look like. Besides, the chapter also will explore the infusion experience of patient and nurse to find the problems and users expectations to new infusion experience. All the results from the analysis of existing IV system in this chapter will be constraints to my final design.

## 3.1 Benchmarking of existing IV devices

*-Fig.10 Existing IV devices in market*
*made by author*

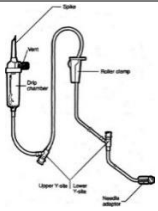
In infusion devices market, many fields related to infusion have been explored and developed in order to establish a good infusion environment for patients and hospital. Meanwhile, a variety of devices (See Fig.10) is designed to improve patient infusion experience, like new IV pole, infusion pump, IV tubing set and infusion fluid warmer and so on.

In order to design a new device about infusion, all the infusion devices will be analyzed to define the possible performance that a new infusion device could have. Therefore, the analysis of existing devices will focus on their features and problems.

### 3.1.1 Features of infusion device

As we all know, infusion therapy is working by gravity. During infusion therapy in hospital, the nurse always inserts an IV line which is attached to a bag of saline solution. The bag is then hung on the IV pole and above the patient's head to form the difference of pressure between liquid gravity pressure and patient blood pressure. The difference of pressure can carry fluid into the veins over time. Therefore, a standard IV set consists of a pre-filled, sterile container (glass bottle, plastic bottle or plastic bag) of fluids, a long sterile tube, an IV pole. Besides, during therapy, in order to ensure the safety of infusion and reduce the side effects of infusion, assistant infusion devices have been developed and released to infusion market, which can be categorized into two types by their performance.

**TABLE 01. FEATURES OF INFUSION DEVICE**

| | | |
|---|---|---|
| TYPICAL INFUSION DEVICE |  <br>BASIC IV STAND | A movable holder for IV fluid bag.<br>A supporter for infusion pump<br>A product offering pressure to force the liquid/solution/medicine to flow into patient's body. |
| |  <br>**IV STERILE TUBING SET** | A sterile tubing contains several important parts which are drip chamber, roller clamp, slide clamp, injection port and needle. |
| ASSISTANT DEVICE |  <br>**INFUSION PUMP** | A device to control and set the precise infusion rate easily for different patient and calculate the infusion time. |
| |  <br>**IV WARMER** | A device to heat the infusion fluid to patient's body temperature in order to protect patient from the danger of hypothermia when large amounts of cold fluids are infused, especially in winter. |

From the research on functions of existing IV device, the performance of a wearable product could be designed with all the necessary functions like a holder for IV fluid, a movable supporter for infusion pump, pressure maker to force liquid into patient body and a sterile IV tubing set. Meanwhile, it could be with the precise rate control, infusion time calculation, and fluid warmer.

### 3.1.2 Problems of infusion device

In order to know the problems of existing of infusion devices like IV stand, infusion pump and infusion warmer, interviews with nurse are necessary to do for the research.

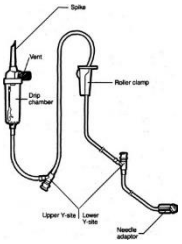
**- Interviews**

Interviews happened:
**When:** Afternoon in 15st of November, 2017
**Where:** Weishi Peoples Hospital in China
**Interviewee:** 10 Nurses and 10 patients in the hospital
**Interviewed topics:** How to use the IV stand, infusion pump, infusion warmer and IV tubing set. Functional defects of these products in their opinion. Problems they want to improve about these products.
**Objective:** the interviews objective is to find the problems and product gaps of existing infusion devices.

*-Fig.11 Problems of IV devices*
*made by author*

**- Interview results**

**TABLE 02. PROBLEMS OF INFUSION DEVICE**

| IV DEVICE | PROBLEMS FROM INTERVIEW | OPPORTUNITIES |
|---|---|---|
|  BASIC IV POLE | • Too heavy to move around and difficult to hold up when go downstairs<br>• More space to store<br>• Easy to fall down and hurt patients accidentally<br>• Not convenient for patients to do ambulation training after surgery<br>• Bind the patients to their bed or seat<br>• Limit the movability of patients<br>• Create the sleepy condition for patients<br>• Unstable infusion bag when moving, maybe it will be fallen down and broken | 1. Lightweight<br>2. Reduce the size to save space for storation<br>3. Expand movability<br>4. Offer stable set for IV fluid |
|  IV STERILE TUBING SET | • Sterile<br>• Unprecise control, roller clamp<br>• Air bubble<br>• Too long,<br>• Sometimes it is easy to be stretched by something. | 5. Organize the tube<br>6. Precise control |
|  INFUSION PUMP | • Expensive<br>• Complex operation and programming<br>• Unfriendly interface design<br>• Heavy with IV pole<br>• Confusing numbers<br>• Many same buttons without explanation<br>• Lack feedback design for infusion finish<br>• Remember to check power/battery | 7. Cheap<br>8. Lightweight<br>9. Simple and clear interface<br>10. Clear status for power |
|  IV WARMER | • Single part which is always used alone<br>• Used for people when weather become cold | 11. Use warmer together with basic IV set |

By analyzing the problems of IV devices, all the problems of existing IV devices should be avoided in the new design. Meanwhile, the improvement suggestions gave in TABLE 02 can be applied as the requirements for new design, which includes to expand patient movability, light weight, a safe container for IV fluid, small size, to save storage space, organized IV tube, precise control, simple interface, clear information for IV status and to reduce the numbers of accessories.

## 3.2 Intravenous infusion experience

By research infusion experience, we can find more problems and new user needs in existing IV system and use them as the limitation to improve user experience. In infusion, the user includes patient and nurse. Therefore, the research will carried out to both of them, which mainly covers existing infusion process in hospital, user's behavior analysis based on infusion process, problem analysis of user's behavior, presenting an ideal experience, summarize user needs and analysis of user expectations by questionnaire to know which expectations is more important for patient and nurse respectively. In the research, interview with patient and nurse, observation to patient behaviors and questionnaire research are carried out to find user's potential needs and get user data to know the ideal infusion experience in their mind.

### 3.2.1 Online research on infusion experience

Firstly, I did online research to find the problems of infusion experience and some patient photos to know what they do in infusion, which helps me have a general understanding to the infusion experience. Therefore, an example of infusion experience of Sara Ringer is found to show the infusion process, which can be divided into three periods, before infusion, during infusion, after infusion and tips for better infusion experience. She shared her infusion experience to treat Crohn's disease online.

**Infusion experience of Sara Ringer:**

*Sara Ringer*

*-Fig.12 Photos from Sara Ringer*
*https://crohnsdisease.com/living/what-expect-infusion-biologic/*

***Before the Infusion***

- *When you arrive you will check in. Some places I have been to require me to get a hospital band put on, but generally you will just check in and wait to be called back.*
- *You might be receiving your infusion at an infusion clinic which usually is one large room with many chairs that have IV poles next to them. Aside from IBD patients there will be patients there with different health conditions receiving different medications. People go to infusion clinics for biologics, chemotherapy, blood transfusions, iron infusions, antibiotics, fluids, and more. When I first began biologic infusions I had them done in an infusion clinic that had private rooms for each patient and you could choose between a reclining chair or a bed. That was nice!*
- *Once you are in your chair (or bed) a nurse will come and take your vitals and your temperature and possibly weigh you. When I was on Remicade I was weighed each time. The nurse might also ask you some questions like if you've been sick recently, have any open wounds, and if you are having any pain.*
- *While all of this is going on the pharmacy will be mixing your infusion. They do not get it ready before you arrive in case you don't show up as they do not want to waste such expensive medication.*

- *Next your IV will be started. If you're anything like me this could take quite a long time. For one infusion it took 4 different nurses and 8 pokes!*
- *Pre-Meds: Some patients receive medications before the infusion starts called pre-meds. Pre-meds are to reduce your chance of a reaction to the infusion. Some doctors start you with pre-meds from the beginning and others add it later on if you have a slight reaction. I was started on pre-meds from the beginning and received oral Tylenol 500 and 50mg Benadryl through my IV.*

***During the Infusion***

- *During your infusion the nurse will check on you periodically and take your vitals a few more times.*
- *Depending on what medication you are on will depend on the amount of time you are there. The standard time for Entyvio infusions are half an hour and the standard time for a Remicade infusion is 2 hours.*
- *For the remainder of the infusion the choice is yours for what you do with your time! It can get pretty boring just sitting there so bringing something to do helps.*
- *During my infusions at one clinic a guy walked around with a bunch of snacks and offered coffee. That was a nice bonus. Thanks, snack man!*

***After the Infusion***

- *Once the infusion ends you might have to let fluids run through the line for a while to get every last bit of the biologic medication through your line.*
- *You may also be required to stay at the clinic for a short period of time so you can be monitored for any kind of reaction. This is usually only required when you first start receiving the infusion and you will not have to do it every time.*

***Tips to Make the Infusion Experience Better***

- *If you are getting Remicade ask your doctor about Rapid Remicade. There have been studies done that found that the standard 2 hour infusion can be done in half the time safely and successfully. I got rapid Remicade when I was on it and it shortened the infusion time by half!*
- *Bring things with you to occupy your time. I liked to bring my computer and headphones with me to keep me entertained. Many of the times I would work on blog posts for my website. Other ideas are: A book to read, coloring books, homework, your planner to organize your week, etc.*
- *Dress comfortable. When I was first on Remicade I used to wear my pajamas and sleep during my infusion because the IV Benedryl I was given as a pre-med would make me sleepy. I got used to it over time and could no longer sleep during infusions but I still liked to dress comfy unless I had somewhere to be afterward.*

**-Results from online**

1. Many patients prefer to move around when they in infusion. All of them have to push the huge IV stand to move around and even need a nurse to accompany them.

*-Fig.13 Moveable problems of patient*
*made by author*

2. Patient always pay more attention to the amount of fluid in order to know the remaining infusion time because of the lack of feedback on infusion finish. And it looks not comfortable to look up frequently for liquid checking.

*-Fig.14 Patient staring on IV drips*
*made by author*

3. When in infusion, patient sleep a lot or doing some entertainment to kill the boring infusion time.

*-Fig.15 Boring patient in infusion*
*made by author*

We can find many suggestions to patient what they can do to pass the time while receiving therapy.

Things to take or do:

- Book
- Magazine
- Newspaper
- Crossword puzzle or Suduko game
- Hand held games - (if they are quiet or have headphones)
- Bring your own music (I-pod or MP3 player)
- A neck pillow - the type used on airplanes
- Pictures of your family or loved ones
- Study for that upcoming test
- Bring your computer and get some work done, watch a movie, or play games.
- Snacks and a drink (if allowed in the infusion room)
- Bring paper and pen - make a list of things you need to do
- Write a letter -a letter of encouragement - of love - of thanks.
- Catch up on paper work
- Plan a party
- Make your shopping list
- Knit
- Crochet
- Draw or doodle
- Plan a trip
- Take a nap
- Pray
- Meditate

*-Fig.16 Things patient can do to kill boring time in infusion*
*https://www.medicinenet.com/iv_drug_infusion_faqs/article.htm#what_happens_during_and_after_the_infusion*

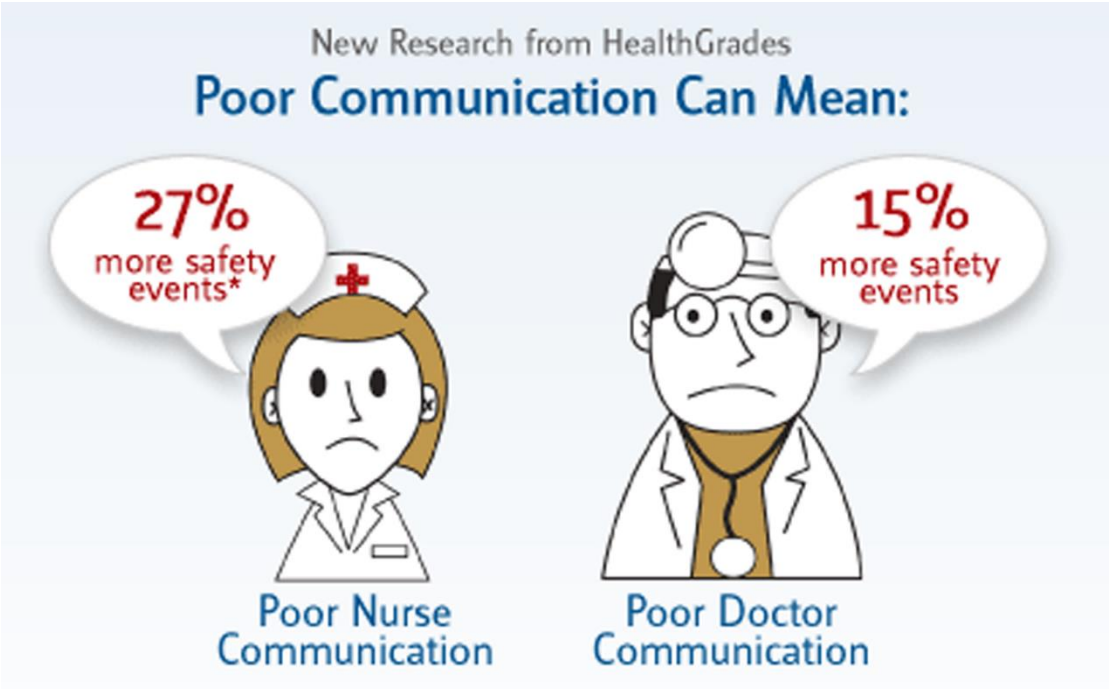
4. Communication problems between patient and nurse in infusion

The gaps in communication can cause serious breakdowns "in continuity of care, inappropriate treatment, and potential harm to the patient." This impacts our practice and the patient outcomes of the nursing care that is provided. Quality improvement is needed in the area of nursing communication in order to ensure the best patient care and outcomes.

A new reporton patient safety[14] and satisfaction rates in hospitals across the United States finds that hospitals with the highest patient ratings in physician and nursing communications on average have fewer patient safety events. The analysis of patient safety data for hospitalizations between 2008 and 2010 was conducted by HealthGrades.

Among the report's key findings:

- 15% more overall patient safety events occurred in hospitals performing in the bottom 10% for physician communication, compared to those in the top 10%
- 27% more overall patient safety events occurred in hospitals performing in the bottom 10% for nursing communication, compared to the top 10%
- 13% more patients at hospitals performing in the top 10% for patient satisfaction reported they received instructions on what to do when they left the hospital, compared to the bottom 10% – key guidance that underscores the importance of communication




*-Fig.17 Communication problems for safety*
*http://www.prweb.com/releases/2012/5/prweb9529417.htm*

Some suggestions for effective communication after the infusion can be found online

- Ask questions and notify the staff immediately if you are not feeling "right" or have a concern.
- Consider talking with someone in the Infusion Center receiving treatment. They may have some advice about their health condition that will help you. You may meet a new friend.
- After your infusion is completed, ask for any important post infusion instructions.
- You may need to take post-infusion medications. Check with your healthcare practitioner or the infusion staff for detailed instructions.
- A dressing will be placed in the area where your infusion was done. This dressing should be kept in place for at least 30 minutes or longer. If you are on a blood thinner, leave the dressing in place longer to avoid any bleeding. Check with the staff at the Infusion Center in regard to the length of time necessary to keep the dressing in place.
- If you have an allergy to tape, inform the infusion staff (advise them of all allergies).
- Obtain a phone number to call in the event that you have any questions or possible side effects to the medication you receive (such as a fever or rash) after your infusion has been completed.

*-Fig.18 Suggestions for effective communication after the infusion*
*https://www.medicinenet.com/iv_drug_infusion_faqs/article.htm#what_happens_during_and_after_the_infusion*

5. Nurse care many patients and have a lot of workload every day. When in infusion, nurse will check on patient periodically to change infusion fluid or finish it.

*-Fig.19 Nurse working status*
*made by author*

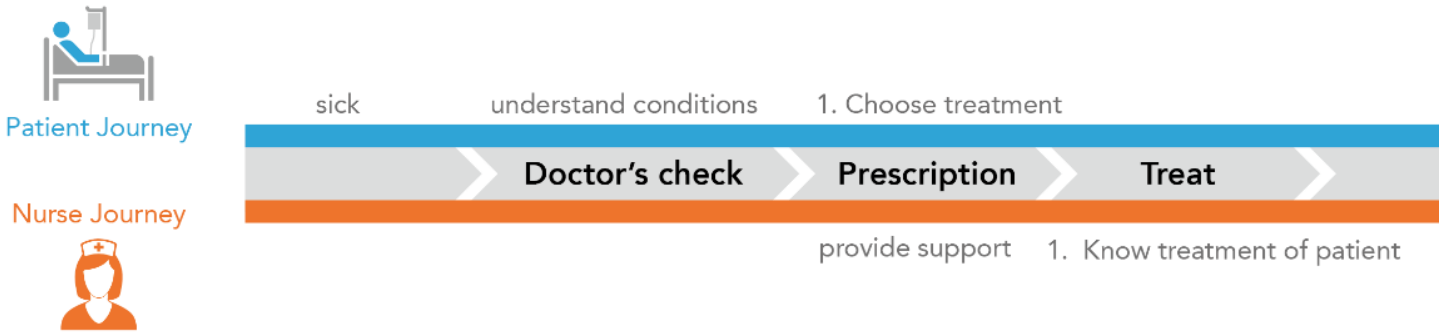
### 3.2.2 Interviews with patient and nurse in hospital

In order to have a deep understand to the existing infusion experience and find more problems patient and nurse concerned, interviews with nurse and doctors was also done to enrich and confirm the problems from online research.

**Interviews happened:**

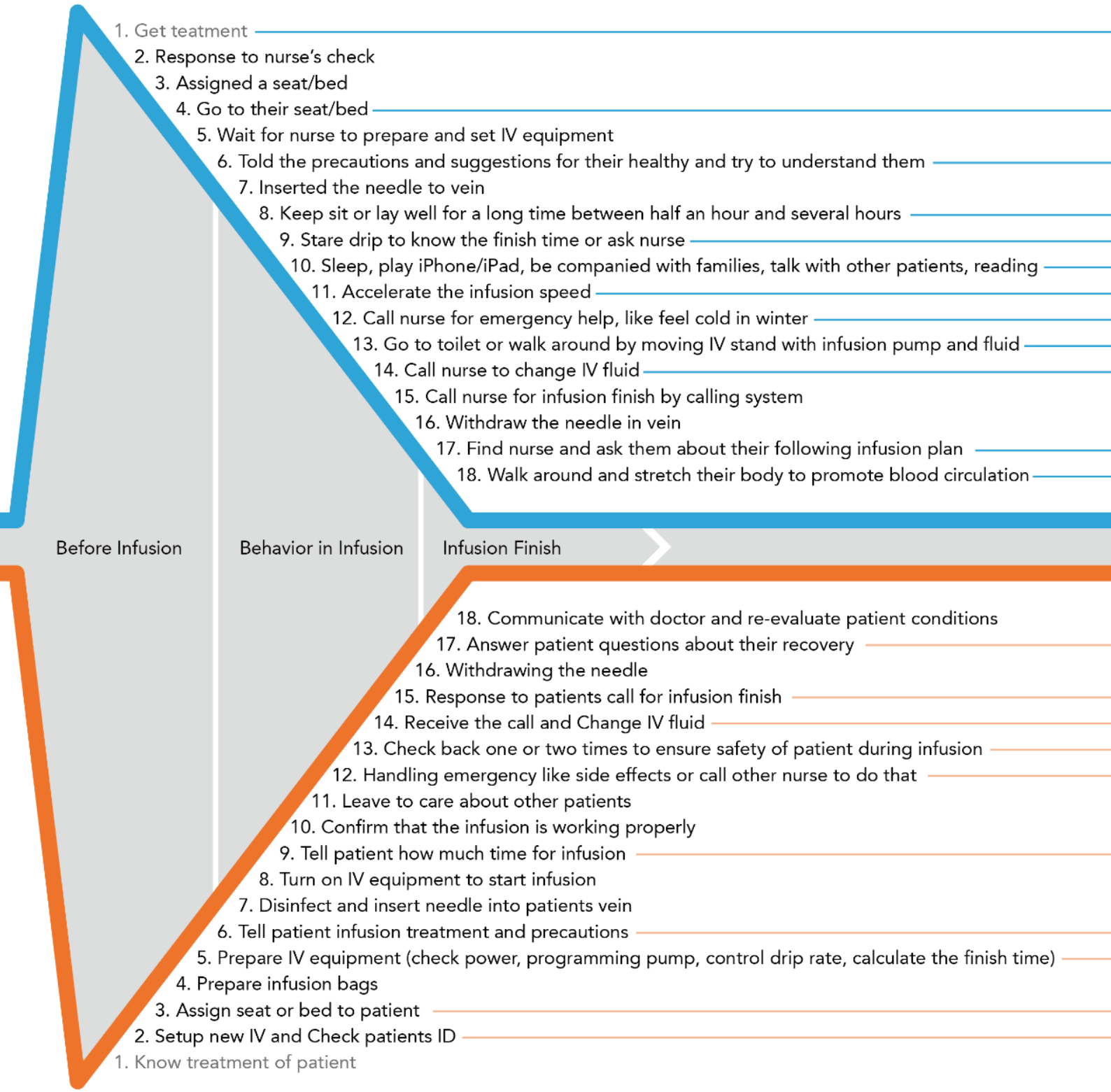
**When:** Morning in 27st of November, 2017
**Where:** Weishi Peoples Hospital in China
**Interviewee:** 10 Patients and 6 Nurses in the hospital
**Interviewed topics:** How to infuse, infusion process, what they do from infusion starting to the end of infusion, what they are worried about in infusion, what they are trouble in.
**Objective:** to know patient and nurse behavior and then analyse their behaviors to find the experience problems in existing infusion.

**Interview results:**




*-Fig.20 Infusion experience process of patient and nurse made by author*

**-User behaviors by steps in infusion treatment**



**-Problems from user behaviors**

1. Don’t know their treatments clearly and couldn’t remember it

4. How to find their seat/bed

6. Difficult to remember the precautions and suggestions for their healthy and tell their carefivers/families

8. Limb becomes numb and patient become anxious and impatient becasue of limited movability
9. Lack time information on finish
10. Forgot to call nurse when infusion finish
11. Lack of patience, hope to finish it early and fast infusion will cause side effects
12. Calling by families/friend/emergency calling system
13. Trouble to move heavy IV stand because IV pole is higher so that it is easy to fall down
14. Forgot to call nurse when infusion finish

17. Expect to know their following infusion plan but have to find nurse and ask them
18. Lack of movement leads to that Limb becomes numb

## Problems in User Experience

17. Communication problem, repeat to tell the related information, which reduces work efficiency of nurse

15. Responding to the patient is not timely and couldn’t find other nurse quickly to deal with it
16. Can't deal with it in time, couldn’t tell other nurse in time, information sharing barriers between nurses
13. Tired to check, waste time, lack of monitor
12. Can't deal with it in time or couldn’t find other nurse quickly to deal with it

9. Lack of time feedback for patient, which increases the workload of nurse

6. Have to repeat two or three times for patient, which costs more time of nurse and reduces work effeciency
5. Complex programming for IV device, worried patient to change it

3. Not sure accessible seat or bed
2. Information written in paper, not conducive to future information management

**-Ideal user experience on IV**

After interviews, an ideal infusion experience is proposed aim to the problems from user experience.

1. Offer treatment information in visible

4. Offer seats maps

6. Offer visible precautions and suggestions for patient healthy they can check as they want

8. Expand patient movability to offer them more comfort
9. A display to show infusion time information
10. Reminder to output reseaonable feedback on finish
11. Offer patient more comfort for their movability, and patient can't controll infusion speed freely
12. Calling by emergency calling system
13. Infusion without heavy IV stand
14. Reminder to output reseaonable feedback on finish

17. Display the following infusion plan, show patient what will be done in the next step
18. Keep patient have enough movability

## Ideal

17. A public information area where nurse can edit and share the information with patient

15. Effecient communication between nurse to improve nurse's effeciency of response to patient

13. Monitor for patient safety to reduce time waste
12. Effecient communication between nurse to improve nurse's effeciency of response to patient

9. Share infusion time for patient to reduce workload of nurse

6. Show precations and suggestions in visible information to improve work efficiency
5. Simple IV device, remote control by nurse

3. Information management for accessible seat or bed
2. Reasonable information management

## 3.3 What an Ideal infusion system should be?

From the above research in section 3.1 and 3.2, an ideal infusion system not only ensure basic infusion functions to keep infusion works well, but also meet patient and nurse new expectations to existing IV system. Therefore, the new expectations from the research on existing IV device and infusion experience will be discussed and analyzed by questionnaire to understand which expectations are important for them. The important expectations can be applied to the new infusion design.

### 3.3.1 User expectations

**Expectations from infusion device**

- Movable
- Lightweight
- Smaller device
- IV fluid warmer
- Simple to programming for nurse
- Clear interface of device to show functions
- Hard container to protect fluid bag

**Expectations from infusion experience**

**Patient**

- Clearly visible Information of conditions, treatment, suggestions for recovery, the following infusion plan, infusion time, seats maps.
- Reminder output feedback to infusion finish and other status for safety
- Emergency call system for safety
- Fast nurse feedback on their emergency call to offer patient more comfort
- Movable infusion to expand patient movability
- Infusion without IV stand

**Nurse**

- A public information platform to share clear visible information of conditions, treatment and suggestions with patient which can reduce nurse workload and improve nurses work efficiency from repeated explanation.
- Information management for accessible seat or bed
- Share patient information in time between nurses to improve communication about patient in emergency
- Reminder to infusion finish and other emergency status to reduce workload and time waste from repeated check
- Remote infusion rate control for nurse
- Simple programming on infusion

### 3.3.2 Ideal IV system

#### Questionnaire Survey

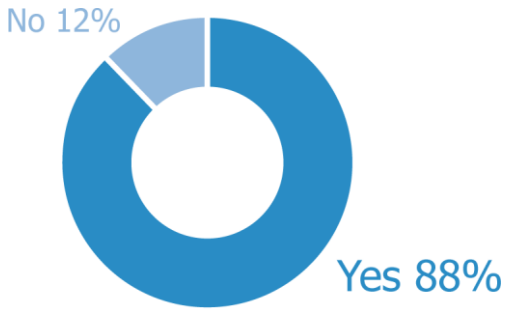
**Questionnaire object:** patient and nurse
**Number of people surveyed:** 110 patients and 52nurses
**When:** From 13th of January in 2018 to 18th of January in 2018
**Where:** Online
**Purpose:** The questionnaire is set to verify if most of patient and nurse have the same expectations to ideal infusion system, which can help us to judge which kind of product is more important for them and then we can focus on the result to improve it.

**Questionnaire:**
Questionnaire is set for patient and nurse separately, which can be found in the end of the thesis.

Questionnaire A for patient (in the end of thesis)
Questionnaire B for nurse (in the end of thesis)

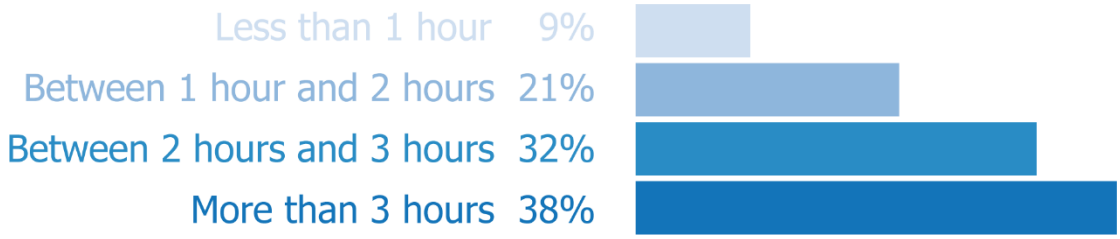
**Questionnaire result:**

Patient:
1. Have you ever infused in hospital?




*-Fig.21 Questionnaire data 1 from patient made by author*

2. How long time did you spend on infusion every time?

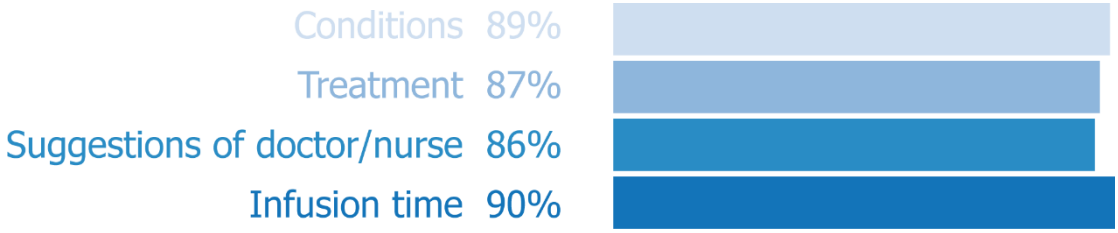



*-Fig.22 Questionnaire data 2 from patient made by author*

3. Do you need hospital map to find your seat or bed?


*-Fig.23 Questionnaire data 3 from patient made by author*

4. What information do you prefer to know in infusion? (Multiple choices)

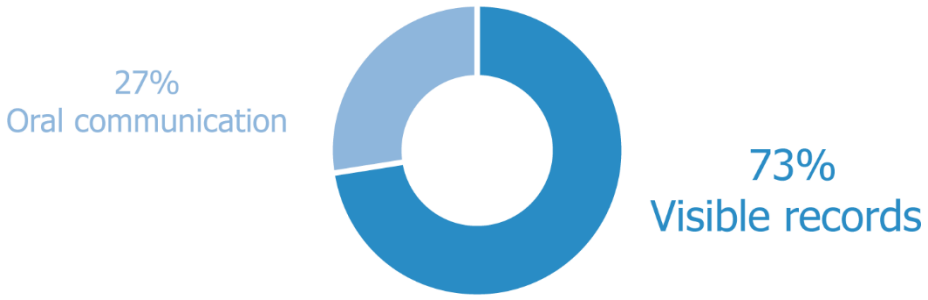



*-Fig.24 Questionnaire data 4 from patient made by author*

5. Can you remember and understand all the information told by doctor and nurse?

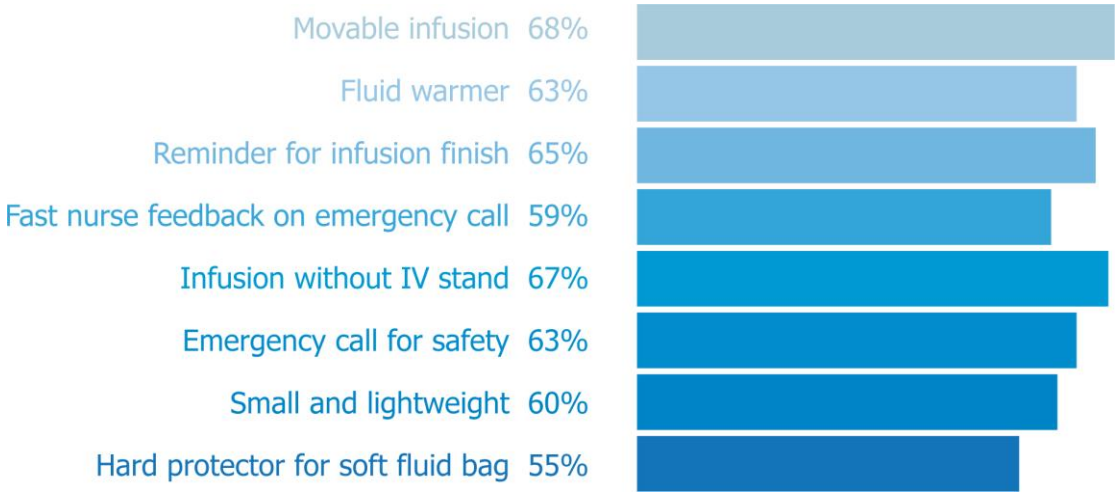

*-Fig.25 Questionnaire data 5 from patient made by author*

6. How do you prefer the above information is showed?




*-Fig.26 Questionnaire data 6 from patient*
*made by author*

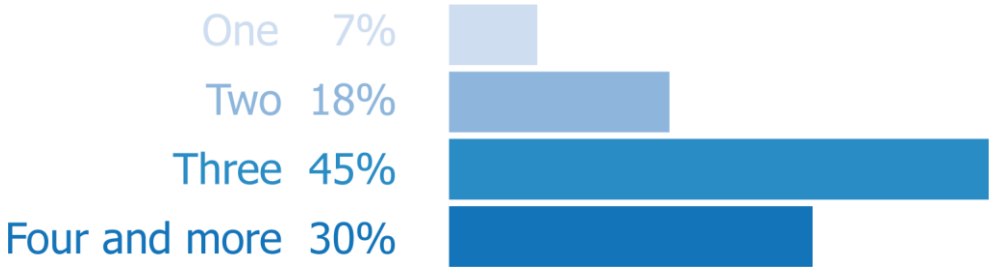
7. What functions do you expect to infusion device? (Multiple choices)




*-Fig.27 Questionnaire data 7 from patient*
*made by author*

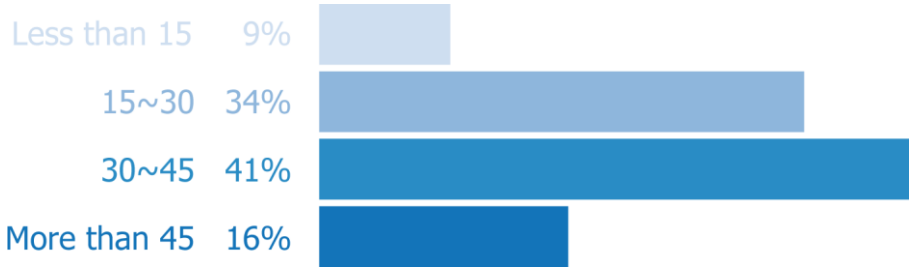
Nurse:

1. How many bags fluid in average do you serve for one patient each time?




*-Fig.28 Questionnaire data 1 from nurse*
*made by author*

2. How many infusion patients do you care for each day?

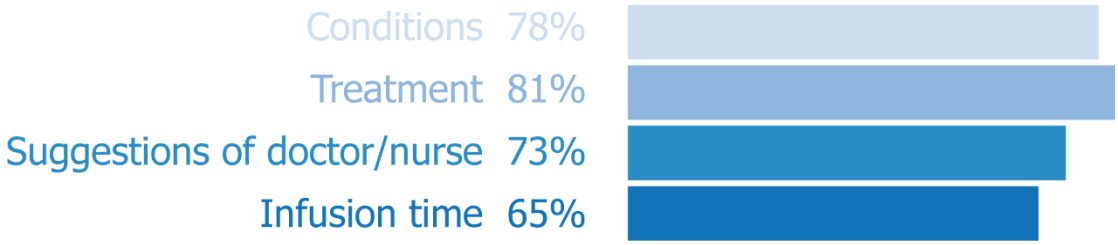



*-Fig.29 Questionnaire data 2 from nurse made by author*

3. Do you want to know the available seats and beds information?

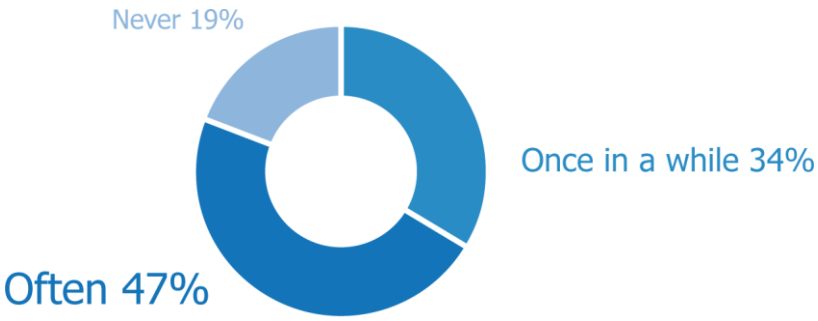

*-Fig.30 Questionnaire data 3 from nurse made by author*

4. What information do you have to show to patient?




*-Fig.31Questionnaire data 4 from nurse made by author*

5. Do you have to repeatedly explain the above information to patient?




*-Fig.32 Questionnaire data 5 from nurse made by author*

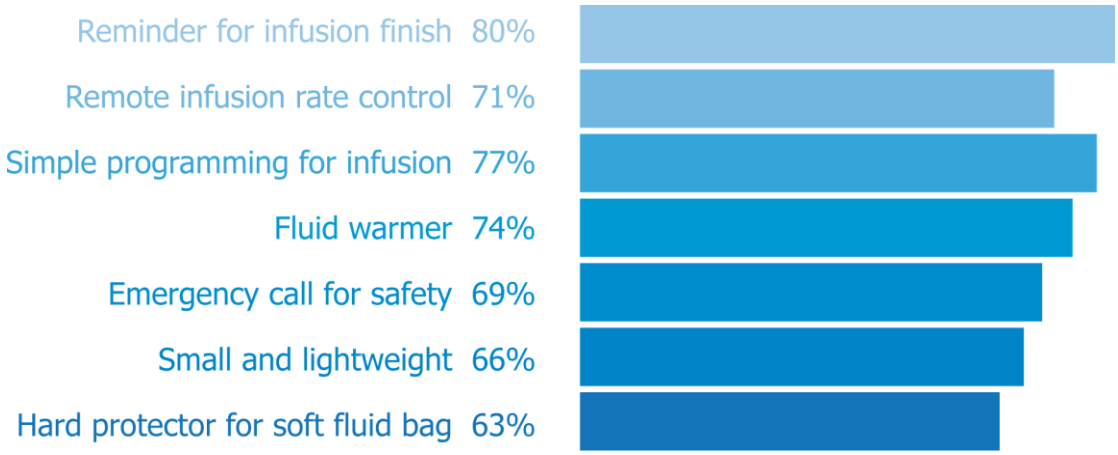
6. Do you prefer to show all the above information to patient in a visible information record, like an APP, to reduce workload from repeated explanation and save time?


*-Fig.33 Questionnaire data 6 from nurse made by author*

7. Do you want to share patient information in time between nurses to improve communication about patient in emergency?


*-Fig.34 Questionnaire data 7 from nurse made by author*

8. What functions do you expect to infusion device?




*-Fig.35 Questionnaire data 8 from nurse made by author*

**Conclusion**

From the result of the research, the most of user have the same expectations to ideal IV system. There is only a difference on the expectation to seat or bed information Patient don't expect too much on it. Therefore, the ideal infusion system from the result should have the following features:

**Wearable infusion**

- Wearable infusion without IV stand would be great for patient, which can expand patient movability, release patient from heavy IV pole, allow patient to move around anywhere and offer patient more comfort for their fast recovery.
- Hard container can protect the soft fluid bag in case of its broken when patient moves.

**Smart**

- Visible information management is necessary to show conditions, treatment and recovery suggestions for patients. All the information is edit and published by patient doctors and nurse, which not only help nurse to reduce workload from repeatedly explanation to patient and save time, but also offer patient all the information they care about in a visible record. The visible information can be checked many times if patient don't remember and understand it clearly. Besides, they can show all the records to their next doctor, which can be helpful for their treatment.
- Available seats or bed information for nurse can help nurse to assign the right ward, right bed or seat to patient easily and fast.

**Safe and friendly**

- Reminder for infusion finish and other emergency status can be helpful to reduce the side effects and offer more comfort to patient. Patient needn't stare on the drips to calculate

the finish time, and even they can be reminded automatically when they sleep on the bed or forget the infusion time. Besides, it can also remind nurse it is the time to help patient. Nurse needn't check patient regularly and lose time on it, which can reduce workload from the frequent check on patient.

- Emergency call to nurse is a must to help patient call nurse for emergency. But it must show feedback to patient effective call for emergency. Besides, patient can know the emergency fast and deal with it.
- Fluid warmer is also expected by most of patient and nurse, because fluid warmer can help patient to be warm when large amount of cold liquid is infused, which can reduce the danger caused by deterioration of body temperature.
- Good communication way to help nurse to share patient emergency call with other nurses can improve the communication between nurse and deal with patient emergency fast when the nurse is busy with other patient emergency.
- Precise infusion rate control for nurse to keep infusion safety for patient.

**Simple**

- Small and lightweight device is better than the mounted IV stand. They hold it up easily and move with it conveniently
- Simple infusion programming can improve the trouble in the complex control of existing IV devices in market.

# 04-
# Wearable Infusion

## 4.1 Wearable infusion

Wearable infusion therapy is a developing trend. Due to a confluence of health care trends, such as an increase in specialty medications that require expert-level administration, a population increasing in age, and large health care costs, a challenging for pharmacies and pharmacists alike has begun to emerge.

The wearable infusion therapy market is currently estimated to represent between $9 billion and $11 billion in annual US health care expenditures.[15] According to CVS/caremark's Insights 2013 Specialty Drug Trend Report, infused drugs make up roughly $35 billion of the specialty drug market. In addition, specialty medications are expected to increase from $92 billion in 2012 to $235 billion by 2018. [16] This heightened emphasis on cost effectiveness and cost containment has prompted a necessary change from long, expensive hospital stays for the duration of infusion therapy. Technological advances have enabled safe and effective alternative methods for obtaining these infusions. Wearable infusion therapy enables patients to decrease or totally avoid hospital or nursing home stays and resume normal routines and work behaviors while still treating their illnesses.

Wearable infusion pumps deliver medication or other solutions to patients intravenously, epidural, or subcutaneously. It allows patients to walk without the need for an IV pole. They are good for patients who require continuous or repeated infusions; sometimes the patient can use the pump at home. Typical uses include chemotherapy for cancer patients, parenteral nutrition for patients with gastrointestinal disorders, insulin delivery for diabetic patients, analgesics to relieve pain, or antibiotics to treat infections.

## 4.2 Benchmarking of Wearable infusion devices

In order to design a wearable infusion device, we must know and research the current similar infusion devices in market and discussed their performance to help me to guide my concept. From the online research, there are two different types wearable infusion device according to their infusion volume, volume from 250 to 1000ml and volume more than 1000ml. But most of them have the same principle for infusion, which consists of a cloth backpack and an ambulatory infusion pump which is designed to be portable or wearable.

Wearable infusion for common volume from 250ml to 1000ml


*-Fig.36 Wearable devices for common volume infusion made by author*

Wearable infusion for lager volume more than 1000ml

*-Fig.37 Wearable devices for large volume infusion made by author*

### 4.2.1 Target device group

In infusion bags market, plastic bags are available in different sizes. The most common sizes are 250, 500, and 1,000 ml.[17] Therefore, wearable device for common volume infusion becomes my main target market and will be researched and discussed more about their functions, technicals, user, user expectations and so on.

### 4.2.2 Analysis of current target devices

Wearable infusion devices for common volume can be divided in to three different types, wearable IV stand, wearable IV bag with pump and wearable IV pressure bag respectively, according to their technical and functions. In the following sections, three typical example is analyzed to understand existing wearable infusion devices.

## EZpole

*-Fig.38 EZpole*
*http://mobiu.tradekorea.com/product/detail/P454344/Wearable-IV-Pole-.html*

The EZpole has been in development by the South Korea-based Mobiu Corporation for the past three years, and is finally ready to begin clinical trials and testing. It's designed to sit on a patient's shoulder, like some wonderful morphine-dispending parrot, so they're able to

move around and easily tackle stairs while still getting the medication they require. Using a shoulder pad and a series of adjustable straps, EZPole can attach to a patient so that their IV bag and drip can be carried hands-free without the risk of it falling over accidentally.

It’s designed with the gravity principle of IV pole, but it is difficult to be used like the typical IV pole because the infusion pumps and other accessories are all developed for standard IV stand, and never considered the possibility of wearable. Therefore, EZpole couldn’t be assemble with the infusion pump and other accessories to offer precise rate control and comfort to patients. While it's designed to accommodate patients of all shapes, sizes, and ages, its use will be limited to a patient's condition. So if they're recovering from surgery under one of their arms, being strapped into this probably isn't ideal for their stitches. But for most patients it should bring some much needed mobility which will assist in their recoveries.

**Features:**
IV pole in a shoulder, Non-electronic, Gravity drip, Wearable
**Material:** PP (Polypropylene)
**Weight:** 0.43kg
Accommodates IV in 500ml, 1000ml types
**Target patients:**
- Patients with only IV administration.
- Patients receiving pain-killer injection after surgery.
- Inpatient without a guardian or caregiver.
- Patients during a light exercise or walk after surgery or meal.
- Patients receiving IV (for Nutrient Therapy) and other short-term IV administration.
- Patients treated at home.

**Patients-friendly**
EZpole is the only Portable IV Pole Stand you can wear. Patients with "IV Bag" can go anywhere corridor, elevator, toilet, in-and-out of hospital - alone!
- There is no longer need of Pushing a mobile IV pole wheels.
- Patients can use toilet alone.
- Patients can take a light exercise after surgery and meal.
- Helps patient’s rapid recovery
- No complex programming, maintenance, power cords, batteries, noisy alarms or IV poles.
- Patients can use stairways.
- EZpole frees both hands.
- Adjustable to fit various body sizes.
- IV containers mounted safely at three points to prevent shaking/rocking and prevents IV Bag from falling accidentally.

## Wolf-Pak® 250-500mL Infusion Pump Pouch

*-Fig.39 Wolf-Pak® 250-500mL Infusion Pump Pouch*
*https://www.wolfmed.com/pump-pouch-1l-6-cs.html*

Wolf-Pak® 250-500mL Infusion Pump Pouch is single-use, disposable infusion bags designed with your patients in mind. It's the current common system focus on safety control and wearable infusion. As we can see, the soft pouches are compatible with most ambulatory infusion pumps to offer the force to drive the fluid into patient's vein. Due to the application of portable infusion pump, the dose and infusion rate can be pre-programmed and control precisely by the pharmacy team. The whole system fits nicely into a small bag that can be worn over shoulder or around waist in belt loop according to patient preferences or hung nearby throughout the infusion. The durable pouches are economical and stylish for patients receiving outpatient TPN, PCA, antibiotic, chemotherapy and other infusion therapies. As with all home infusion therapies, the intent is for the patient to be as mobile as he or she would like to accommodate their lifestyle.

**Features:**
A wearable bag with infusion pump and IV fluid bag, precise control and safe
**Material:** cloth
**Weight:** 0.3KG+1KG fluid + weight of pump (500g) =1.8KG
Accommodates IV in 250ml, 500ml, 1000ml types
**Target patients:**
Patients receiving outpatient TPN, PCA, antibiotic, chemotherapy and other infusion therapies
**Patients-friendly**
Infusion pump pouch allows patients optimal mobility, e.g. going to the toilet, going up and downstairs, canteen visits etc.
- There is no longer need of pushing a mobile IV pole wheels.
- Comfortable material for patients
- Allows patient mobility for patients to maintain lifestyle at home.
- Used with infusion pump to control of volumes and flow rates precisely and safely.

- More comfort for patients to keep normal lifestyle and help patient's rapid recovery
- It can prevent IV Bag from falling accidentally.
- Patients can take a light exercise after surgery and meal.
- Adjustable to fit various body sizes.

## Statpack G3 Intravenous Cell

*-Fig.40 Statpack G3 Intravenous Cell*
*http://statpacks.com/product/g3-intravenous-cell/*

The Stat Packs G3 Intravenous Cell is a foam molded book style design helps keep IV therapies organized and at your fingertips. Drip sets, IV bag(s), catheters, needles and Start Kits™ are neatly arranged for fast access. The pressure bag is wrapped around the IV bag and inflated with a hand held pump to a desired and measured pressure. The increased pressure surrounding the fluids causes them to flow faster or continuously flow into the patient. In addition, a valve is used to control the airflow through the bladder, optimizing the pressure on the IV bag by increasing or decreasing the air inside the bladder. The IV bag contains fluids (blood, medications or nutrients) and connects via IV tubing to an IV line in the patient. A pressure bag is used when a critically ill or injured patient requires a rapid administration of fluids.

**Features:**
A portable pressure bag with handheld pump, fast infusion
**Material:** cloth
**Weight: 0.27kg +1kg fluid**
Accommodates IV in 250ml, 500ml, 1000ml types
**Target patients:**
Patients receiving outpatient TPN, PCA, antibiotic, chemotherapy and other infusion therapies

### 4.2.3 Opportunities for wearable IV system

From the research on existing IV system in chapter 3, an ideal infusion system have been showed clearly, therefore, it can be used to evaluate the three current wearable IV product in market to find which part can be improved for future.

TABLE 03. OPPORTUNITIES FOR WEARABLE INFUSION DEVICE

| | EZpole | Wolf-Pak | Statpack G3 Intravenous Cell |
|---|---|---|---|
| **Wearable without IV stand** | ● | ● | ● |
| **Smart visible information like treatment and available seat or bed information to nurse** | ○ | ○ | ○ |
| **Reminder to infusion finish** | ○ | ● | ○ |
| **Emergency call system for safety** | ○ | ○ | ○ |
| **Fluid warmer** | ○ | ○ | ○ |
| **Hard container to protect soft fluid bag** | ● | ○ | ○ |
| **Simple programming for precise infusion** | ○ | ● | ○ |
| **Small and lightweight** | ● | ● | ● |

From the TABLE 03, the three typical wearable infusion device have already meet patient small, and lightweight wearable expectations, but all of them can't meet the other important expectations to an ideal infusion experience for patient and nurse. Besides, there is a large gap to combine smart information management, emergency call system and fluid warmer with wearable, which have become the great chance for current wearable infusion. Therefore, a new smart wearable infusion system can be developed to meet all users' expectations for ideal infusion.

## 4.3 Wearable research on users

Wearable infusion is different with existing IV system. When infusion becomes wearable, user will have different requirements on wearable performance, like wearable weight and wearable way. Therefore, wearable research on users is necessary to understand the right weight and comfortable wearable way.

### 4.3.1 Target patient group

#### Patient of current target devices

From the research on existing wearable infusion device, the target user group of current wearable product can be known, which are

- Patients with only IV administration.
- Patients receiving pain-killer injection after surgery.
- Inpatient without a guardian or caregiver.
- Patients during a light exercise or walk after surgery or meal.
- Patients receiving IV (for Nutrient Therapy) and other IV administration.
- Patients treated at home.
- Patients receiving outpatient TPN, PCA, antibiotic, chemotherapy and other infusion therapies

#### Interviews with nurse about patient group

To know what kind of patient can wear it to infuse and move around.

**- Interviewee1:**

Kai Liu,
30 years old
Doctor in surgical department, People Hospital of Weishi, China

Q: How do you think a wearable infusion device?
*A: Very nice. If a patient wear it, the patient could move around and walk along the corridor freely, and even get downstairs conveniently. They could be free very much and get more comfort even have a good mood, which will be benefit for patient quick recovery.*

Q: How much the maximum weight do you think patient in infusion could accept to the wearable infusion device?
*A: I think the weight could be ok between 1kg and 1.5kg, including the fluid, because the*

*common size of an IV fluid bag we used for adult is 250ml, 500ml, 1000ml. The most common one is 500ml. Generally, most of the patient in infusion is enough strong to wear the weight and have the abilities to move around. Of course, the lighter the better.*

Q: What kind of patient do you think needs the wearable device?
*A: I think most of patient in infusion can use it, especially patients with chronic conditions who need receive outpatient TPN, antibiotic, chemotherapy, enteral nutrition, pain management and other infusion therapies. They need infuse regularly and meanwhile they can keep their normal life style, so it will be better for these patients. Besides, the patients in the medium and later recovering period after surgery can use it for their infusion because they become stronger to walk around and to do more exercise for their health.*

**- Interviewee2:**

Shaolong Yao
30 years old
Doctor in bone surgery department, People Hospital of Weishi, China

Q: How do you think a wearable infusion device?
*A: It's patient-friendly. In our department, we have some wearable infusion bags to help patient walk around because we often suggest patients with movability to do more exercise or ambulation training for their fast recovery. It is a wearable bag with a infusion pump, and many patients in our department like to use it when infusing. It is very convenient for patient to free them from IV stand.*

Q: What kind of patient can use the wearable device?
*A: It depends on patients conditions. Generally, most of the patients after surgery in bone surgery department have movability to get out of bed and walk around, except patients with leg or spine surgery. The patients with serious conditions could walk around to use it after the early recovery phase.*

Q: How much the maximum weight do you think patient in infusion could accept to the wearable infusion device?
*A: I think the weight patient could accepted is about 1.5kg because the weight of the wearable bag we have, including the fluid and infusion pump, is about 1.5kg~2kg because of the different pump. You can search the bag online.*

**- Interviewee3:**

Gucsni Govsrnaiori Rariwa

Nurse, working in ASST Great Metropolitan Niguarda in Milano

Q: Do you think what kind of patients can use it?
*A: certainly an independent patient, with chronic diseases, in case of confused patients it would be ideal that this device is not self-managed by them, but perhaps with a password that guarantees access only to the medical / nursing staff, thus avoiding any changes to the set values. This device could be useful to avoid accidental falls due to its comfort compared with the IV stand.*

## Patient group

From the research on infusion patient, they have different complex conditions and treatment. It's difficult to set the accurate patient group. But I researched what kind of disease can be treated by infusion, and then add the patient features from the description of nurse interview to set patient who can use wearable infusion device.

Generally, diseases commonly treated by infusion therapy include infections unresponsive to oral antibiotics, dehydration, cancer and cancer-related pain, gastrointestinal diseases or disorders which prevent normal functioning of the gastrointestinal system, and more. Other conditions treated with specialty infusion therapies may include cancers, congestive heart failure, Crohn's Disease, hemophilia, immune deficiencies, multiple sclerosis, rheumatoid arthritis, and more. Typical uses include chemotherapy for cancer patients, parenteral nutrition for patients with gastrointestinal disorders, insulin delivery for diabetic patients, analgesics to relieve pain, or antibiotics to treat infections.

Features of patient group who can wear it to infuse:

- Adult patient in continuous infusion with ability to move
- Patients with only IV administration.
- Patients receiving pain-killer injection after surgery.
- Inpatient without a guardian or caregiver.
- Patients during a light exercise or walk after surgery or meal.
- Patients receiving IV (for Nutrient Therapy) and other IV administration.
- Patients treated at home.
- Patients receiving outpatient TPN, PCA, antibiotic, chemotherapy and other infusion therapies
- Patient with a long time infusion
- Patient with infusion fluid volume between 250ml and 1000ml
- Patient with pain management in recovery after surgery
- Patients are encouraged to do ambulation training early after surgery
- Patient who are easy to be anxiety
- Patients after surgery in bone surgery department have movability to get out of bed and walk around, except patients with leg or spine surgery

### 4.3.2 Wearable requirements research

*-Fig.41 ASST Great Metropolitan Niguarda*
*photographed by author*

**Wearable test**

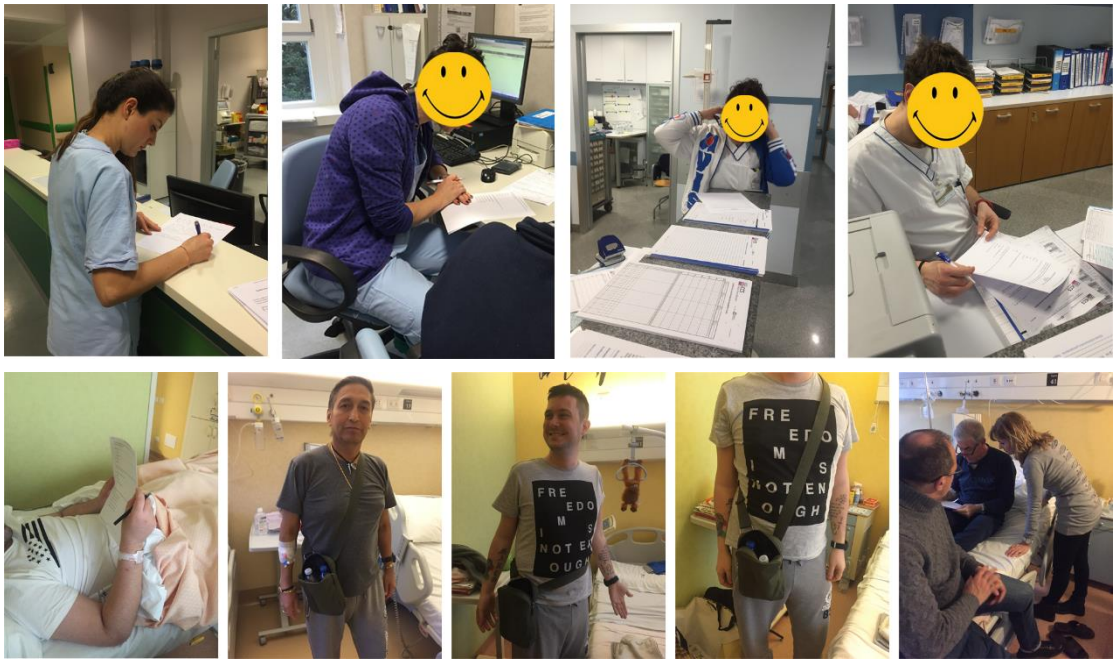
**Where:** ASST Great Metropolitan Niguarda, Istituto Clinico Città Studi, Milano
**Test object:** 50 patients in infusion and 30 Nurses
**Test purpose:** to know patient requirements on wearable weight and wearable method

**Test settings:**

-Wearable weight
The average weight of wearable infusion device in market is about 1.5kg from the analysis of wearable infusion product listed in section 4.2.2. Besides, the common IV fluid is between 250ml~1000ml and maximum fluid weight is about 1KG, so the weight level for the test is less than 1KG, 1KG~1.5KG, 1.5Kg~2KG and more than 2KG~3KG.

-Wearable way
In market, wearable products often are worn in four different method, such as messenger bag, waist bag, backpack and arm. Therefore, the test on wearable way is around the four different ways.

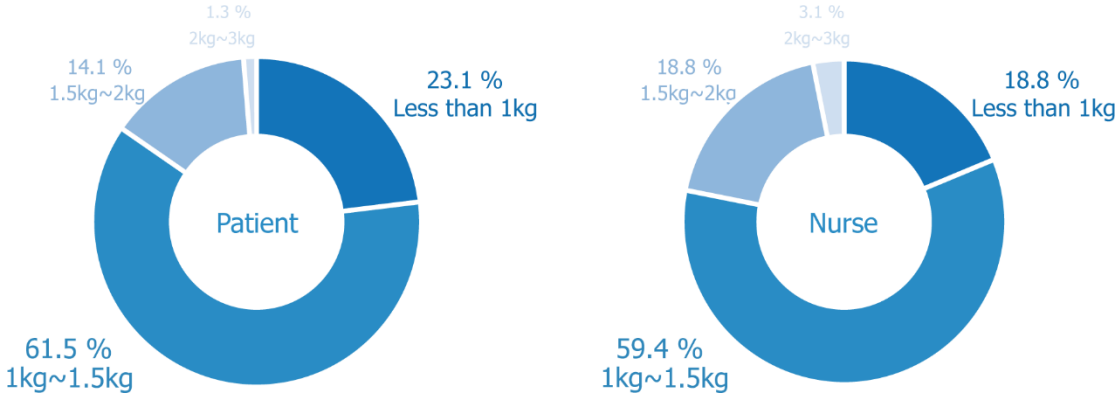
-Test data is collected by questionnaire after test. Questionnaire can be found in the end of thesis, which are Questionnaire C (in the end of thesis) for nurse and Questionnaire D (in the end of thesis) for patient.



*-Fig.42 Weight test in hospital photographed by author*

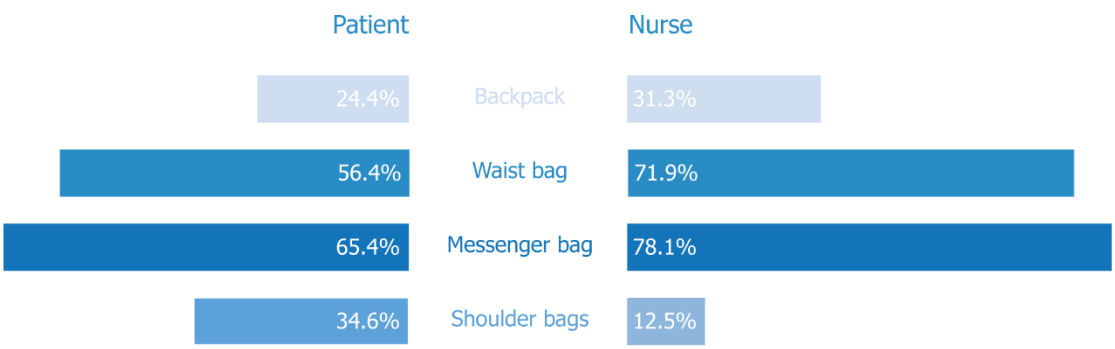
**Test results:**

Maximum wearable weight patients and nurses can accept




*-Fig.43 Wearable weight test data made by author*

Favorite wearable way




*-Fig.44 Wearable methods test data made by author*

From the wearable test result, patient and nurse have the same requirements on the maximum weight and wearable methods. The maximum weight patient and nurse can accept is between 1Kg and 1.5Kg and the better wearable ways for them are messenger bag and waist bag.

# 5-

# From Research to Concept

## 5.1 Brief

According to the research on existing IV devices, current infusion experience in hospital, and wearable infusion product, patient and nurse have different expectations and requirements to new IV device, infusion experience and wearable infusion, all of the results structured a new brief to develop an ideal wearable infusion system.

The new smart wearable infusion system is expected by patient during infusion and nurse with much workload to improve existing infusion experience, which should be designed with wearable features to expand patient movability; visible information management platform to strengthen communications between patient and nurse about patient conditions, treatment and doctors advices for patient recovery; basic IV functions to ensure infusion works well; safe from cold fluid and emergency; more comfort for patient to offer infusion time and reminder feedback on infusion finish.

### 5.1.1 Requirements and Functions for patient

**Basic IV Functions**
The new IV device should ensure the basic infusion functions, which should be a supporter for IV pump, a safe holder for IV fluid, fluid warmer,

**Wearable**
Based on the wearable investigation to patient, the device should be:
Wearable in both positions of waist and single shoulder.
With a wearable weight patient can accept, which is around 1.5KG
Reduce restrictive to patient movement needs

**Information**
Treatment tracking
Clearly visible and organized doctor's suggestions to patient healthy, patient can read it anytime and share it with families or their caregivers
Infusion time they will spend
Feedback on infusion finish

**Safety**
Emergency call,
They can stop it for emergency
Effectively patient-friendly feedback on infusion finish and infusion time

**Patient friendly feedback**
Comfortable for wearable
Low noise to remind

### 5.1.2 Requirements and Functions for nurse

**IV device**

Simple interface
Precise rate control
Infusion rate control
Lightweight to manage
Small and easy to store
Clear feedback on power status
Controlled by nurse
Easy to assemble

**Safety**

Easy to sterile
Clear power status of IV device
Air bubble detector to send signal to nurse for emergency

**Information management**

Treatment tracking
Share doctor's suggestions to patient healthy, patient can read it anytime and share it with families or their caregivers
Patient information management
Accessible seat or bed information

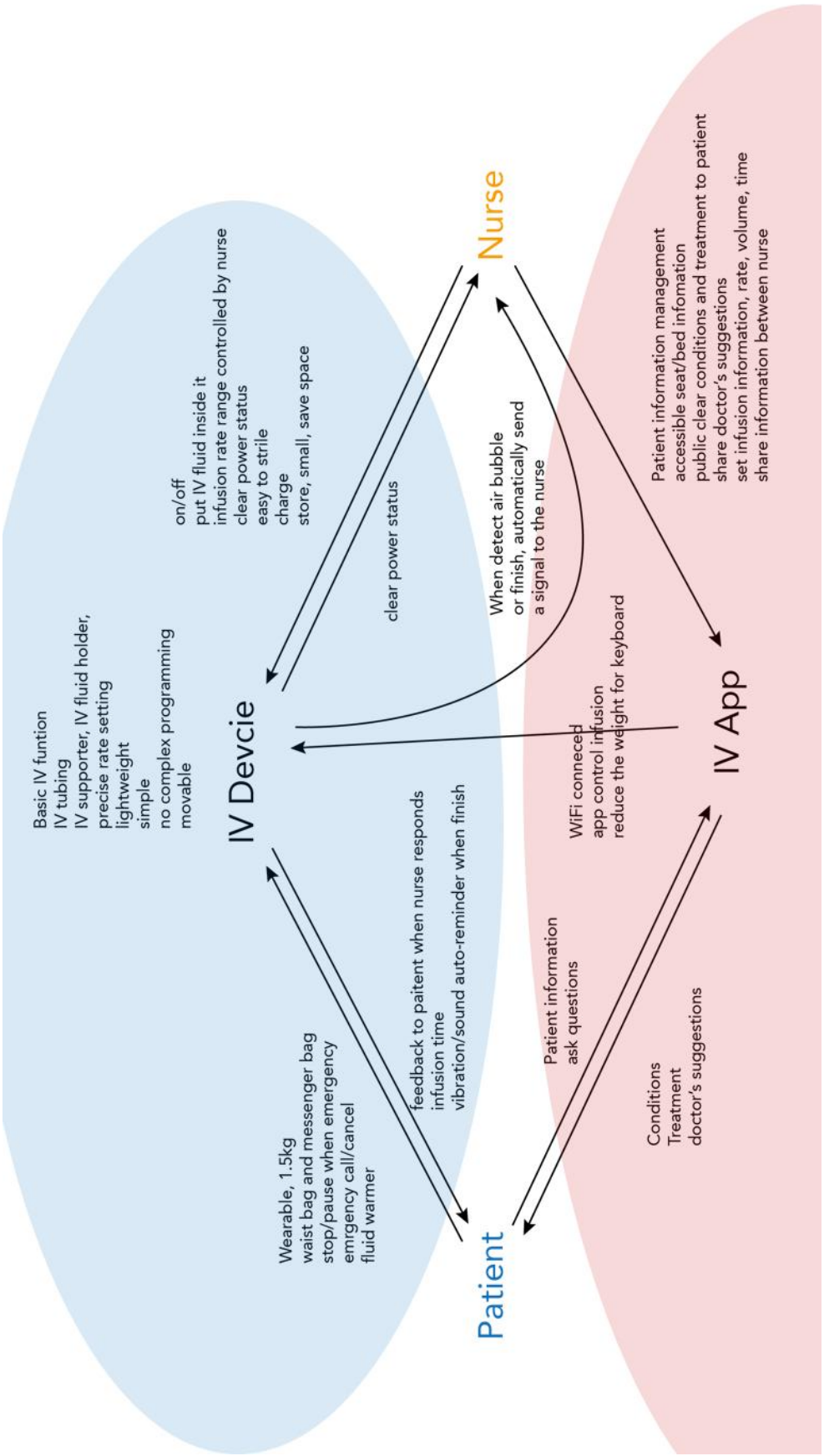
Smart control

Share information between nurses

## 5.2 New specification for infusion system

From the research results of existing IV system, existing infusion system have been applied in hospital for many years, and other related products also were developed to improve patient infusion experience in the recent years. There is no doubt that existing infusion system could ensure infusion works well to help patient recover. But they cannot meet new patient expectations to movability. Nowadays, some and wearable infusion product can be bought in infusion market to meet patient need on walking around, but they are just some bags of backpacks used together with infusion pump, which are not combined with necessary infusion functions very well for safe infusion. Besides, many product is centered to patient and ignored their controller nurse. Therefore, this project is to design a new kind of wearable infusion system to improve the existing infusion experience for patient and nurse at the same time.

Based on existing IV system, design of the new kind of wearable infusion device will ensure the basic infusion functions, like fluid container, pressure maker, IV tubes set, IV fluid bags, IV pump, IV fluid warmer and so on. Moreover, from the above requirements to user experience, the new wearable infusion system should provide other functions like visible treatment tracking, doctor suggestions, available beds or room information, remaining infusion time for patient, emergency call, effect interaction between nurse and patient, automatically reminder for infusion finish and so on. So the wearable infusion system design can be designed in two parts, wearable infusion device and information management platform, to improve existing IV system in user experience and infusion functions for medical requirements.




*-Fig.45 Product architecture made by author*

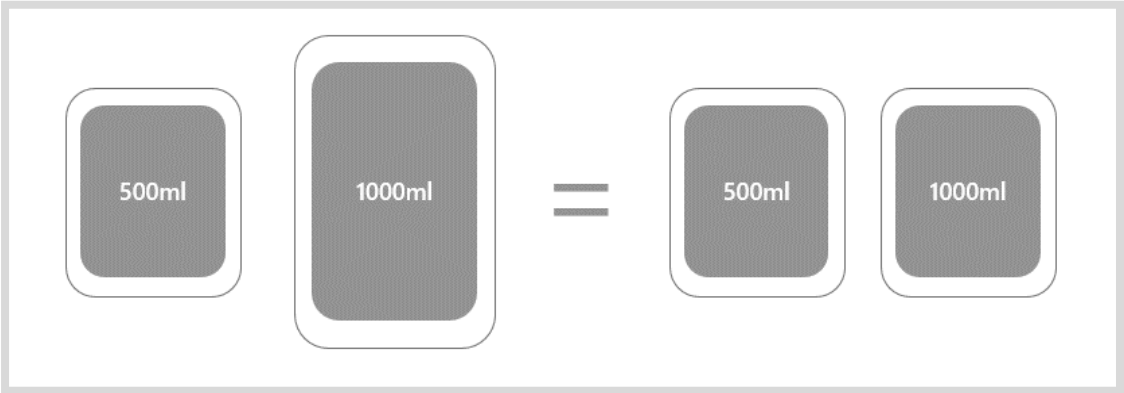
### 5.2.1 Device features

**-Fluid Container**

*-Fig.46 Fluid container*
*made by author*

A fluid container would be designed instead of typical IV stand. The container should be stable to hold the infusion bag to prevent it falling down, like a bag or plastic box.

**-Size**




*-Fig.47 Size requirement for fluid bag*
*made by author*

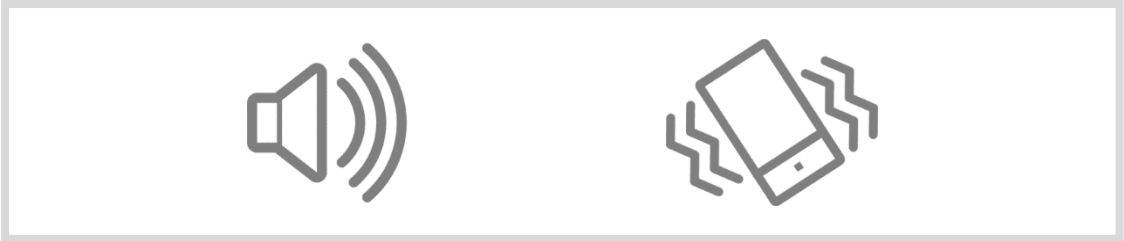
Because of the maximum volume of infusion bag we set is 1000ml, and normal size of the infusion bag in market is so long and looks big. We will redesign the size of fluid bag in a right way to make it look small and save the space for the device.

**-Screen**


*-Fig.48 Screen requirements*
*made by author*

In figure 48, the device should show some necessary information to nurse and patient.
For patient, the information includes the remaining infusion time.
For nurse, the information includes the power status, Wifi connection status, temperature of liquid.
Therefore, a screen interface would be designed to effectively display all the above information they need.

**-Reminder**



*-Fig.49 Reminder types*
*made by author*

The reminder is designed to notice the patient automatically when the infusion is finished or when it detects an emergency, for example, air embolism caused by air. The common reminders are sound reminder and vibration reminder. Because the sound reminder is so noisy, we will apply the technology of a vibration reminder to notice patient. After all, the wearable device is close to patient body, so vibration could be the better way to remind patient.

**-Wearable**

*-Fig.50 Wearable method*
*made by author*

From the research on patient favorite wearable way, the device will be designed with two different wearable ways, like messenger bag and waist bag, to meet patient's expectations to the wearable infusion. Therefore, a structure will be designed to adjust it to both wearable ways.
Besides, the weight of wearable device will be limited to about 1.5KG.

**-Pump**

*-Fig.51 Peristaltic pump*
*made by author*

Based on existing infusion pump technology, a small peristaltic pump could be applied to force the medical fluid into patient body and control infusion rate precisely, which can ensure the basic infusion works well.

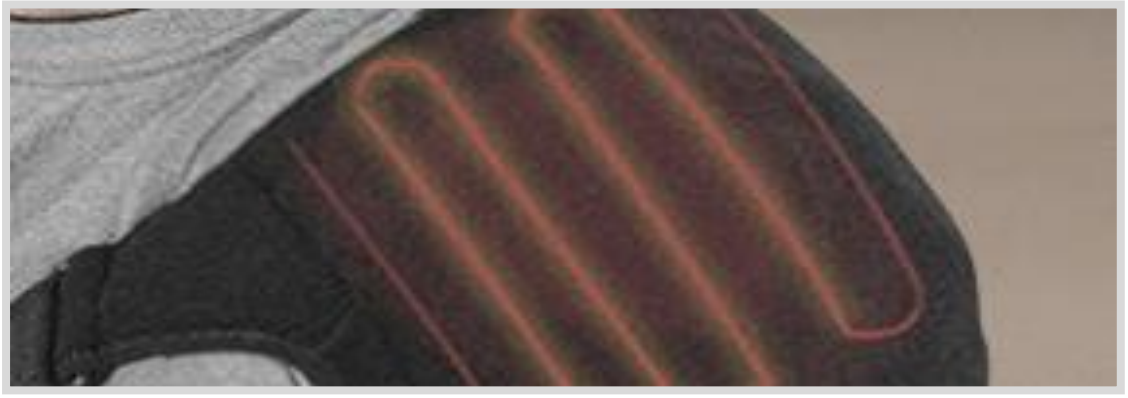
**-Communication Functions**

*-Fig.52 Communication functions setting*
*made by author*

Patient can use the device to send an emergency call when emergency happens. If the nurse read their emergency message, they can get feedback that nurse have known their requirement. Besides, if patient make a mistake to press the emergency key/button, a cancel key should be design to cancel their wrong operation to emergency key/button in time.

When emergency happens, the infusion pump should be stopped immediately. Therefore, a start / stop function is necessary for the situation.

**-Fluid warmer**

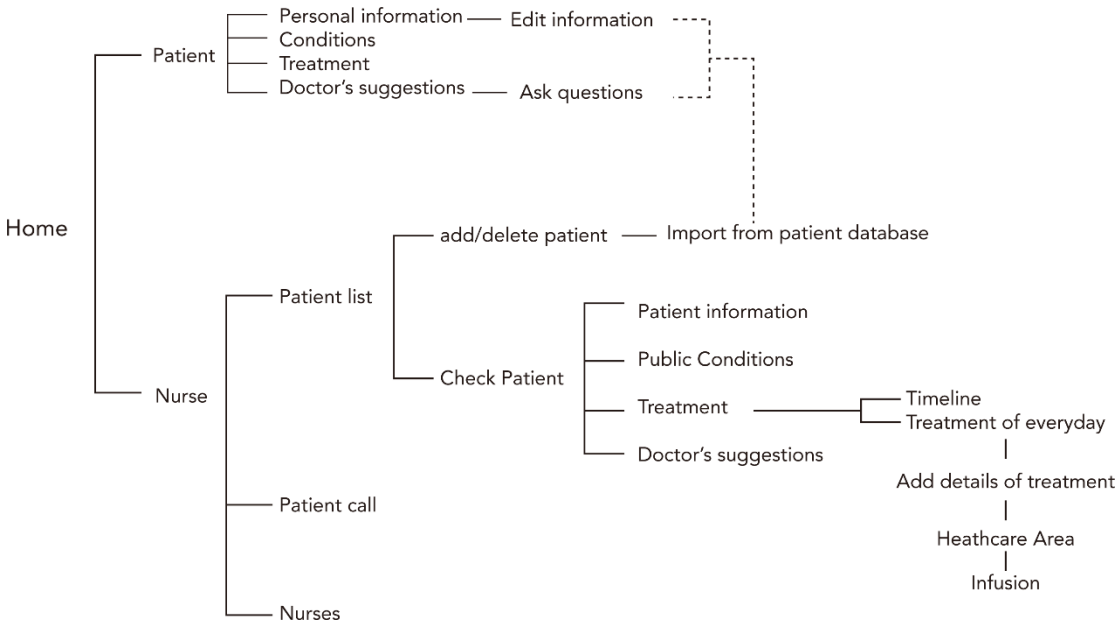


*-Fig.53 Fluid warmer*
*made by author*

According to the patients' needs and heating technology used in the exiting fluid warmer, the proper heating system will be applied to warm the fluid to the comfortable temperature.

## 5.2.2 APP features

Because the effective communication between patient and nurse is very important to Informatics important to reduce the medical accident and dangers for patient. Therefore, an information platform will be designed to manage all the information for nurse and patient, which could be built in an APP.




*-Fig.54 Information APP frame -made by author*

**-APP design for nurse**

The APP design for nurse should show the clear available beds or ward information in hospital, offer a method to manage patient information, build an public area for nurse to share patient conditions, treatment and doctors suggestions with patient.

**-APP design for patient**

The app should show clear conditions, treatment plan and doctors suggestions for patient healthy. It can help patient to remember the confused professional medical information. They can check all the detailed information in any time. Besides, they can show the detailed medical records to their caregivers or the future doctors for the next stage of treatment.

**-APP design for infusion device**

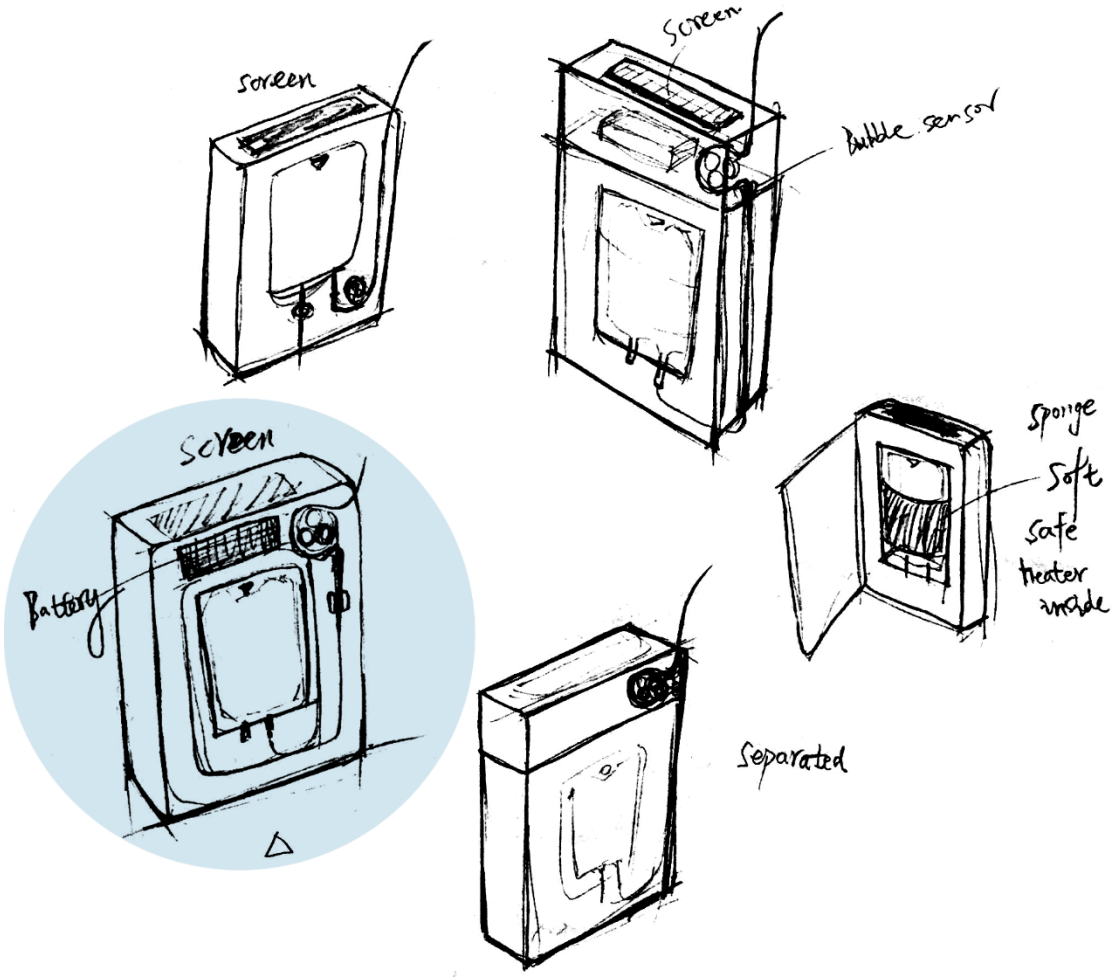
In order to control the device easily, remote control will be designed with the app. The combination between device and APP can reduce nurse workload and the waste of time costed for checking the device. Therefore, the APP would be designed to control the infusion rate and temperature, to remind nurse what happened to patient by receiving emergency signal automatically sent by the device.

## 5.3 Concept design

### 5.3.1 Device concept

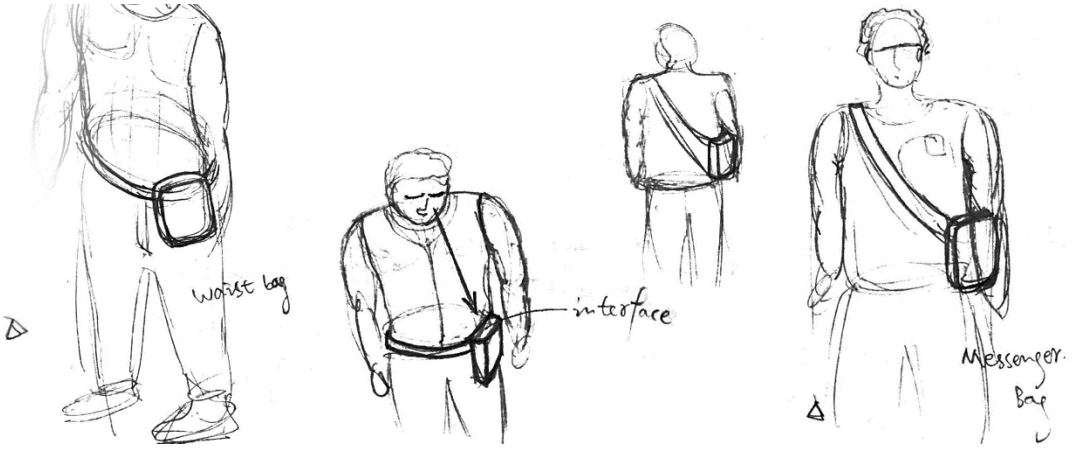
MOTIV is a smart wearable infusion product based on the infusion principle and patient behavior habits. A screen is designed to show infusion time, fluid temperature, Wifi connection status and power status. The position of the surface is on the top surface of the device because of the wearable way. When patient wearing it in infusion want to know their remaining time or check the Wifi and power status, they just look down at the device in their waist, then they can have a clear view on the screen about the time, Wifi and power. Similarly, three buttons for emergency are also designed on the top surface, where they can control it easily. Two LEDs is used to give feedback to patient control on the buttons. For wearable function, a special rotational structure is developed to realize two wearable ways. Besides, the application of small infusion pump can guarantee the precise infusion. In order to control the size of the device, the fluid bag is redesigned to save space.

Principle for device



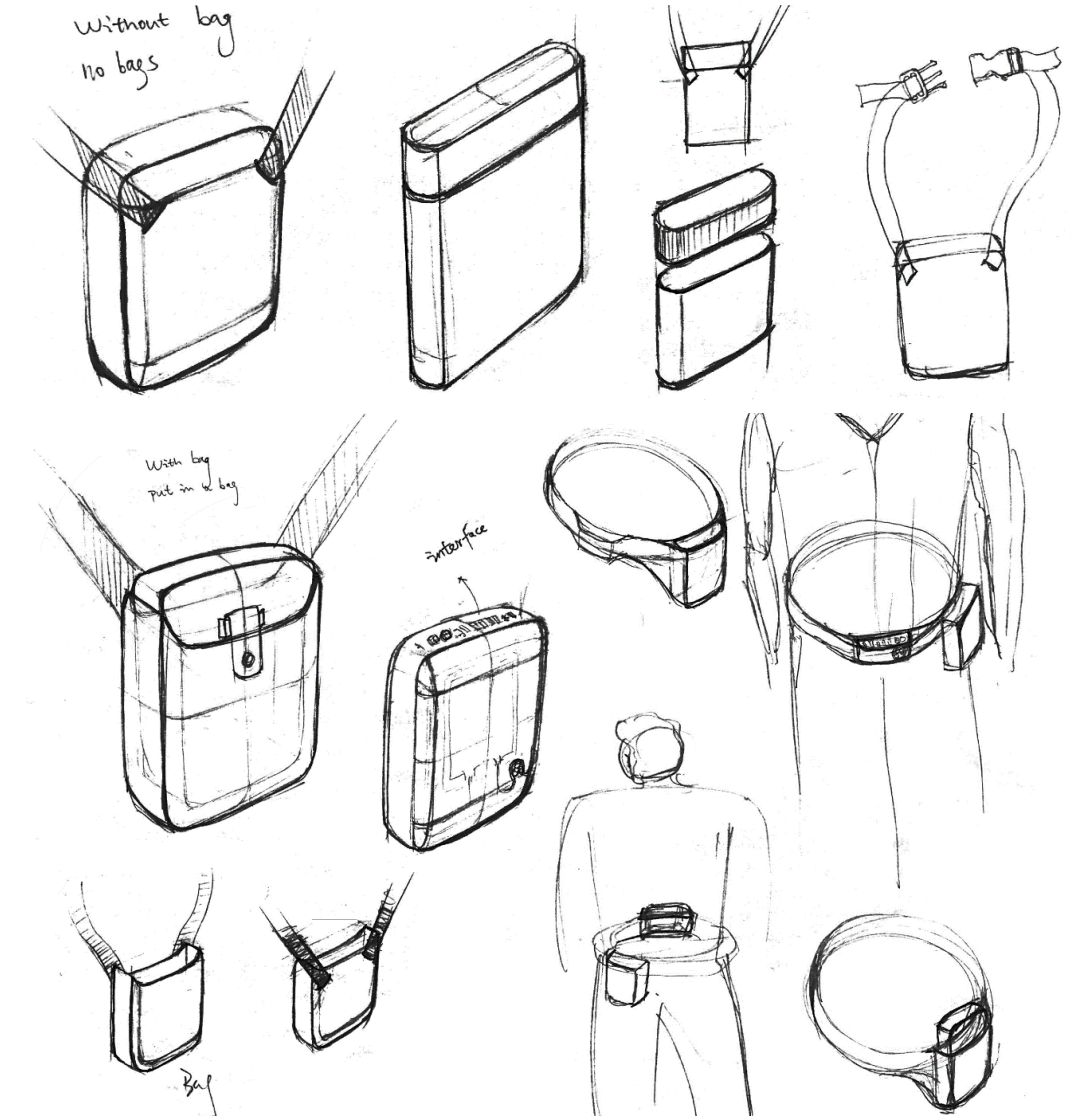

*-Fig.55 Concept sketches made by author*

Wearable way




*-Fig.56 Wearable way sketches -made by author*

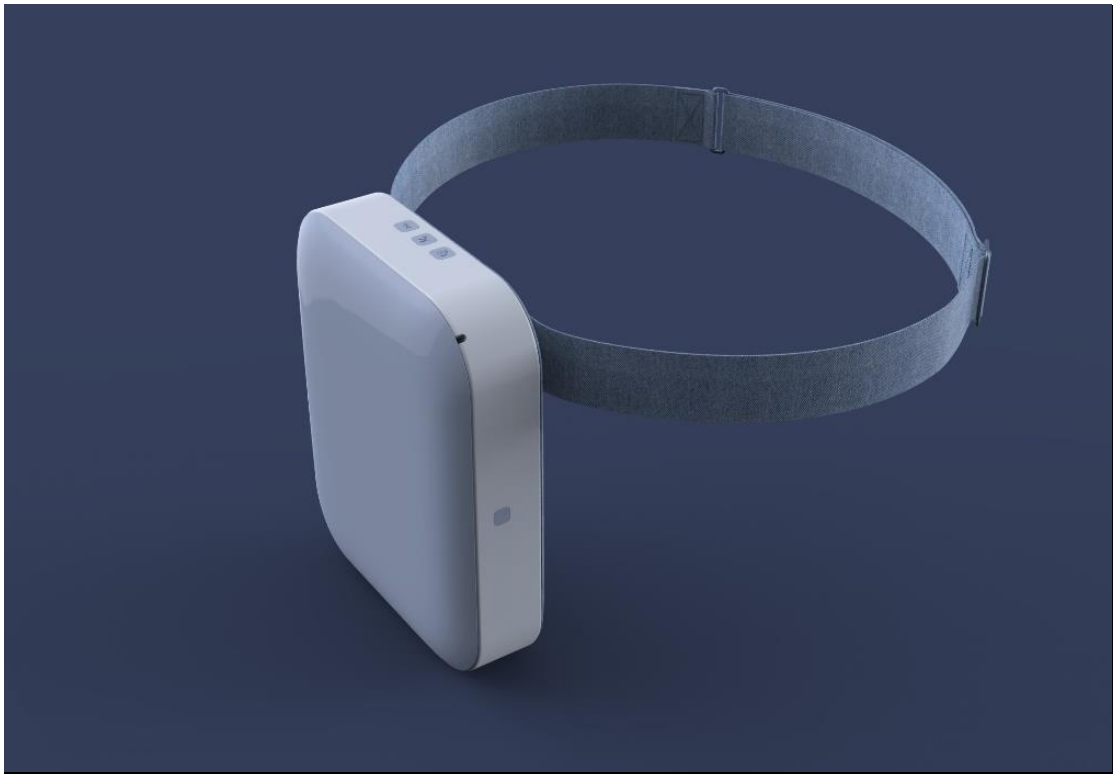
Sketch for shape



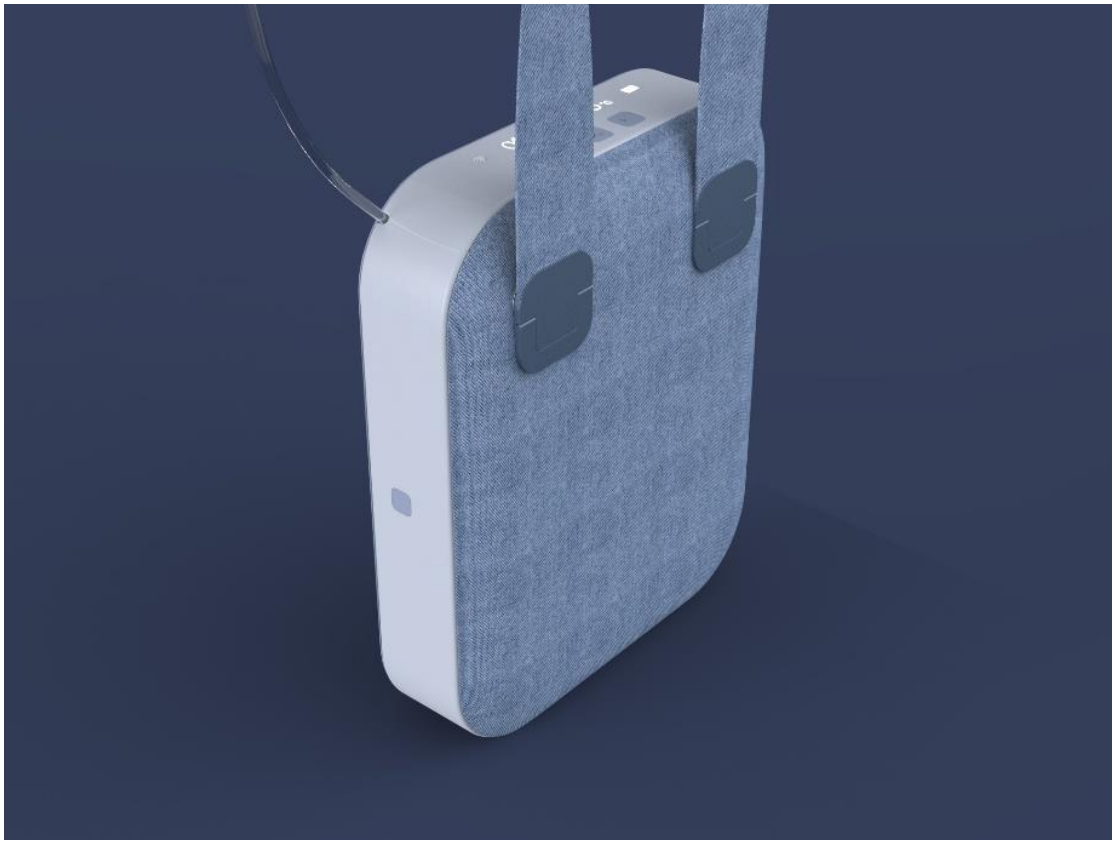

*-Fig.57 Sketches of shape concept -made by author*

**- Design for patient**

*-Fig.58 Concept for shoulder -made by author*



*-Fig.59 Concept for Waist -made by author*



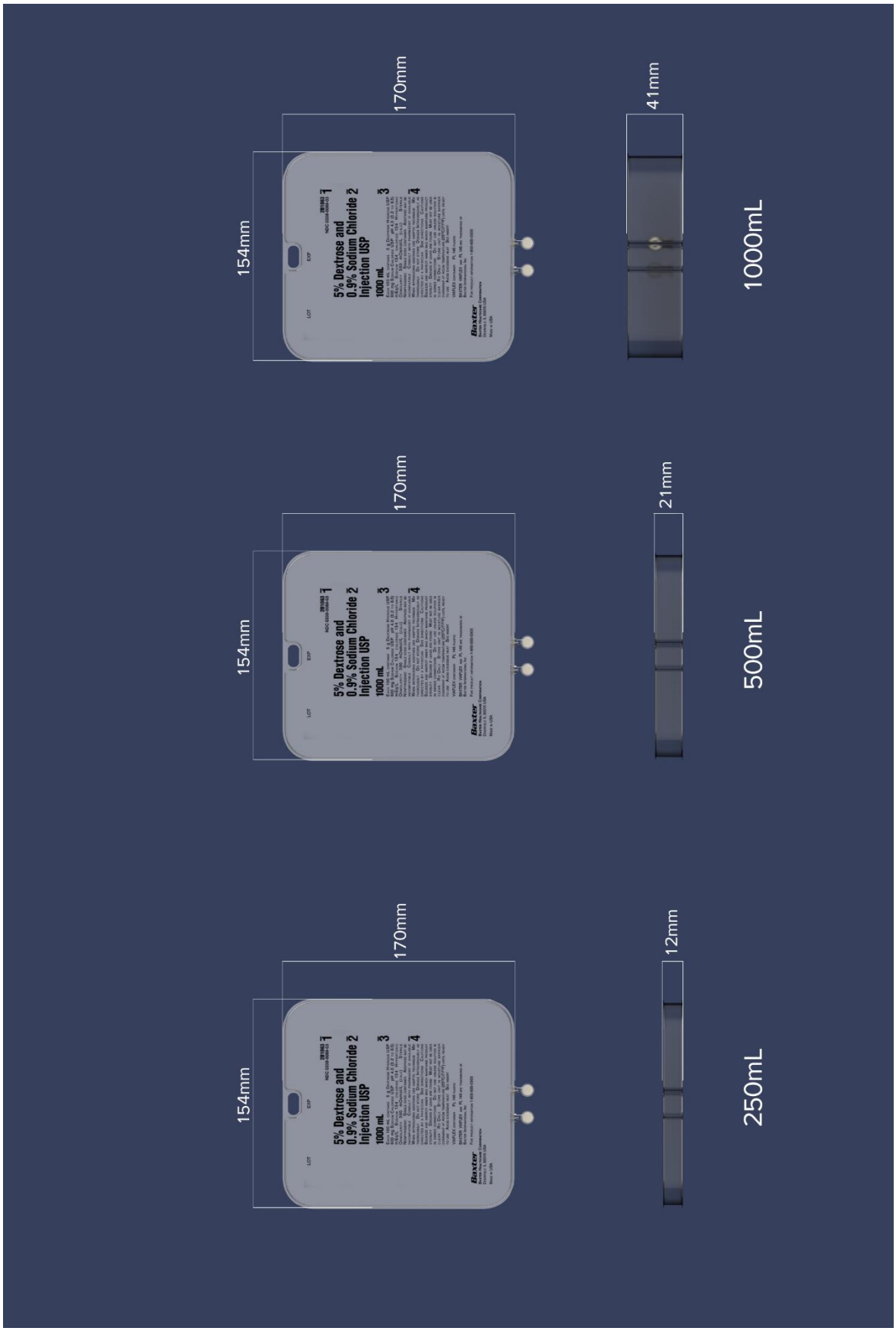
*-Fig.60 Concept for comfortable wear -made by author*


*-Fig.61 Concept for interface -made by author*

**- Design for nurse**

*-Fig.62 Concept for fluid protector -made by author*


*-Fig.63 Concept for nurse to put fluid inside it -made by author*




*-Fig.64 Concept for the size of fluid bags -made by author*

### 5.3.2 App concept

**- Design for nurse**

A. After landing, the nurse can check the available beds information in each room.

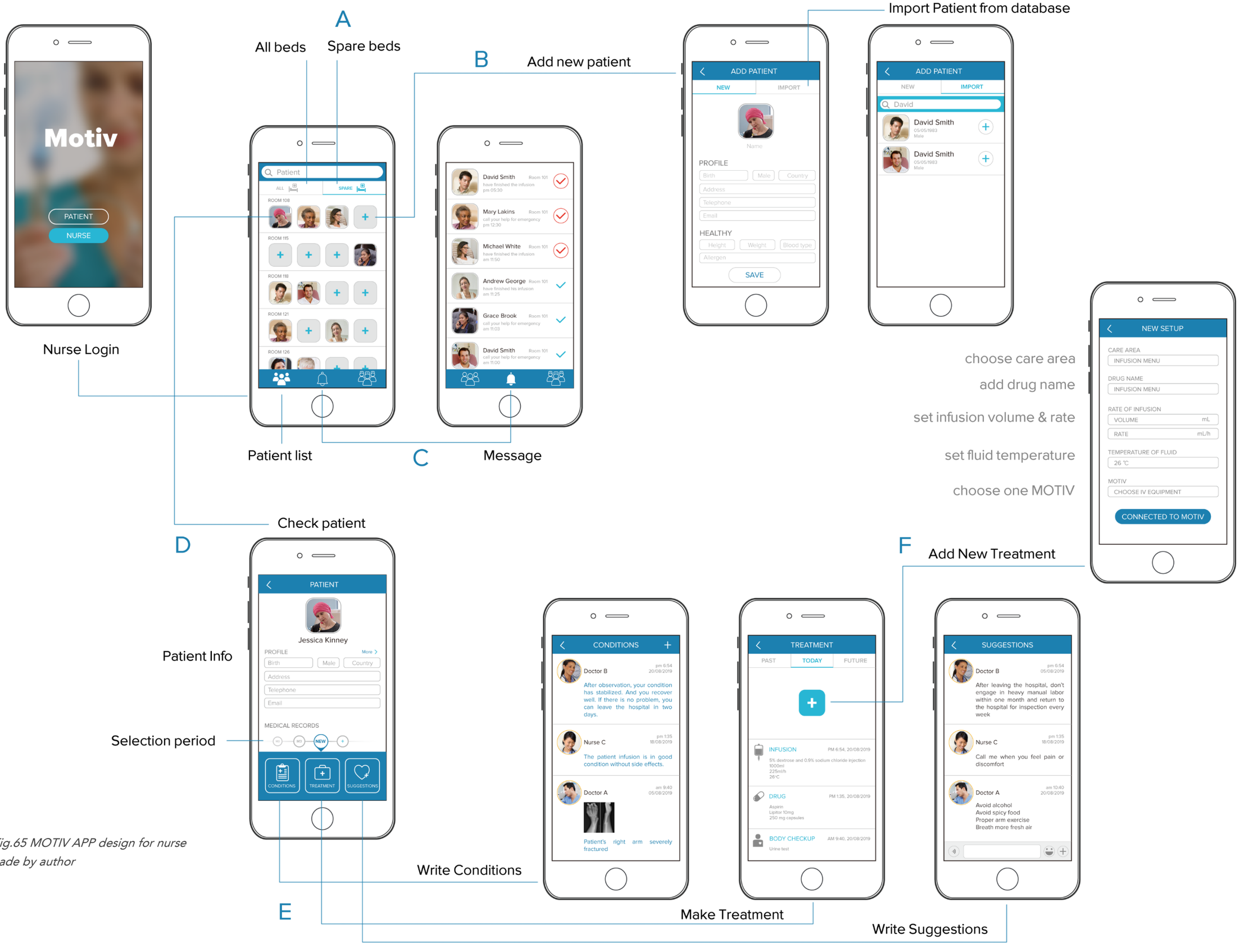
B. Nurses can easily add patients to the appropriate bed and room. At this stage, nurse can add new patient information, and can also directly import patient's personal information from patient database by searching patient name.

C. Nurse can get clear view of the patient's calls for emergency and infusion finish.

D. Nurse can visit patient personal page to update patient information and set new medical records.

E. Nurse can check and update patient conditions, treatment, suggestions for patient healthy.

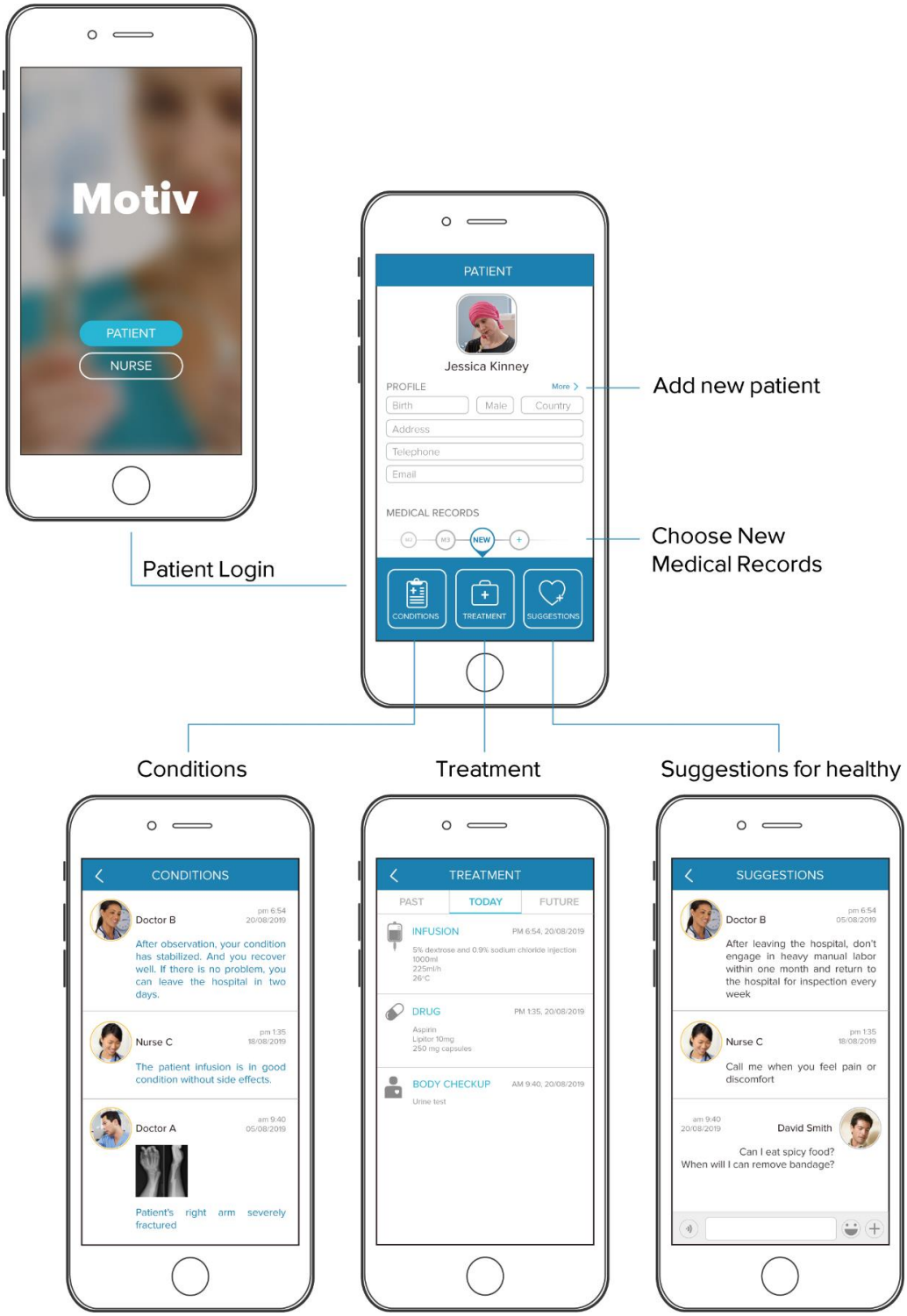
F. When nurse plan to infuse for patient, they can visit treatment and add new treatment for today or for future. When adding a new infusion, nurse can choose the care area, input drug name, set infusion volume, rate and temperature, then just choose a wearable infusion device MOTIVE and connect it by Wifi to control the patient infusion.




*-Fig.65 MOTIV APP design for nurse made by author*

**- Design for patient**

Patient can log in to the personal page, view and edit personal information, select medical records at different time periods, check their condition, treatment plan, and doctor's advice for recovery. In addition, patients can also share the information with their family and the future doctor.




*-Fig.66 MOTIV APP design for patient -made by author*

### 5.3.3 How to use Wearable infusion system (Storyboard)

Press power button

Check power and WiFi status

Press lock of cover

Open cover

Remove pump cover

Put IV fluid and tube inside it

Check remaining infusion time


Press button to start infusion

Tube connection

Patient wear it

App connection
set infusion rate, temperature


Close the cover

Close the pump cover

When emrgency happens,
press button for emergency

Sent signal to nurse APP

If nurse read the patient alert
Feedback light become yellow

Walk around

Toilet

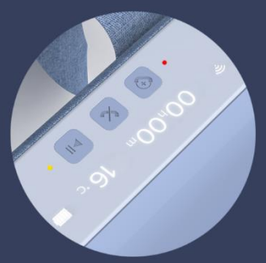
Drink

Stretch Body

Up&Down Stairs

Infusion finish

Infusion is stopped,
light becomes yellow




Vibration reminder to Patient

Automatically send signal to nurse APP
to remind nurse


Charging and disinfection

# 6-

# Product Development

## 6.1 Rendering final details

**-Power ON/OFF**

Power status is clearly showed on the interface. Nurse just press the power button then they check the power icon to know.


*-Fig.67 Rendering to power on/off -made by author*

**-Interface**

Interface to show Wifi connection status, remaining infusion time, fluid temperature and power status.

Three buttons are emergency call with a LED, Cancel for emergency, infusion start& stop with a LED.

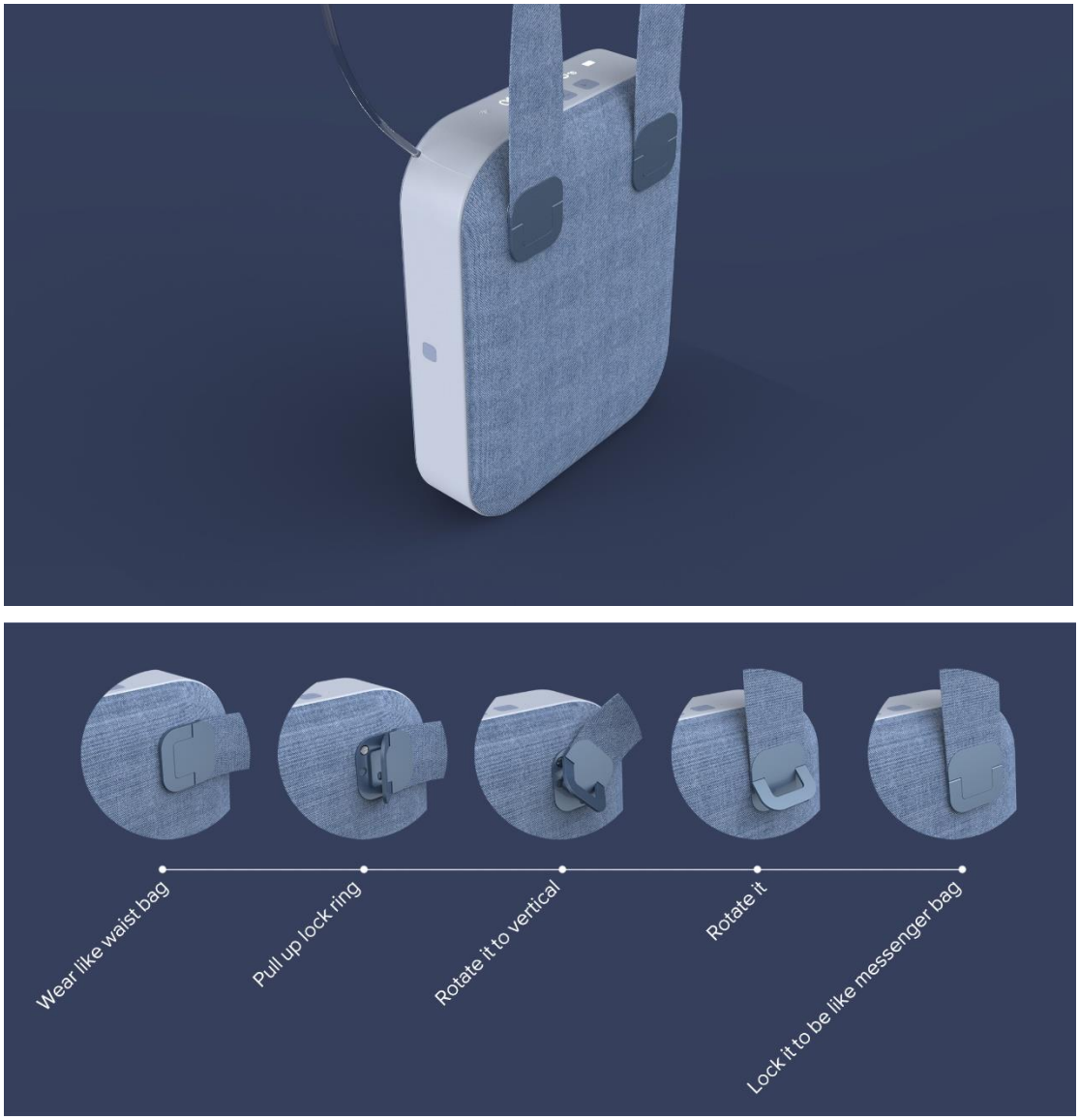

*-Fig.68 Interface of MOTIV -made by author*

**-How to put infusion bag inside it**


*-Fig.69 IV fluid inside MOTIV -made by author*

**- How to change the way to wear**

MOTIV is designed with two favorite ways to wear for patient, like messenger bag and waist bag, which is realized by a using a rotation structure.



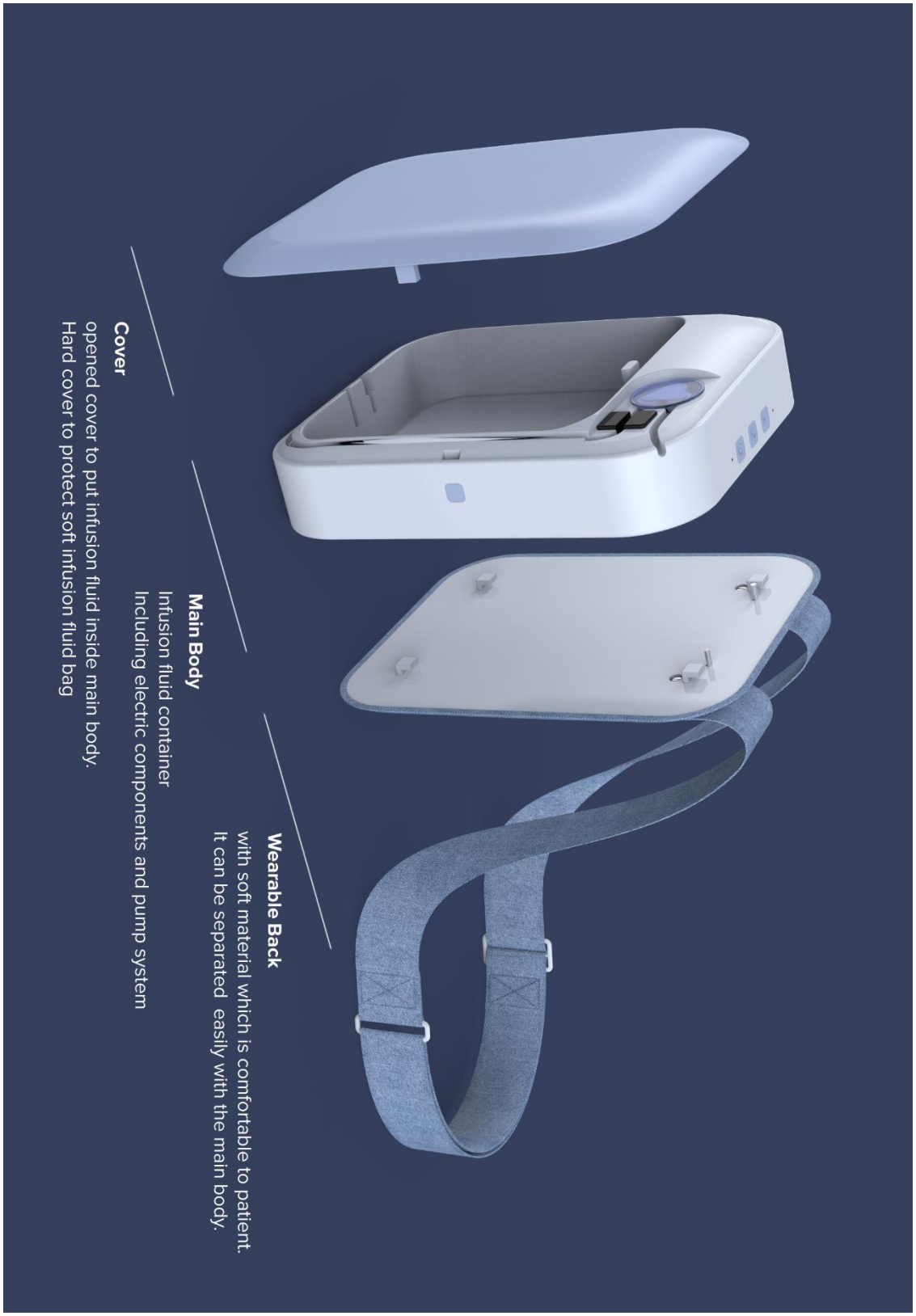

*-Fig.70 Structure to change wearable method -made by author*

*-Fig.71 Wearable like messenger bag made by author*

*-Fig.72 Wearable like waist bag*
*made by author*

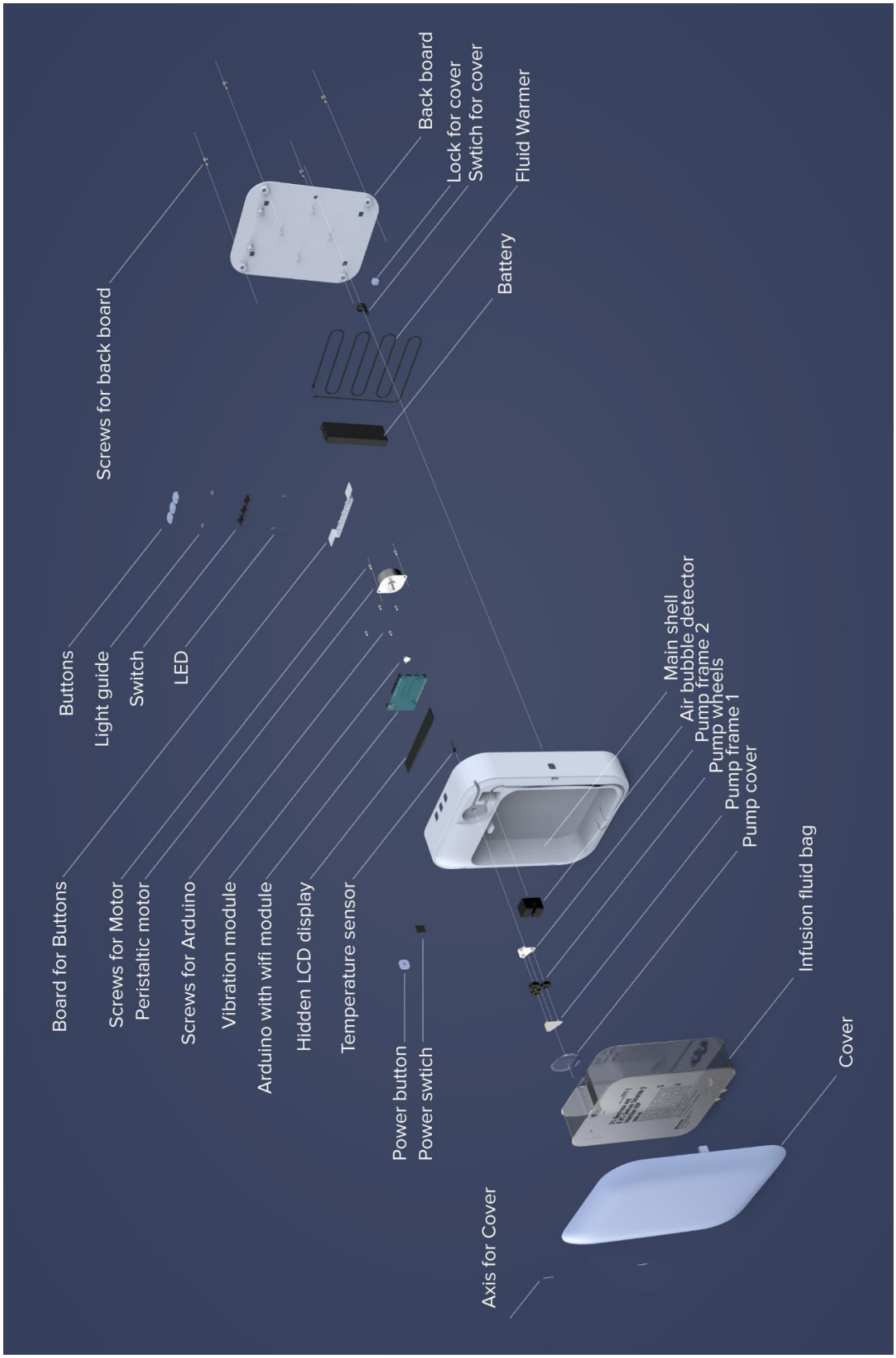
## 6.2 Structure

### -Groups



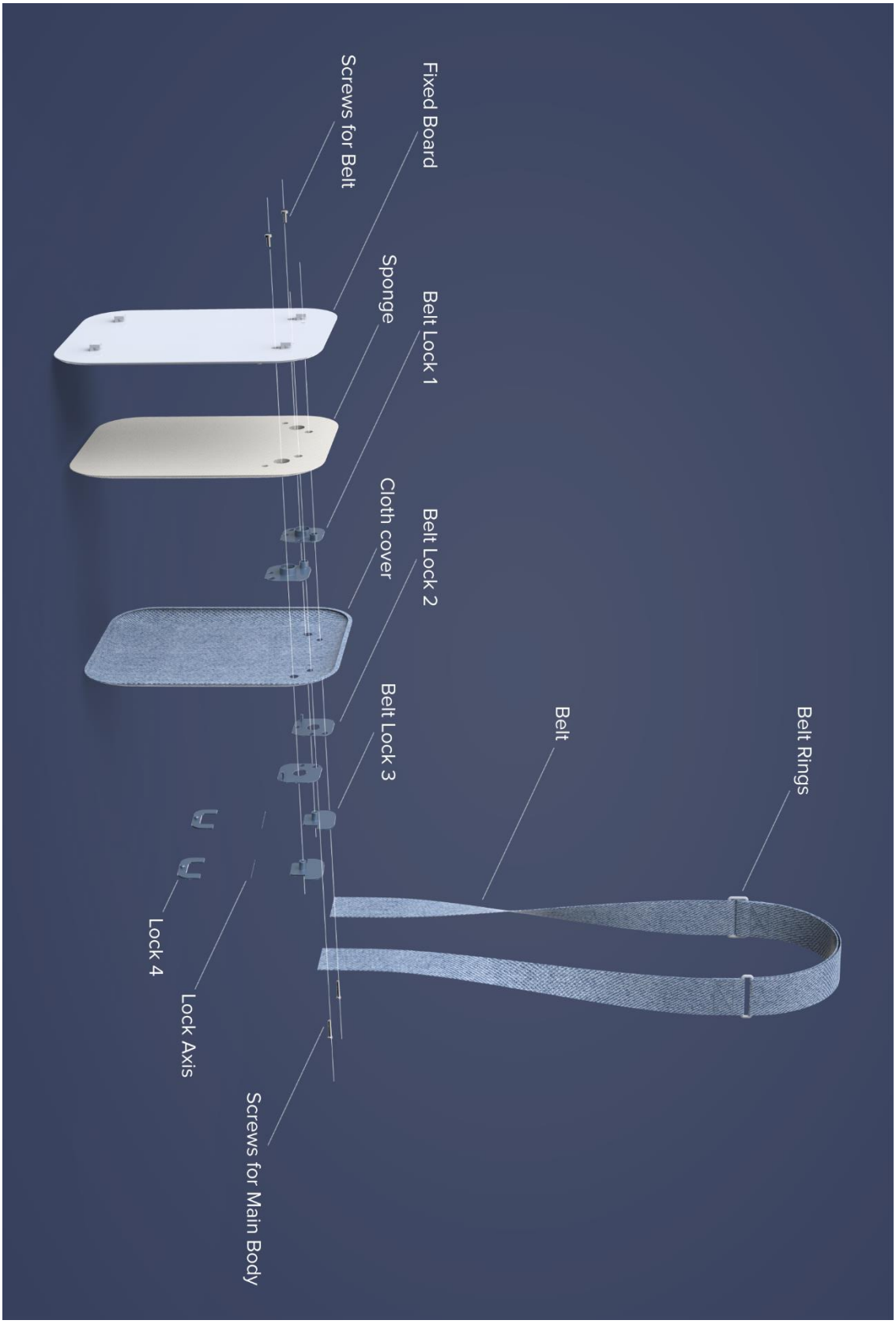

*-Fig.73 Structure for groups -made by author*

**-Explosion of Main Body**




*-Fig.74 Structure explosion view -made by author*

## -Explosion of Wearable Back

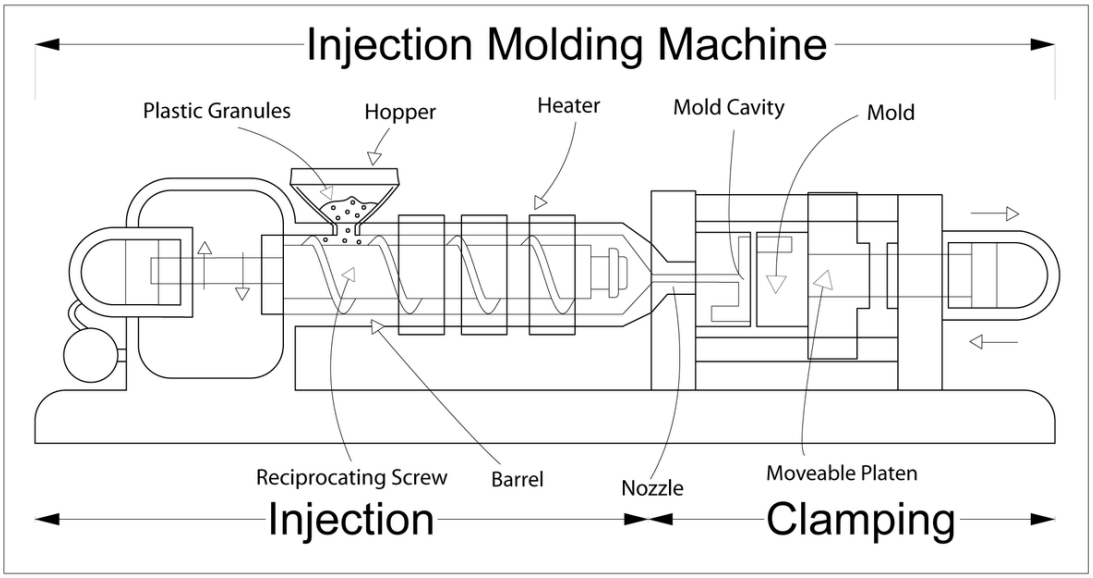



*-Fig.75 Explosion view of wearable back structure -made by author*

**How to manufacture**

Injection modeling

Injection modeling is a manufacturing process for producing parts by injecting molten material into a mould. Injection moulding can be performed with a host of materials, most commonly thermoplastic and thermosetting polymers. Plastic material for the part in the form of granules is melted until soft enough to be injected under pressure to fill a mould. The result is that the shape is exactly copied. Once the plastic moulding has cooled sufficiently to harden the injection mould opens releasing the part. The whole injection moulding process then repeats. The plastic injection moulding process produces large numbers of parts of high quality with great accuracy, very quickly.



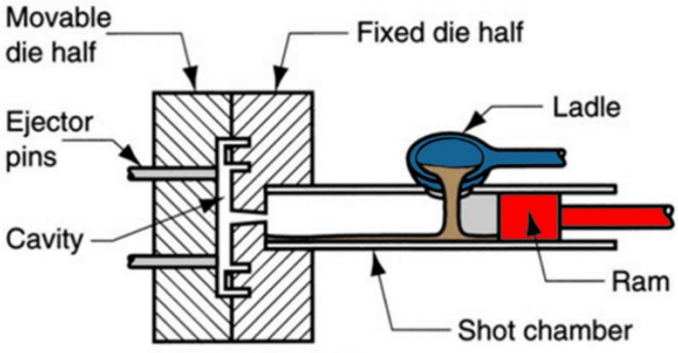

*-Fig.76 Injection modeling*
*https://en.wikipedia.org/wiki/Injection_moulding*

## Die casting

Die casting is a metal casting process that is characterized by forcing molten metal under high pressure into a mold cavity. The mold cavity is created using two hardened tool steel dies which have been machined into shape and work similarly to an injection mold during the process. Most die castings are made from non-ferrous metals, specifically zinc, copper, aluminum, magnesium, lead, pewter and tin-based alloys. Depending on the type of metal being cast, a hot- or cold-chamber machine is used.

Cold chamber die casting is a type of die casting that is used for alloys with high melting temperatures (i.e. Aluminum and some Magnesium alloys). Molten metal is ladled from the furnace into the shot chamber through a pouring hole. While the general function of the cold chamber machine is similar to hot chamber, cold chamber works with a horizontal orientation and does not have a gooseneck. The ram is pushing the molten metal from the shot chamber into the die cavity to create the die cast part. Instead, the plunger forces metal through the shot chamber into the die at pressures ranging from 2,000 and 20,000 psi. The plunger holds the pressure and retracts after solidification. The clamping unit and mounting of dies is set up the same as hot chamber, however the cover die for a cold chamber machine does not have a gooseneck or nozzle, and therefore aligns directly from the shot chamber.

The casting equipment and the metal dies represent large capital costs and this tends to limit the process to high-volume production. Manufacture of parts using die casting is relatively simple, involving only four main steps, which keeps the incremental cost per item low. It is especially suited for a large quantity of small- to medium-sized castings, which is why die casting produces more castings than any other casting process. Die castings are characterized by a very good surface finish (by casting standards) and dimensional consistency.




*-Fig.77 Die casting*
*https://www.cwmdiecast.com/blog/2016/05/24/die-casting-101-hot-chamber-vs-cold-chamber/*

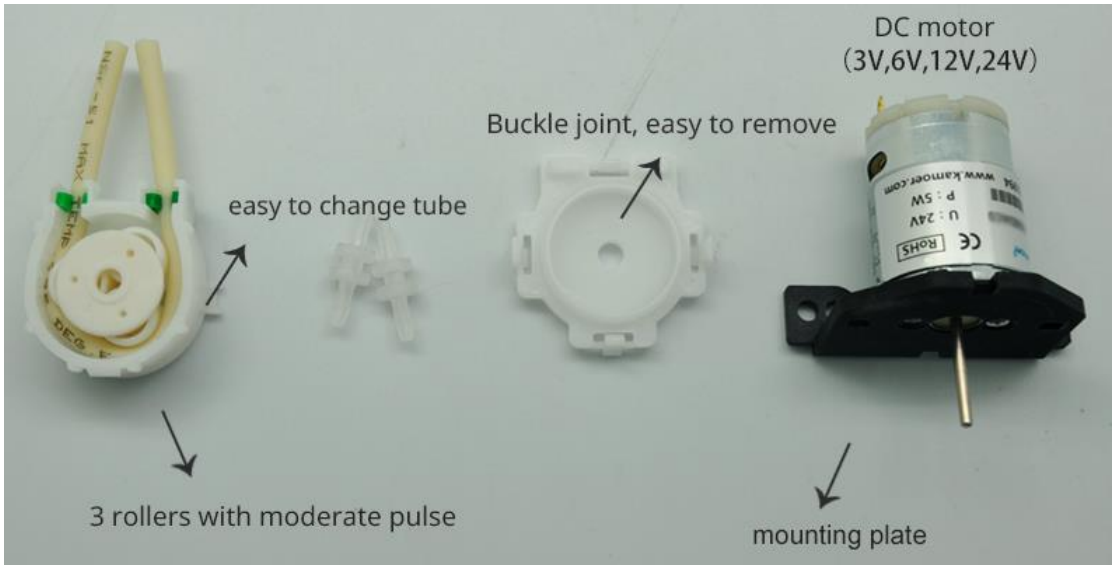
## 6.3 Technology

**-Peristaltic Pump**

A peristaltic pump is a type of positive displacement pump used for pumping a variety of fluids. The fluid is contained within a flexible tube fitted inside a circular pump casing (though linear peristaltic pumps have been made). A rotor with a number of "rollers", "shoes", "wipers", or "lobes" attached to the external circumference of the rotor compresses the flexible tube. As the rotor turns, the part of the tube under compression is pinched closed (or "occludes") thus forcing the fluid to be pumped to move through the tube. Additionally, as the tube opens to its natural state after the passing of the cam ("restitution" or "resilience") fluid flow is induced to the pump.

Typically, there will be two or more rollers, or wipers, occluding the tube, trapping between them a body of fluid. The body of fluid is then transported, at ambient pressure, toward the pump outlet. Peristaltic pumps may run continuously, or they may be indexed through partial revolutions to deliver smaller amounts of fluid. A fixed amount of fluid is pumped per rotation, so it can be used to roughly measure the amount of pumped fluid.

Peristaltic pumps are typically used to pump clean/sterile or aggressive fluids without exposing those fluids to contamination from exposed pump components. Some common applications include pumping IV fluids through an infusion device. Because the only part of the pump in contact with the fluid being pumped is the interior of the tube, it is easy to sterilize and clean the inside surfaces of the pump.




*-Fig.78 Peristaltic Pump*
*http://www.kamoer.com/shop/showproduct.php?id=101&lang=en*

**-Peristaltic motor**

To force the fluid into patient body

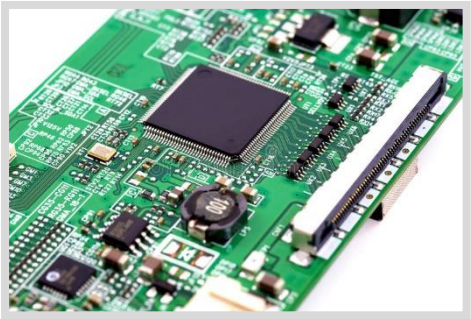
A peristaltic motor or step motor or stepping motor is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can then be commanded to move and hold at one of these steps without any feedback sensor (an open-loop controller), as long as the motor is carefully sized to the application in respect to torque and speed.

Switched reluctance motors are very large stepping motors with a reduced pole count, and generally are closed-loop commutated.


*-Fig.79 Peristaltic motor*
*https://www.sparkfun.com/products/10551*

**-PCB / Arduino board**

To control all the emblements



*-Fig.80 Arduino board*

**-Temperature sensor**

To detect the fluid temperature

The TMP36 is a low voltage, precision centigrade temperature sensor. It provides a voltage output that is linearly proportional to the Celsius temperature. It also doesn't require any external calibration to provide typical accuracies of ±1°C at +25°C and ±2°C over the −40°C to +125°C temperature range.  Price: 1.6$

*-Fig.81 Temperature sensor*
*https://www.sparkfun.com/products/10988*

**-Fluid warmer**
To warm the fluid to comfortable temperature

A fluid warmer is a medical device used in healthcare facilities for warming fluids, crystalloid, colloid, or blood product, prior to being administered (intravenously or by other parenteral routes) to body temperature levels in order to prevent hypothermia in physically traumatized or surgical patients. Infusion Fluid Warmers are FDA regulated medical devices, product code LGZ. They are unclassified devices with special considerations and require 510(k) clearance to be legally marketed in the United States. There are two primary categories of fluid warmers- those that warm fluids before use, typically warming cabinets, and those that actively warm fluids while being administered, in-line warming.


*-Fig.82 Fluid warmer*
*https://ems.penncare.net/p-3525-soft-sack-iv-fluid-warmer-12-volt.aspx*

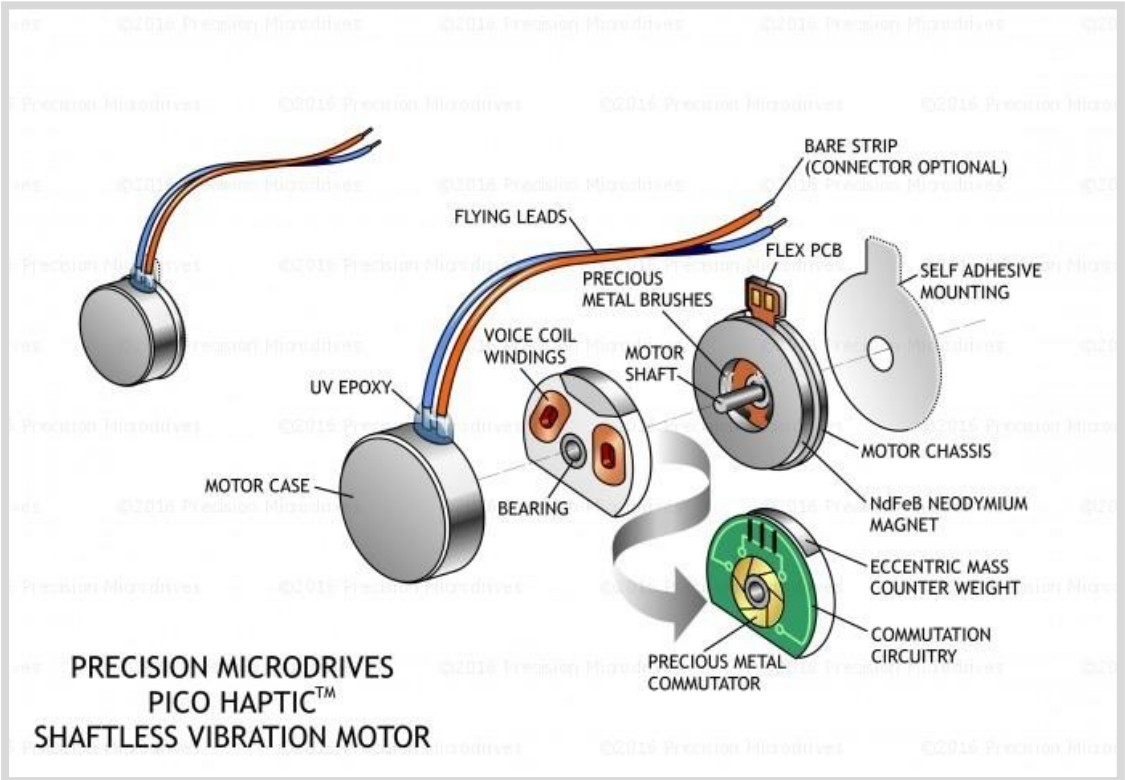
**-Vibration module**

To remind patient for infusion finish and emergency status

Precision Microdrive currently produces coin vibration motors, also known as shaft less or pancake vibrator motors, generally in Ø8mm - Ø12mm diameters for our Pico Vibe range. Pancake motors are compact and convenient to use. They integrate into many designs because they have no external moving parts, and can be affixed in place with a strong permanent self-adhesive mounting system.

Enclosures can easily be moulded to accept the coin form of our shaft less vibration motors. Within the coin motor range, we offer both leaded and spring & pad mountable versions. Like all of our vibration motors, we are happy to quote for variations to the base design such as a modification to the lead length and also connectors.

Due to their small size and enclosed vibration mechanism, coin vibrating motors are a popular choice for many different applications, like mobile phones, RFID scanners, portable instruments and medical applications.



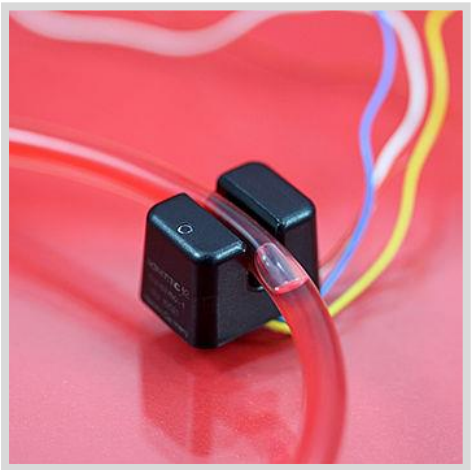

*-Fig.83 Vibration module*

*https://www.precisionmicrodrives.com/vibration-motors/coin-vibration-motors*

**-Bubble detector**

To prevent air from flowing into the patient

Bubble sensors are used to detect the presence of bubbles in fluid filled tubes. They play a vital role in many fields, including medical technology, process control, pharmaceuticals, and the petroleum industry. These intelligent sensors can be used for the monitoring of bubbles in fluids, for wet/dry alarm notifications and as liquid level sensors. In various medical treatments that the detection of air bubbles in the blood is vital for the patient safety.



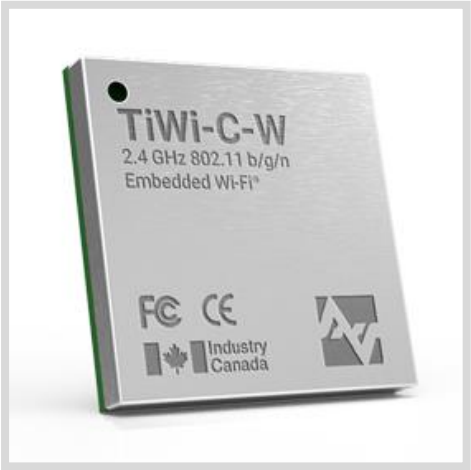
*-Fig.84 Air bubble detector*
*https://www.sonotec.eu/products/non-invasive-fluid-monitoring/air-bubble-detection/sonocheck-abd07/*

**-Hidden LED Display**
Hidden LED matrix is completely hidden until it comes on


*-Fig.85 Hidden LED Display*
*https://www.aliexpress.com/item/SAMSUNG-Original-Samsung-LED-View-Cover-Smart-Cover-Phone-Case-For-Samsung-GALAXY-S7-edge-G9350/32825930548.html*

**-Wifi Modular**
To connect device to internet

Connecting your product to the internet through Wi-Fi™ integration is simplified with the use of pre-certified Wi-Fi™ modules from LSR. The modules' pre-certified design, small footprint, and rich features make them perfect for network applications such as smart energy, home monitoring, sensor networks, and home entertainment control.




*-Fig.86 Wifi Modular*
*https://www.lsr.com/embedded-wireless-modules/wifi-module*

**-Wifi Control Principle**


*-Fig.87 Wifi Control Principle*
*made by author*

## 6.4 Material

*-Fig.88 Material moodboard*
*made by author*

MOTIV is a wearable medical product. Therefore, the material we choose for the part closer to body is based on the "clothes we love to wear", which could make MOTIV look cozy, warm, modern, simple and natural. Besides, MOTIV is also for medical application. The material we choose for medical should be serious and I took many medical factors into my consideration.

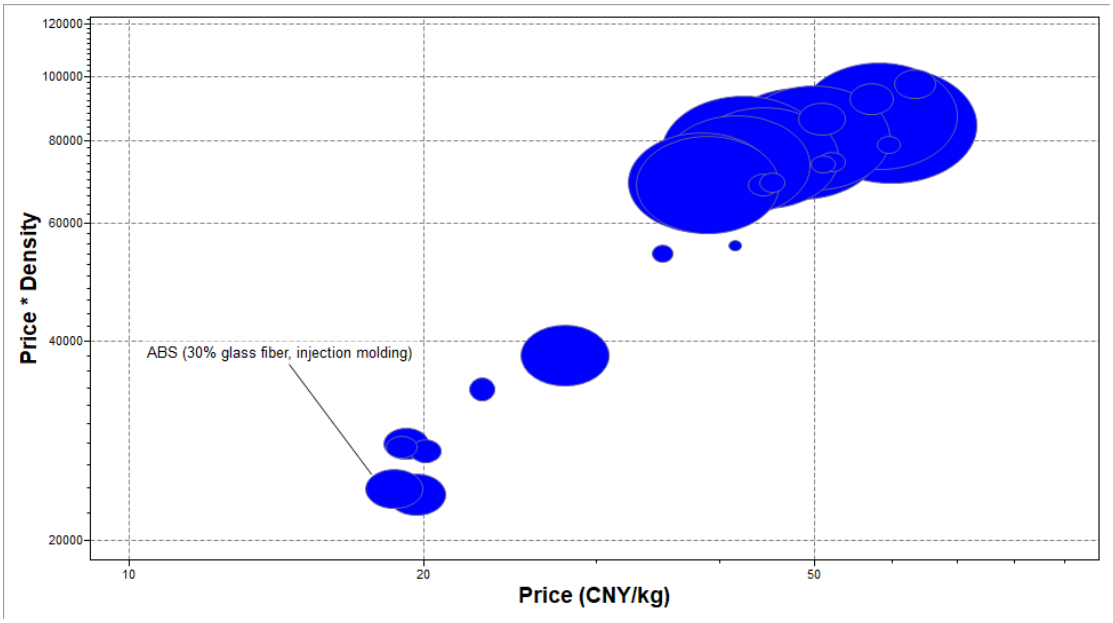
**Material for Shell and Back Board**

Constrains:
1. Can be manufactured using injection molding
2.Minimum service temp>50℃ (enough heat resistance because of heat made by step motor and fluid warmer)
3. Can have surface printing and texturing
4. Enough stiffness, toughness and hardness (safe to hold the fluid bag)
5. Sufficient resistance to sunlight and
6. Opaque material

Object:

Minimum cost
Minimum weight

At last, **ABS (30% glass fiber, injection molding)** is the better choice for the shell (Level 3 in CES)



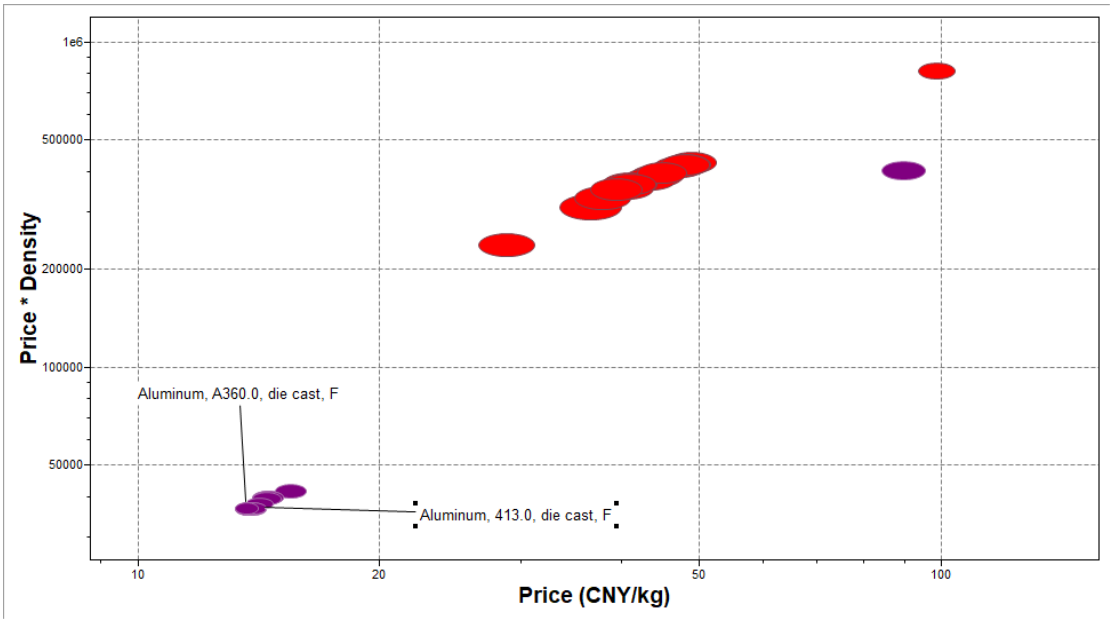

*-Fig.89 Material selection for shell made by author*

**Material for the Belt Connection**

Constrains:
1. Can be manufactured die casting
2.Minimum service temp>50℃ (enough heat resistance because of heat made by step motor and fluid warmer)
4. Enough stiffness, toughness and hardness (safe to support the device)
5. Sufficient resistance to sweat

Object:
Minimum cost
Minimum weight

At last, **Aluminum (die casting)** is the better choice for the shell (Level 3 in CES)




*-Fig.90 Material selection for belt connection*
*made by author*

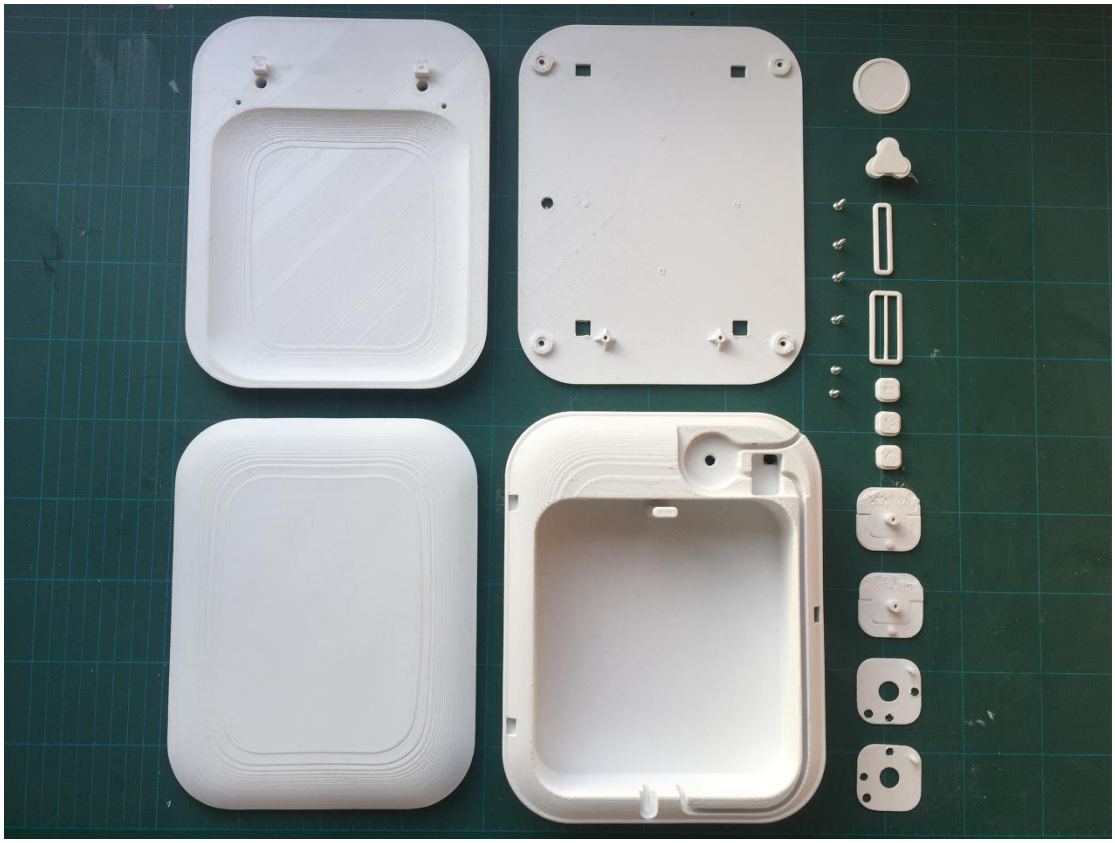
**Material for the Back Part**

MOTIV is a wearable medical product. Therefore, the material I choose for the part closer to body is based on the "clothes we love to wear". Therefore, I choose the soft, breathable fabric for this part. Besides, cloth looks very cozy, warm, which can send more comfort to patient.

*-Fig.91 Daydream VR Headset*
*http://www.businessinsider.com/google-vr-daydream-view-2016-10?IR=T*

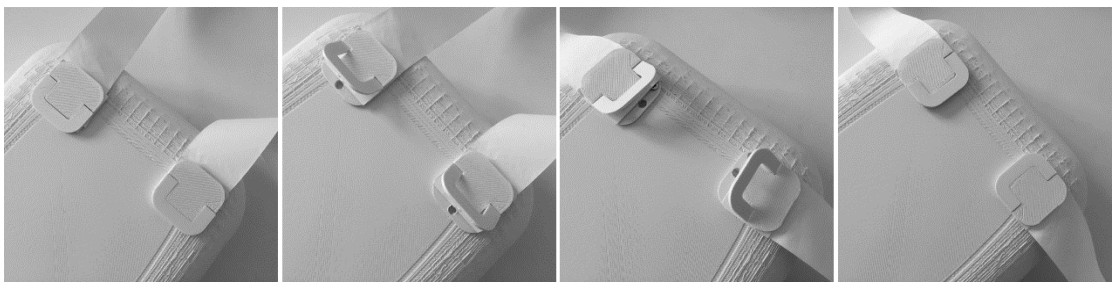
## 6.5 Prototype

The prototype is printed by 3D printer to evaluate the volume size, wearable comfort.

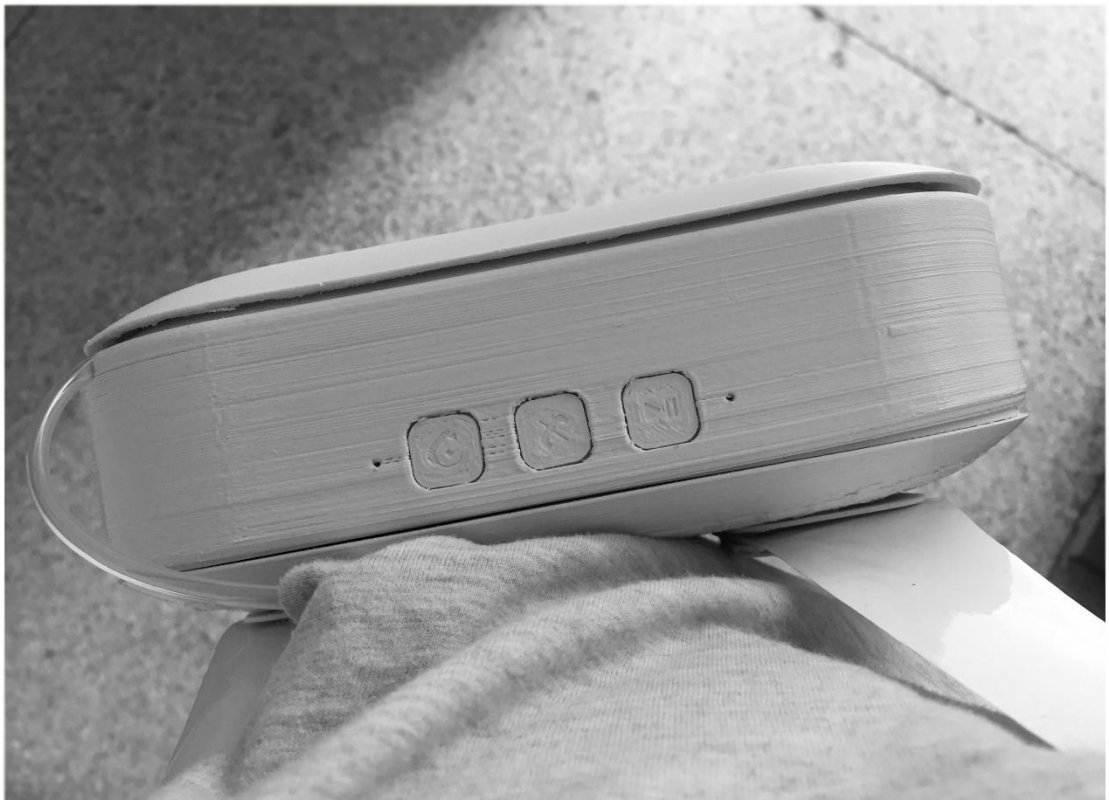


*-Fig.92 Prototype for wearable*
*made by author*


Change messenger bag to waist bag




HERITAGE
96
S. ATHLETIC
DEPARTMENT



# 07-

# Conclusion

## 7.1 Summary

The thesis describes the current status of typical infusion and wearable infusion in hospital, typical IV device problems and functions, the patient and nurse experience in infusion, patient and nurse expectations, existing wearable IV device, user expectations and requirements for wearable infusion. From the better understanding on the current infusion and product technology, wearable infusion could be better and more innovative in order to create a patient-friendly infusion experience from the angle of IV device. In the thesis, an accessible wearable infusion device MOTIV is proposed and developed from research to concept. MOTIV is designed with smart wearable technology to improve the existing IV system, which can offer the convenience of patient movement and also ensure a normal infusion can work well and safely.

**Wearable Design**

MOTIV is a new type of wearable infusion device. Compared with the typical heavy IV stand, MOTIV greatly expands the patient's use environment and offers more comfort to patient. Patient can wear it in two ways, like messenger bag and waist bag. By wearing wearable MOTIV with themselves, patients can infuse without IV stand and released from heavy IV stand and IV pump. They can walk around alone and move to anywhere they want, like corridor, elevator, toilet, in-and-out of hospital. Besides, wearable infusion MOTIV can offer more comfort for patients to keep normal lifestyle and help patient's rapid recovery.

**Infusion Function Design**

Based on the research of the existing infusion system, a safe and effective infusion has many requirements for infusion equipment, like the pressure to force fluid to flow into patient body, the infusion pump to control infusion rate precisely and a warmer to heat the fluid to reach the comfortable temperature for patient. All those functions combined with MOTIV is very necessary to ensure wearable infusion works well and safely.

Compared with the situation of typical infusion system that many different devices (heavy pump, infusion reminder and fluid warmer) are mounted on the IV stand, MOTIV integrates all those devices into one device to make them smarter and lightweight.

**Communication design**

In typical infusion, many information about patient conditions, patient treatment and doctor's suggestions for patient healthy are often told to patient in oral communication. Because of the difficult professional vocabulary, patient couldn't remember and understand it in time. Therefore, instead of the oral communication on medical advice among patient, doctor and nurse, MOTIV app is design to manage all the information for patient and nurse in a visible and readable way. They can check the information again and again in case that they don't remember or understand it clearly and even when they restatement them to their caregiver or families. Besides, medical records of patient also can be showed in the APP clearly, which can helps patient to share them with other doctor for next treatment.

Besides, MOTIV is also designed with effective interaction on infusion time and the effectiveness of emergency calls for patient and nurse. Patient can read clear infusion time from the display on MOTIV to reduce the anxiety caused by the longer unknown infusion process. When emergency happens, patient can send effect message to nurse app and remind nurse they need emergency help. Nurse can read the message in time and when the nurse read it, the LED light on MOTIV also can change color and give feedback to patient to let them know that their emergency call is received by nurse.

## 7.2 Future activity

Now, the wearable infusion concept is still in development, which is far away to put it into infusion market and apply it to the clinical. As we all know, Medical equipment have to pass clinical tests successfully before it can be put into use. Therefore, in the future, many clinical tests need to be finished firstly to ensure the safety and performance stability of the equipment. In order to realize it, the main activity would be to find some hospitals and medical equipment company for cooperation to develop and optimize it into a professional healthcare device.

Besides, the future activity will also be focused on the technology research to find a better way to strengthen the performance stability of MOTIV and reduce its size and weight.

## 7.3 Acknowledgements

First of all, I would like to thank my supervisor Professor Venere Farraro. She is very professional on wearable design. Therefore, in the development of my thesis, she has given me a lot of good advices and great help to develop a wearable product. Although my English was not very fluent, she was always very patient to listen to my presentation and guide me to find the right wearable requirements of a product. I am always thankful that I get a supervisor like she is.

Furthermore, I would like to thank my tutor and my proprietor of HABITS studio Innocenzo Rifino. He always urged me to work hard on my thesis, and because of his concern, my project was developed in a fast way. He gave me the opportunity to work as a professional product designer in the HABITS studio, which helps me to know more much about product design in Italy and practice all my design skills during the whole DESIGN & ENGINEERING master.

Besides, I would like to thank my colleagues from HABITS studio, Diego Rossi, Juan Pablo Giraldo, Mauro Piatti and Min Dong. Thank HABITS studio for giving me the permission to use all the equipment in the laboratory to make my prototype. Without your help, the development of my thesis could be very hard.

In the end, I have to thank all the nurse and patient I visited during my research. Some of them are my friends working as a resident physician in China, like Kai Liu, Shaolong Yao and Shixun Zhu and so on. The other nurse and patient are from the large hospital of ASST Great Metropolitan Niguarda in Milan. Thank all of you to share your time and professional suggestions to my graduation thesis on wearable infusion.

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## TABLES

# Questionnaire A for patient

1. Have you ever infused in hospital?
   - ○ Yes
   - ○ NO

2. How long time did you spend on infusion every time?
   - ○ Less than 1 hour
   - ○ Between 1 hour and 2 hours
   - ○ Between 2 hours and 3 hours
   - ○ More than 3 hours

3. Do you need hospital map to find your seat or bed?
   - ○ Yes
   - ○ NO

4. What information do you prefer to know in infusion? (Multiple choices)
   - ☐ Conditions
   - ☐ Treatment
   - ☐ Rehabilitation suggestions of doctor/nurse
   - ☐ Infusion time

5. Can you remember and understand all the information told by doctor and nurse?
   - ○ Yes
   - ○ NO

6. How do you prefer the above information is showed?
   - ○ Visible information, like text, pictures, medical records
   - ○ Oral information told by nurse

7. What functions do you expect to infusion device? (Multiple choices)
   - ☐ Movable infusion to expand patient movability and allow patient to move around anywhere
   - ☐ Fluid warmer
   - ☐ Reminder for infusion finish and other status for safety
   - ☐ Fast nurse feedback on their emergency call to offer patient more comfort
   - ☐ Infusion without IV stand
   - ☐ Emergency call for safety
   - ☐ Small and lightweight to be easily movable
   - ☐ Hard protector for soft fluid bag when move around

# Questionnaire B for nurse

1. How many bags fluid in average do you serve for one patient each time?
   - ○ One
   - ○ Two
   - ○ Three
   - ○ Four and more
2. How many infusion patients do you care for each day?
   - ○ Less than 15
   - ○ 15~30
   - ○ 30~45
   - ○ More than 45
3. Do you want to know the available seats and beds information?
   - ○ Yes
   - ○ NO
4. What information do you have to show to patient?
   - ☐ Conditions
   - ☐ Treatment
   - ☐ Rehabilitation suggestions of doctor/nurse
   - ☐ Infusion time
5. Do you have to repeatedly explain the above information to patient?
   - ○ Once in a while
   - ○ Often
   - ○ Never
6. Do you prefer to show all the above information to patient in a visible information record, like an APP, to reduce workload from repeated explanation and save time?
   - ○ Yes
   - ○ NO
7. Do you want to share patient information in time between nurses to improve communication about patient in emergency?
   - ○ Yes
   - ○ NO
8. What functions do you expect to infusion device?
   - ☐ Reminder for infusion finish and other status to reduce workload and time waste from repeated check
   - ☐ Remote infusion rate control
   - ☐ Simple programming for infusion
   - ☐ Fluid warmer
   - ☐ Emergency call for safety
   - ☐ Small and lightweight to be easily movable
   - ☐ Hard protector for soft fluid bag when move around

# Questionnaire C

## Questionario sull'attrezzatura per infusione endovenosa Medico

Ciao! Sono uno studente del Politecnico di Milano. Ora sto progettando di progettare un dispositivo IV (infusione endovenosa) indossabile. Spero di trovare i pazienti per aiutarmi a completare un test del peso e un test da indossare. Grazie mille per il tuo aiuto!

1. Nel processo di infusione, quale capacità di sacca per infusione viene utilizzata più spesso durante l'infusione?
   - ○ 250ml
   - ○ 500ml
   - ○ 750ml
   - ○ 1000ml
   - ○ più di 1000 ml

2. Hai mai usato un supporto per infusione endovenosa?
   - ○ Sì
   - ○ No

3. Per un dispositivo per infusione indossabile di circa 20 cm × 20 cm, come lo si indossa per sentirsi più a suo agio? ( Scegli 2 opzioni )
   - ☐ Parte posteriore delle spalle, come gli zaini
   - ☐ Marsupio
   - ☐ Borsa messenger
   - ☐ Spalla, come il cinturino del cellulare
   - ☐ Altro

4. Come operatore sanitario, qual è il peso di un dispositivo per infusione indossabile (compresa l'infusione di liquido) che un paziente può permettersi?
   - ○ Meno di 1kg
   - ○ 1kg~1.5kg
   - ○ 1.5kg~2kg
   - ○ 2kg~3kg
   - ○ 3 kg o più

5. Cosa ti aspetti dai dispositivi per infusione indossabili? ( Scegli 4 opzioni )
   - ☐ Monitoraggio della velocità di infusione
   - ☐ Controllo della velocità di infusione
   - ☐ Ricorda la finitura per infusione
   - ☐ Mostra il tempo di infusione rimanente
   - ☐ Chiamata d'emergenza all'infermiera
   - ☐ Regolare la temperatura di infusion

# Questionnaire D

## Questionario sull'attrezzatura per infusione endovenosa

Ciao! Sono uno studente del Politecnico di Milano. Ora sto progettando di progettare un dispositivo IV (infusione endovenosa) indossabile. Spero di trovare i pazienti per aiutarmi a completare un test del peso e un test da indossare. Grazie mille per il tuo aiuto!

1. Nel processo di infusione, la capacità della sacca per infusione più grande infusa è?
   - ○ 250ml
   - ○ 500ml
   - ○ 750ml
   - ○ 1000ml
   - ○ più di 1000 ml

2. Quando infusione endovenosa, vuoi andare in giro?
   - ○ occasionalmente
   - ○ spesso
   - ○ Non muoverti

3. Hai mai usato un supporto per infusione endovenosa?
   - ○ Sì
   - ○ No

4. un supporto per infusione endovenosa e l'attrezzatura per infusione endovenosa indossabile, che siete più inclini a usare?
   - ○ un supporto per infusione endovenosa
   - ○ l'attrezzatura per infusione endovenosa indossabile
   - ○ Non sono sicuro

5. Se si utilizza un dispositivo per infusione indossabile, qual è il peso massimo del dispositivo che è possibile accettare (compreso il fluido IV)?
   - ○ Meno di 1kg
   - ○ 1kg~1.5kg
   - ○ 1.5kg~2kg
   - ○ 2kg~3kg
   - ○ 3 kg o più

6. Per un dispositivo per infusione indossabile di circa 20 cm × 20 cm, come lo si indossa per sentirsi più a suo agio? ( Scegli 2 opzioni )
   - ☐ Parte posteriore delle spalle, come gli zaini
   - ☐ Marsupio
   - ☐ Borsa messenger

- ☐ Spalla, come il cinturino del cellulare
- ☐ Altro

7. Cosa ti aspetti dai dispositivi per infusione indossabili? ( Scegli 4 opzioni )
   - ☐ Monitoraggio della velocità di infusione
   - ☐ Controllo della velocità di infusione
   - ☐ Ricorda la finitura per infusione
   - ☐ Mostra il tempo di infusione rimanente
   - ☐ Chiamata d'emergenza all'infermiera
   - ☐ Regolare la temperatura di infusion