A conceptual design and research of automatic blood sampling device

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Abstract. With the continuous development of science and technology, informatization has begun to blend into people's daily lives. In today's era, medical treatment has also begun to develop in the direction of digitalization and informatization. Blood sample collection is a common detection method in clinical treatment. At present, blood sample collection is still dominated by manual collection. Since the last century, there have been a number of researchers in the field of venous location and venipuncture, to assist medical personnel to carry out puncture or to achieve the purpose of robotic venipuncture. At this stage, robotic puncture is already technically possible. However, the current design of automatic blood collection device does not consider the user's psychological level and using the process, which is easy to bring psychological pressure to the user. Therefore, from product design point of view, this project designs an automatic blood sampling device with the consideration of ergonomics and user journey. The device can not only reduce the working pressure and training cost of medical staff, but also improve the user's experience.

Keywords: Ergonomics, Blood sampling, Automatic

1 Introduction

Blood routine test is a commonly used means of clinical detection, and its results have important reference value in the clinical diagnosis, treatment and prognosis evaluation of many diseases [1]. In current clinical practice, blood sample collection is a common basic operation in clinical nursing. Currently the blood sample collection method is still using the manual way. A tourniquet is usually attached to the patient to make the blood vessels stand out and allow for puncture. Artificial methods of finding blood vessels are visual recognition or touch of veins, which have a certain error rate. In a survey with a sample size of 2,861, 20.78% of nurses had been injured in the past year [2]. The occurrence of needle puncture injury greatly increases the risk of infection with blood-borne infectious diseases among caregivers. Especially during the 2019-nCoV, health care workers are prone to fatigue and drowsiness in high-risk, high-stress work environments. This not only affects their sense of control and accuracy in the work process [3], but also increases the probability of being scratched. With the continuous development of information technology, intelligent medical treatment has a very broad prospect, which is of great significance to reduce the medical cost and relieve the pressure of medical staff [4].

With the continuous development of medical science and technology, a variety of venipuncture auxiliary methods have been invented. In the early days, researchers designed a skin patch based on the characteristic that the temperature of the body's veins is higher than the surrounding skin. The patch is attached to a material that displays different colors depending on the temperature. But the patch is very unstable, and it is easy to cause infection of the patient [5]. Later, some researchers proposed another method. Because red blood cells in the blood absorb part of visible light more efficiently, the veins would appear darker than the rest of the skin by shining bright light on the skin's surface. Using this principle, researchers have created a vene-locator called the Veinlite. However, it still has the disadvantage of stability, and for people with dark skin color, the error is large [6]. Similar to its principle, blood vessels have a higher absorption rate of infrared light than other human tissues, so the visualization of blood vessels can also be realized by proactively providing infrared light source projection. But the heat of high-power infrared light source is too large, so it is not suitable for widespread use [6]. Near-infrared venous projector is a combination of near-infrared imaging and image algorithm to project the computed venous image onto the skin surface. The formed vein image projection can help the auxiliary medical staff to identify the vein and play the role of auxiliary puncture [7]. A research team has designed a vein imaging device using a single-chip microcomputer to control a red-orange mixed light source. This device improves the clarity and accuracy of venous imaging. However, the device needs to be applied to the user's skin, which can cause a certain amount of pressure on the skin surface. This pressure can cause the veins to deform, which can interfere with the medical staff's ability to carry out the puncture [8]. Researchers have also proposed a vein imaging device based on optical imaging. The device mainly uses dual-color laser scanning method to carry out venous imaging, to detect and locate the patient's blood vessels. Its positioning is clear and accurate, but its realization method mainly benefits from the application of laser technology, so the cost is very high [9]. In addition to optical imaging, the use of ultrasonic technology for imaging devices has also been developed [10]. Sounds encounters different obstacles and produces different echoes. Ultrasonic echoes from blood vessels and other human tissues are also different. A handheld device called the Sonic Window (BK Ultrasound, Analogic, Inc) is based on this principle to image veins. The advantage of the device is that it can automatically adjust the sound wave intensity to different usage conditions to make the image clearer [11]. Intravenous imaging can also be achieved by combining photoacoustic imaging with optical imaging and acoustic imaging [12]. Kolkman RG et al. [13] have developed a set of photoacoustic imaging device for human forearm angiography. The device has unique advantages over pure optical or pure ultrasonic technology. However, the device is huge and expensive, so it is not suitable for normal venous imaging.

In the case of venipuncture robots, researchers have also made conceptual devices. Okuno et al. [14] first proposed a device for venipuncture through force feedback and tested it on rabbits' ears. Zivanovic et al. [15] proposed a device called BloodBot, which is more advanced than previous devices. The device mainly achieves puncture through force and position profile, but it has only one degree of freedom and the needle must be changed before each use. De Boer et al. [16] developed a six-degree-of-freedom automatic puncture device. The device first requires the clinician to manually place the device on the target position and then achieve puncture through ultrasound imaging and force induction. In the following study, Carvalho et al. [17] proposed a compact portable device called the PhleBot. It uses infrared monocular imaging to achieve venous imaging and force feedback to achieve puncture. Its imaging model is only linear, but in the actual venipuncture process, the form of human blood vessels is far more complex than a straight line.

There are also some researchers who have actually developed the design of venipuncture robot. For example, VeeBot uses industrial robotic arms and photoacoustic imaging technology to achieve venipuncture. Tests showed that the device found the right vein 83% of the time. But the device is large, and its shape is psychologically frightening [18]. In addition, Venouspro is also a system for automatic venipuncture. This system can not only improve the accuracy of puncture, reduce the diagnosis time, but also greatly reduce the responsibility of the medical staff [19]. In addition, a controlled trial on automatic venous blood collection and nurse venous blood collection was conducted jointly in Beijing Jishuitan

Hospital and Beijing You' an Hospital affiliated to Capital Medical University. In the experiment, the success rate of automatic venous blood sampling robot was 94.44% (85 cases /90 cases), which was higher than that of nurses 82.22% (74 cases /90 cases) [20]. Under the existing technical conditions, a series of actions including blood vessel identification, precise positioning, automatic blood sampling, skin disinfection, arm banding and blood vessel pressing can be achieved by mechanical means. This makes it possible to replace manual blood sampling with automatic blood collection device at technical level.

Therefore, designing an automatic blood sampling device instead of manual blood sampling will not only help reduce the work pressure of medical staff, and decrease the training cost of health care workers, also benefit through improve the success rate of the blood to reduce waiting for inspection personnel due to factors such as nurse independent or involuntary vibration caused by the pain, optimize the use of quarantine personnel experience.

In the design process of medical devices, it has become a consensus to follow the design principle of human body as the center. On the one hand, it is necessary to ensure that the device fits the patient's body and will not cause secondary injury due to the use of the device. On the other hand, it is necessary to ensure the convenience of medical staffs in accessing, using and maintaining the equipment easily. In the design process of automatic blood sampling device, human factor engineering elements should be fully considered, and the safety and stability of the device should be guaranteed on the basis of guaranteeing the basic blood sampling function [21].

For the persons to be examined, the blood sample collection is the entire process from identity verification to collection and departure. If machine sampling is used instead of manual sampling, users may have fear due to the cold feeling and strangeness brought by machine. At the same time, if there is a lack of effective guidance in the whole process, it is easy for first-time users to make operational mistakes and panic. Therefore, in the design process of products related to medical devices, it is necessary to give full consideration to the user's psychology and relieve the user's tension through design.

On the basis of previous research, we designed an automatic blood sampling device based on human factors engineering and service system design. Based on the full understanding of human scale and user psychology, the design provides a more stable and convenient automatic collection method to improve user experience and collection efficiency. First of all, the methods of user research are observation and interview. The purpose of the research is to understand the user's behavior and psychology during the blood sample collection process. These methods can also identify human engineering issues that need to be addressed during the design process. And according to these design criteria, put forward the design scheme. This paper introduces in detail the application of human factor engineering principle in the design of automatic blood sample collection device.

2 User Research

User research includes two parts: (a) Observation: the designer mainly observes the behavior process of users in the current stage of manual blood collection, finds and summarizes the problems existing in the existing behavior process, and finds design insights based on it. (b) Interview: Through interviews with medical staff and patients, the design insights in part (a) are verified and more design concepts are explored.

2.1 Observation

The designer observed and recorded two complete blood sample collection processes participant A goes to the hospital for routine check-ups. Participant A completed a series of actions of payment, identity verification and receiving blood collection tube according to the prescription of blood routine check issued by the doctor, and then went to the blood sample collection window for collection. The first was the number, the personnel to be examined could choose to take the number through the automatic numbering machine, according to the number assigned to different windows for blood collection. The personnel to be tested could also choose to line up manually at the non-call window for blood sample collection. The second was the process of formal collection. The person to be examined extends his arm into the collection window, and the medical staff completes the whole process of arm binding, disinfection and blood sample collection. Finally, the medical staff will distribute cotton swabs to the testing staff, and the testing staff will press the injection point to stop bleeding. In this process, the designer found that the steps of blood sample collection by medical staff were relatively fixed, and the main operation process was the mechanical repetition process of the above process, which had the basic conditions for replacing manual labor with machine. Secondly, the height of the blood sample collection window is fixed and immutable, so it is not suitable for all people to collect blood samples.

Participant B is a special person who developed fever during the covid-19 and went to a fever clinic for taking a blood sample. During the covid-19, Chinese hospitals at all levels set up fever clinics for pre-testing and triaged all patients in accordance with the requirements of epidemic prevention and control, so as to eliminate the hidden danger of the spread of the epidemic. After participant B came to the fever clinic, blood samples were collected for nucleic acid testing according to the requirements of the clinic. The fever clinic had only one nurse, and needed to take care of both the information input of the waiting staff and the collection of blood samples. Even though there were only four persons waiting for examination when participant B arrived at the fever clinic, it still took more than half an hour for blood sample collection, which wasted a lot of time in the waiting process of participant B. In this process, the designer found that, at the present stage, there is still a shortage of medical staff, and the manual collection is not stable in time compared with the machine collection.

2.2 Interview

The designers interviewed the tested personnel and the medical staff respectively. Through interviews, users' views on manual blood sample collection and their expectations on automatic blood collection device, so as to facilitate further design and exploration. In the interview with the medical staff, the designer learned that the medical staff often cannot leave the test window for a long time and often work overtime because of the large number of waiting patients when collecting blood samples. For new medical staff, puncture failure caused by unskilled operation also causes tension between doctors and patients. Therefore, they hope to design an automatic blood collection device to reduce the work pressure of medical staff. Through the interview of the personnel to be inspected, it is found that they believe that intelligence is the inevitable trend of development. If the queue for manual detection is too long, they are willing to try automatic blood collection equipment for blood sample collection.

Through observation and interview, the designers drew user portraits and empathy maps of health care workers and prospective patients (Fig. 1) to analyze user behaviors and user psychology.

Fig. 1. User portraits and user empathy maps of prospective and healthcare personnel

The following are specific design problems that emerged from user research. First, they want the device to be easy to operate and clear with instructions that don't add extra learning costs. Secondly, the device should be adjustable to meet the requirements of the personnel in different ages and different physical conditions. Finally, the equipment can automatically collect the collected samples, and after each collection is completed, the equipment is closely sterilized.

3 Design Process

Through literature review and user research, we summarized the collection process of manual blood sample collection (Fig. 2).

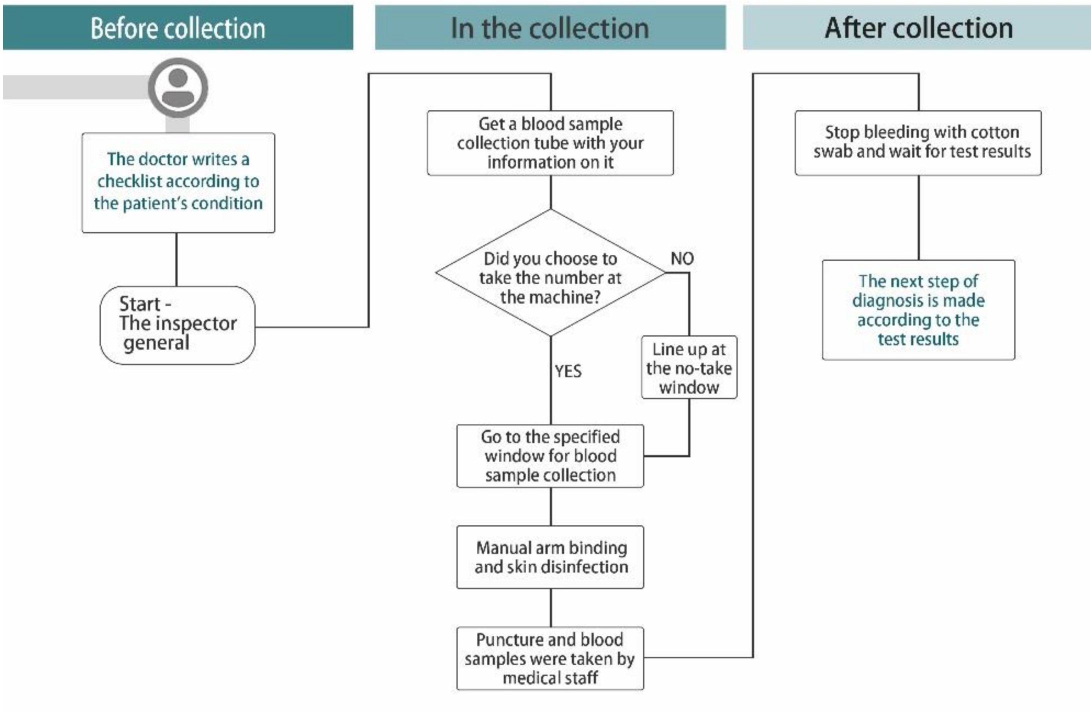

Fig. 2. Manual blood sample collection process

3.1 User Journey Map

The analysis of the existing process provides valid data for the design concept. In the analysis process, this research found that the work of identity verification, collection of test tubes, blood sample collection and post-collection of test tubes are all mechanical repetitive work. Therefore, an automatic blood sample collection device can be design to replace the manual operation. The optimized user journey mapping is shown in Figure 3.

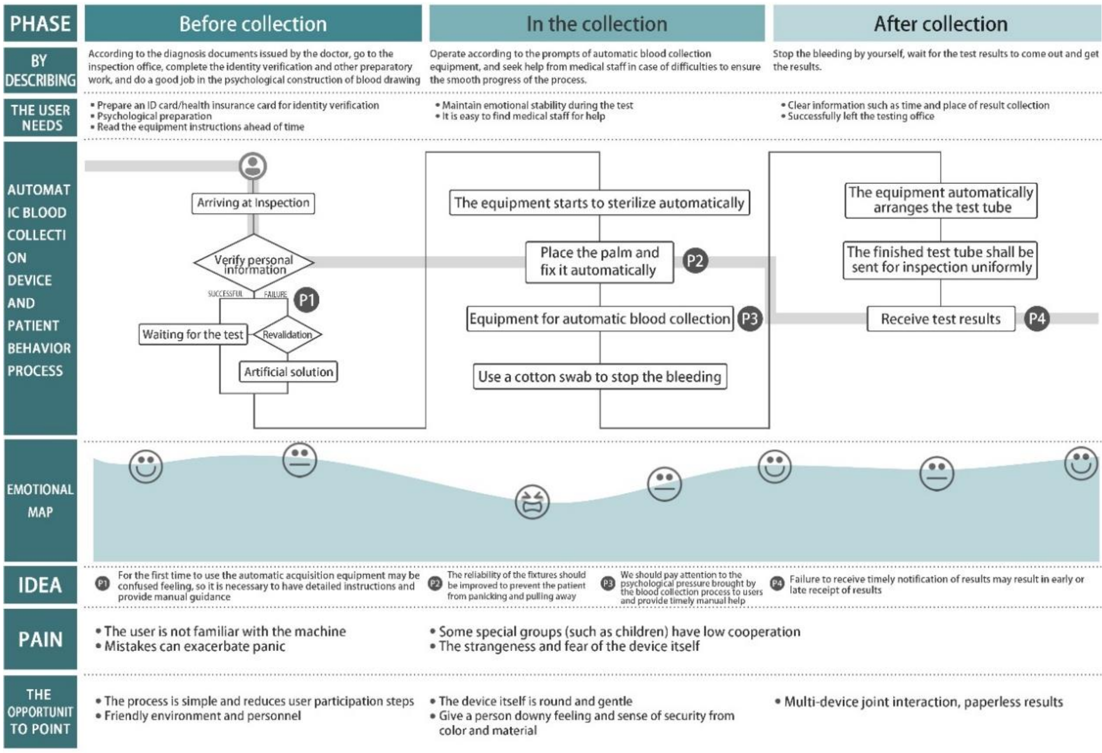

Fig. 3. The optimized User Journey Mapping

First of all, this device can inspect the identity authentication of the personnel and realize automatic arm tie. And it can automatically position and accurately pierce the needle into the blood vessel. Then, automatic disinfection can be completed after the collection of blood samples. At last, this product can automatically storage the blood samples after collection. Based on the above design requirements, the conceptual sketching is designed by brainstorm, as shown in Figure 4.

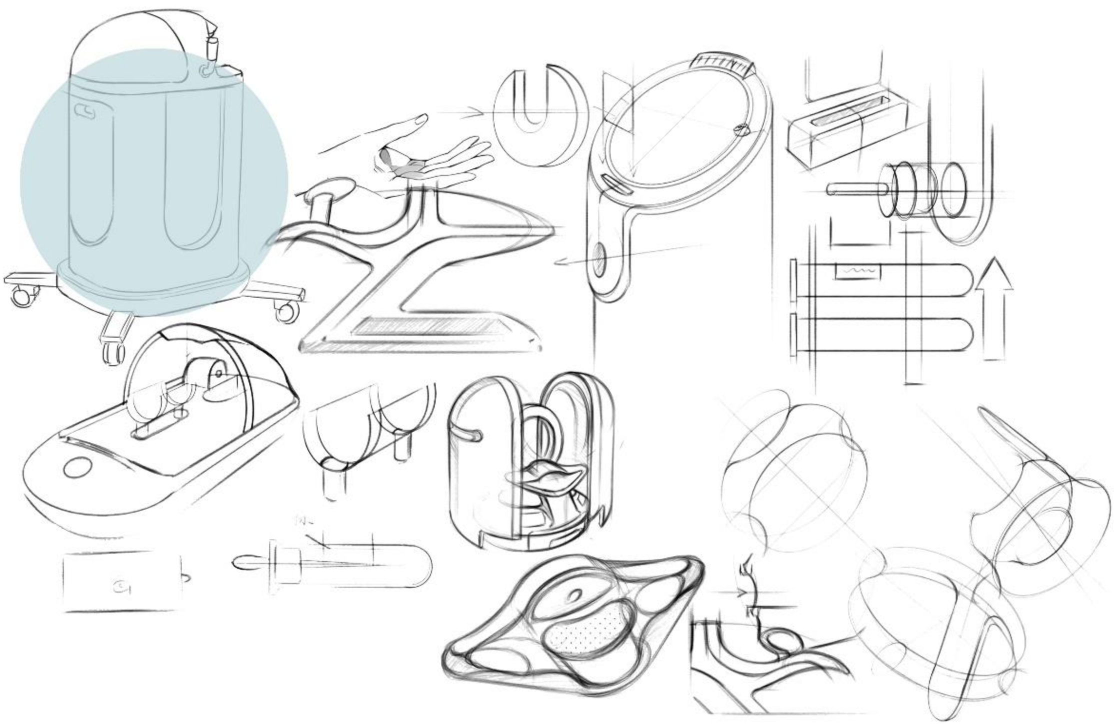

Fig. 4. The conceptual sketching

3.2 Human Body Data

Considering that the automatic blood collection device should have all functions of verification, detection and collection, and can meet the requirements of placing in the hospital space, the automatic blood collection device adopts the cabinet shaped structure. Based on the general human body data collected in Figure 5 of Ref. [22] and combined with the working posture, it should meet the use needs of more than 95% of adults. As shown in Fig. 5, the design should not be higher than 591mm. At the same time, a blood sample can be collected from the elbow or the back of the hand vein. The results of relevant researchers showed that there was no significant difference in the one-time puncture success rate and specimen pass rate between venous blood collections in the elbow and in the dorsal hand. At the same time, the dorsal hand vein blood collection time is shorter, the operation is more convenient, and the patient satisfaction is higher [23]. Therefore, in the design of the automatic blood collection equipment, the back of the hand is used for blood collection.

Units: mm

GROUPING / PERCENTILE / MEASURING PROJECT	Male (18 ~ 60 years old)							Female (18 ~ 55 years old)						
	1	5	10	50	90	95	99	1	5	10	50	90	95	99
SITTING CUBITS HIGH	214	228	235	263	291	298	312	201	215	223	251	277	284	299
ADD FULL HEIGHT TO YOUR CALVES	372	383	389	413	439	448	463	331	342	350	382	399	405	417
FOREARM LENGTH	206	216	220	237	253	258	268	185	193	198	213	229	234	242

Fig. 5. Body size (part)

3.3 Material selection

The overall shape of the device is relatively complicated, and the style should be adapted to the environmental style of different hospitals. Neither the texture nor the color of the device can bring tension and oppression to the inspectors. Therefore, whether from the product processing technology or from the psychological fitness of the patient to be tested or from the point of view of the adaptability of the product to the environment, the overall shell material is suitable for the use of opaque plastic material. Translucent plastic material is used in the rear tube compartment, so that the medical staff can observe the remaining condition of the tube in real time and replace it in time. In the position of the arm band, take into consideration the band for frequent opening and closing, and the role of the band should be played to expose blood vessels. The final design prototype rendering is shown in Figure 6.

Fig. 6. The final design prototype renderings

4 Evaluation of Design

This design mainly put forward a conceptual model of automatic blood collection device to optimize the testing process of the personnel to be tested. Through the analysis of man-machine dimensions, it provides reference data for the design of the same type of products in the future. In the whole design, there are still the following deficiencies.

Firstly, there is no prototype test for the design, which is unpredictable for the problems that may be encountered in the actual use process.

Secondly, although the device has been designed to take into account the fear of the personnel to be examined because of the coldness and strangeness of the equipment itself, and the device has chosen a more rounded shape as far as possible, it cannot completely eliminate the strangeness of users to the design. In the subsequent design of related products, users' psychological factors should also be fully considered.

Finally, in the design process of products, there is the situation of neglecting one and losing the other. The automatic blood collection device adds a runner structure at the bottom for ease of movement, but the addition of this structure also introduces extra problems in the fixation of the product.

5 Conclusion

This study mainly focuses on the discussion of automatic blood collection device, with the purpose of replacing artificial blood sample collection with automatic blood collection device to improve the collection efficiency and reduce the risk of infection of blood-borne diseases caused by stab wounds of medical staff. According to the user survey, there is a real demand for the device and the person to be inspected has shown a willingness to try it. The project also determined the required dimensions of the device through the relevant knowledge of thermal engineering, which provided reference data for the design of similar products.

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