DESIGN OF A NOVEL BLOOD COLLECTION DEVICE FOR PSA ANALYSIS

Graduation report

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TU Delft

ANTONI VAN LEEUWENHOEK
NEDERLANDS KANKER INSTITUUT

1.1 COLOPHON

Master Integrated Product Design
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1.2 Preface

"Designing a novel blood collection device" triggered my attention when I came across this research topic that was offered by Antoni Van Leeuwenhoek hospital and Nederlands Kanker Institute. The impact that can be made within this topic really appealed to me as the creation of a novel blood collection system could save patients hours of their time. This has a lot of impact, especially when patients are in bad condition.

When I began working on this graduation project I had absolutely no knowledge in clinical chemistry whatsoever. This changed quickly when I emerged myself with people that worked in the hospital's laboratory. This change in work context was definitely very inspirational for me as I never could have imagined how much knowledge and mysteries exist around one tiny drop of blood.

Together with the department of the "Algemeen Klinisch Laboratorium" we managed to develop a blood collection kit for PSA that empowered the patient to sample his own blood for PSA at his own home. The development of this system never could have happened without the help of all the enthusiastic people around me.

I would like to thank the supervisory team of TU Delft, chair Armagan Albayrak and mentor Iemkje Ruiter for their support during the project. They gave me clear and direct guidence which I appreciate.

Thanks to Huub van Rossum, my mentor at the hospital. Huub is very open to innovation which is something I definitely share. Also his sacrifices to do lots of finger punctures were indispensable to the creation of the blood collection device.

Many thanks to Mehek, Bastiaan, Lennart, Ruben, Mirthe, Kalpana, Daan and Onur, my fellow students and collegues at the department. You created a relaxed atmosphere, helped me along with the user tests and definitely learned me a lot of clinical and laboratory stuff.

I also want to thank Enver and Suki for their enthusiasm and support.

My parents and sister also sacrificed a lot of blood during this project which I am thankful for. I hope your finger punctures have healed soon.

Thanks to Storm, Peter, Matthijs and Rosa for their feedback and discussions we had on this report.

Kind regards,

Nicas van den Brink

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1.3 Glossary

This glossary is meant to help the reader understand medical jargon that is used in this report. The reader of this report can go back to this chapter to check the explanation of such words.

AKL - Algemeen klinisch laboratorium (general clinical laboratory)

Asymptomatic - (of a condition or a person) producing or showing no symptoms.

Biomarkers - Chemical analysts are able to measure a huge amount of different parameters within the human body which are called “biomarkers”. The measuring process of these biomarkers can be done in different fractions of the blood, dependent on the type of biomarker that is desired to measure. The most used sampling methods are done within plasma and serum. Measuring in an hemolysed sample is less frequently used (figure 1). The measuring process of the PSA biomarker at NKI-AVL is done in a hemolysed sample.

EDTA - Ethyleendiaminetetra-azijnzuur (Type of anticoagulant)

Hematocrit - Percentage of red blood cells in a person’s blood.

In-vitro-diagnostica - These are medical tools that can be used to examine samples extracted from the human body like blood or urine outside the human body.

NKI-AVL - Nederland Kanker Instituut - Antoni Van Leeuwenhoek hospital.

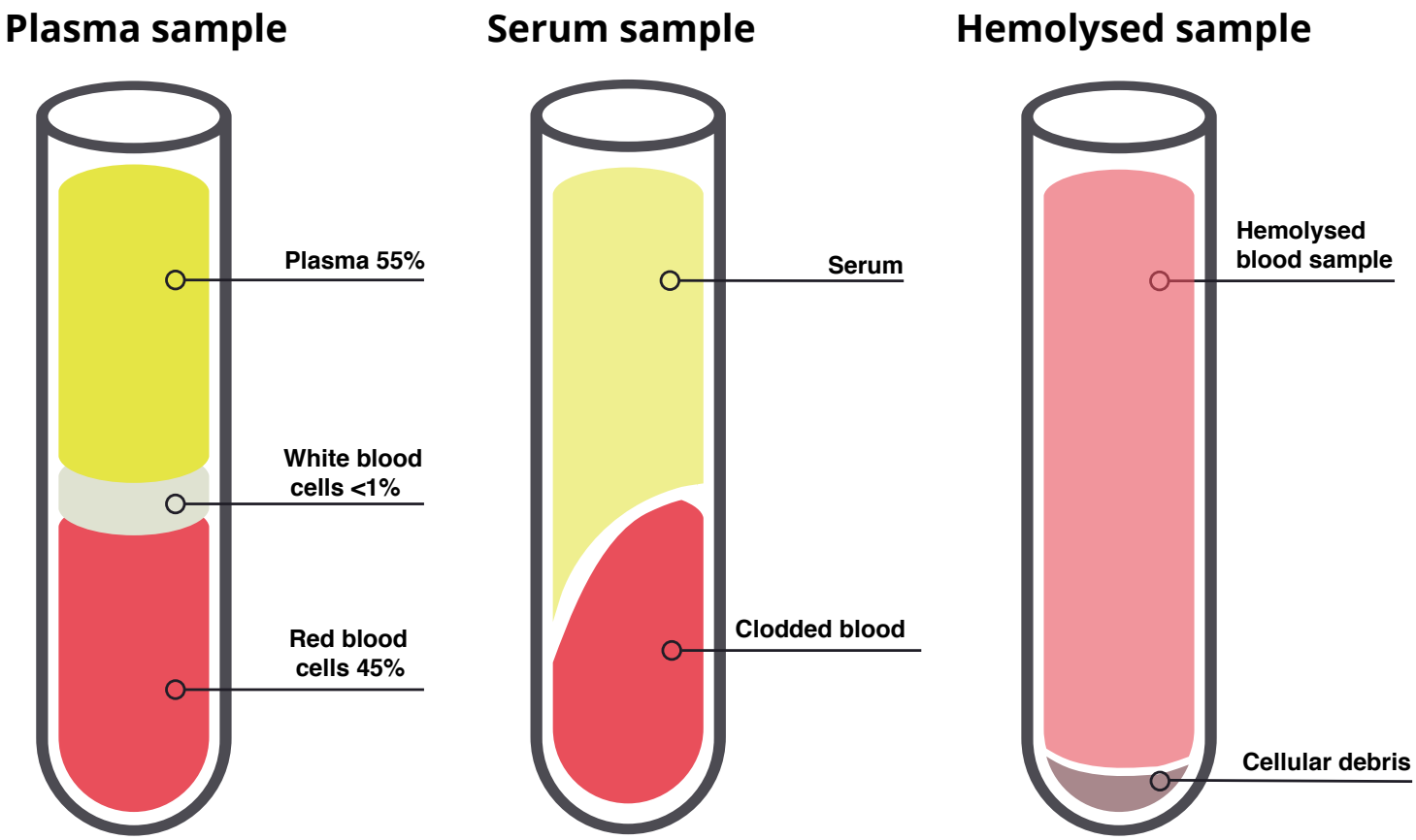
Prevalence - The proportion of disease found to have been affecting a particular population. Often expressed in a number that is collected by comparing the number of people found to have the condition with the total number of people studied.

Phlebotomist - This is a person who is trained to draw blood from a patient for clinical or medical testing, transfusions, donations, or research.

Prostatectomy - The surgical removal of all or part of the prostate gland.

PSA - Prostate specific antigen.

"These types of blood samples are often mentioned througout the report. Scroll back to this page to review the definitions "



Blood sample with anticoagulants

Blood sample after caogulation
Serum = plasma - coagulants

Blood sample after hemolysation
Red blood cells have been ruptured. Hemaglobin floats freely in sample. NKI-AVL makes use of hemolysed blood samples for PSA test

Figure 1 – Various blood sampling methods

1.4 Executive summary

This chapter summarizes the graduation project for each phase in which it is divided.

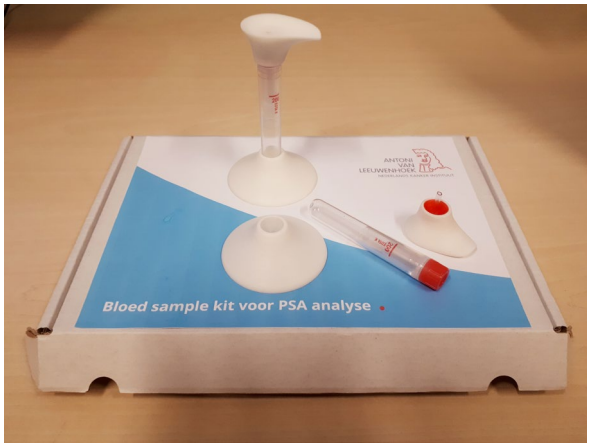
Prostate cancer is the most common type of cancer for Dutch males. 1 out 9 males is diagnosed with prostate cancer during his life. 48% Of the diagnosis is for men older than 70 (IKNL, 2014). Antoni van Leeuwenhoek hospital and Nederlands Kanker Instituut do research in cancer diagnostics. This graduation project focuses on the development of a device that should enable prostate cancer patients to collect their own blood sample within their home. The sample will be analyzed at the hospital for "prostate specific antigen" (PSA). The results of such measurements determine the patients treatment. The system should omit patient visits to the hospital for such PSA checks. The report is divided in the following four phases:

Analysis phase
This phase is meant to get to know the context in which the future blood collection device will function. Interviews with important stakeholders determine needs and product requirements. Market research led to a complete overview of state of the art products that are already in use for similar purposes. The target group is determined (50-80 year old man with prostate cancer) The comparison between current method in blood sampling (venipuncture) and the desired future sampling technique led to insights and requirement for the development of the future device. Combining all these analytical insights led to the formulation of a design vision and design challenges that together form a framework for the conceptualization phase.

Conceptualization phase
The analytical insights are being translated towards ideas and concepts that should solve the design challenges that were formulated within the analysis phase. The design vision is kept in mind during the ideation. Various creative methods such as brainstorming, sketching, prototyping and the organization of a creative session led to various ideas. The working principles in the collection of blood were then being validated by prototyping and testing, The validated techniques were integrated in the proposition of three concepts. The phase ends with the choice of one single concept which is called: "The Capillar".

Embodiment phase
This phase focuses on the realization of The Capillar. Within the first half of the phase, the concept is materialized and a suitable production technique is found. The Capillar will be SLS 3D printed with PA2200 polymer. The blood flow within The Capillar is also optimized through an iterative process. Until now, the focus of The Capillars development was mostly technical and ergonomically. Aesthetics have been integrated in the design to make sure that the device conveys the desired meaning during product user interaction. The second half of the phase focuses on transportation of The Capillar to the user and from the user towards the hospital. Also a package is designed that is accompanied with user instructions for the use of The Capillar. The phase ends with an implementation proposal including a cost calculation.

Evaluation
This phase in not part of the design process anymore. It will reflect on the design process, the end result and my personal achievements. It also gives recommendations towards the hospital, how to further develop The Capillar and to bring it to the next level.



Final prototype of The Capillar and its packaging

1.5 Graphic introduction

This chapter introduces graphics that can be found in this report.

Point of attention

These points of attention can be found at the sides throughout the report. This box emphasizes an interesting insight that could be useful during the design of the blood collection device.

Design implications

Design implications can be found at the sides throughout the report and at the end of chapters. They show how insights from that chapter influence the framework in which the blood collection device will be developed.

These blue circled symbols can be found at the beginning of a chapter. The symbol corresponds with the symbols in the phase's framework.

Important text

Extra attention should be payed when text is placed in a red box,

This coloured plane at the side of the page means that it is part of the analysis phase.

This coloured plane at the side of the page means that it is part of the conceptualisation phase.

This coloured plane at the side of the page means that it is part of the embodiment phase.

The symbol within the plane indicates what chapter the page is about. The symbol corresponds with the symbols in the phase's framework.

This coloured plane at the side of the page means that it is part of the evaluation.

1.6 Design approach

This chapter describes how this project was set up in order to make it to a successful end. The general approach of the graduation project follows design guidelines set up by Roozenburg en Eekels (Roozenburg, 1998) , in which converging and diverging are considered key features within the overall process.

The project is divided in three different phases.

Analysis phase

The project starts of with exploration of the context in which blood collection within NKI-AVL takes place. These analyses are important to create a holistic view of all things that are going on in this context. The phase ends in the formulation of a design vision which forms the basis for the creation of ideas and concepts.

Conceptualization phase

This phase builds upon knowledge that is created during the analysis phase. Ideas and concepts are created that provide solutions to insights derived within the analysis phase. The phase ends with the creation of a final concept.

Embodiment phase

This phase has the purpose to realize the final concept that is proposed during the conceptualization phase. The concept will be materialized and validated by means of a working prototype and final user test.

Plannings

At the beginning of the project a planning for the entire graduation project was made with a strong focus on the analysis phase, as this was the first phase to focus on. For other phases and important moments (conceptualization phase, embodiment phase and graduation deadline) additional smaller plannings were constructed as guideline for both me and as communication tool towards the TU Delft board and NKI-AVL. These plannings can be seen in appendix V.

Design approach

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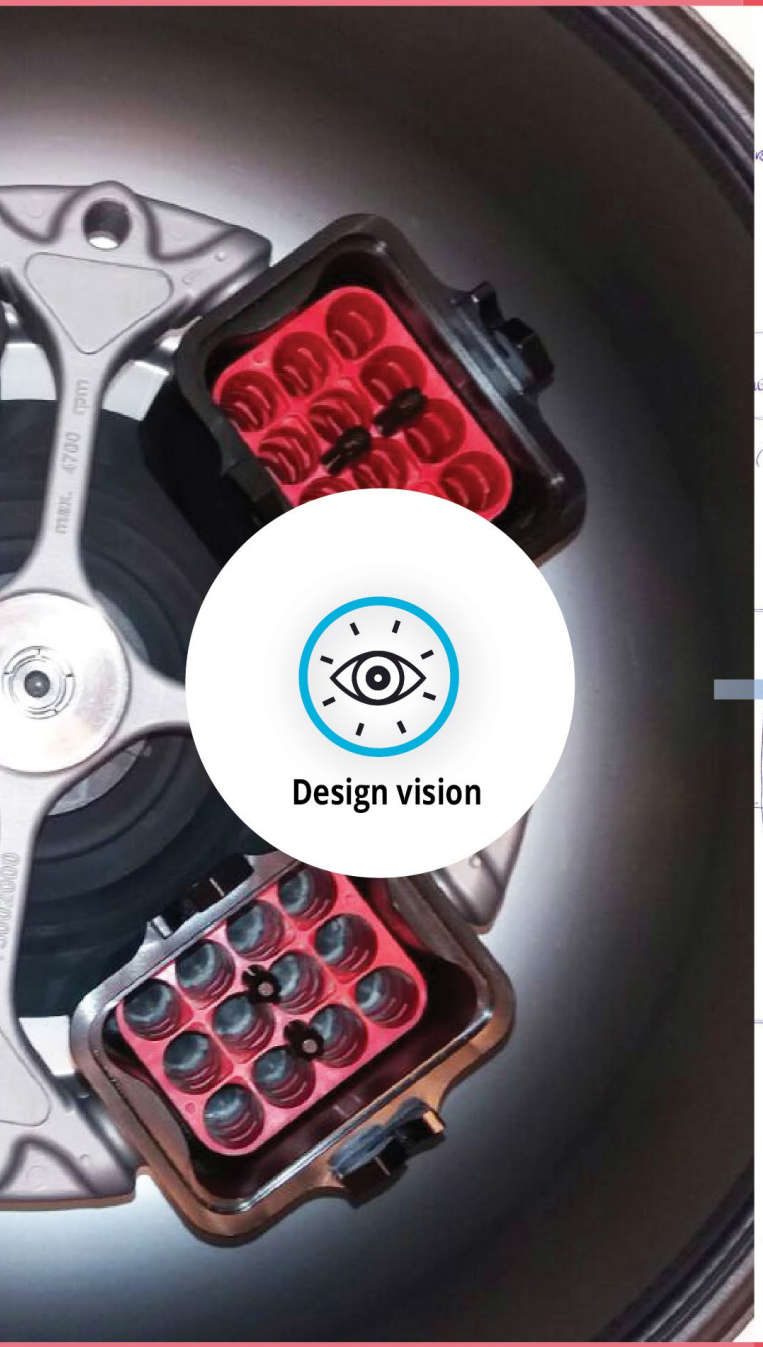
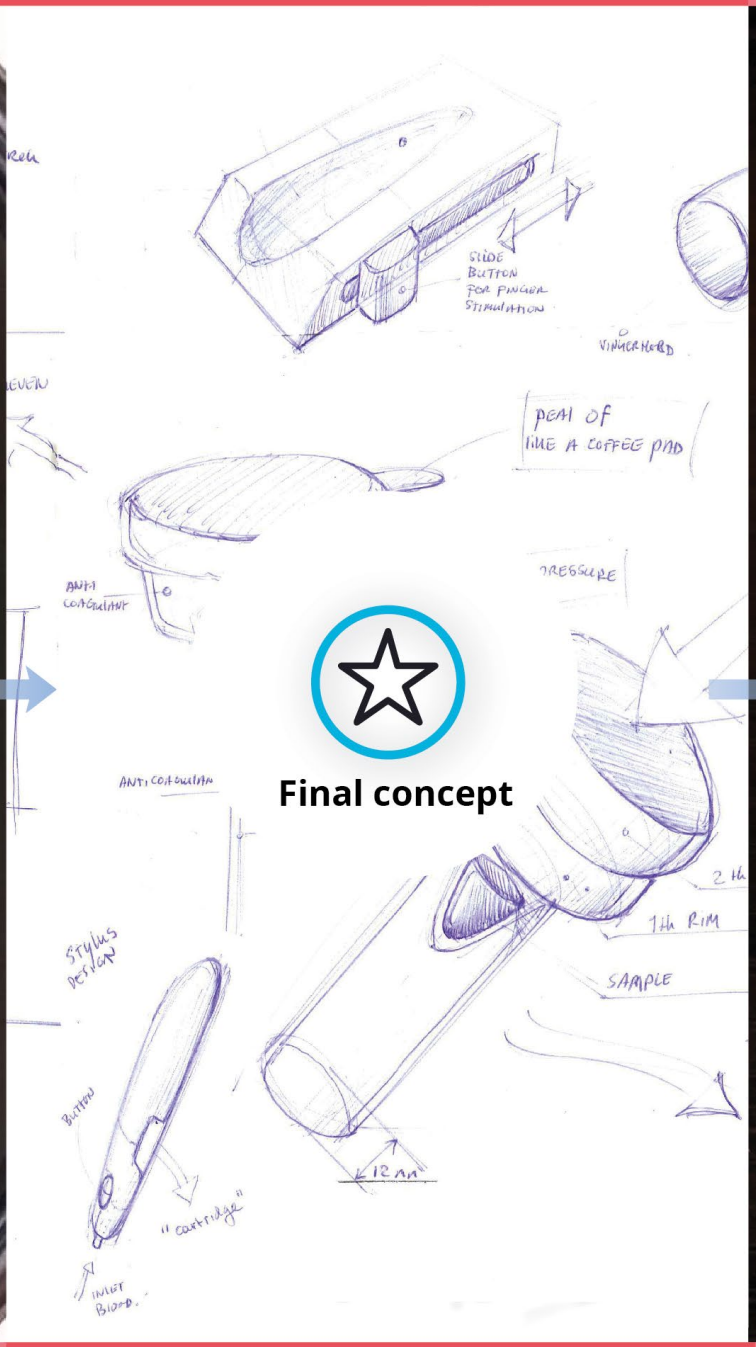
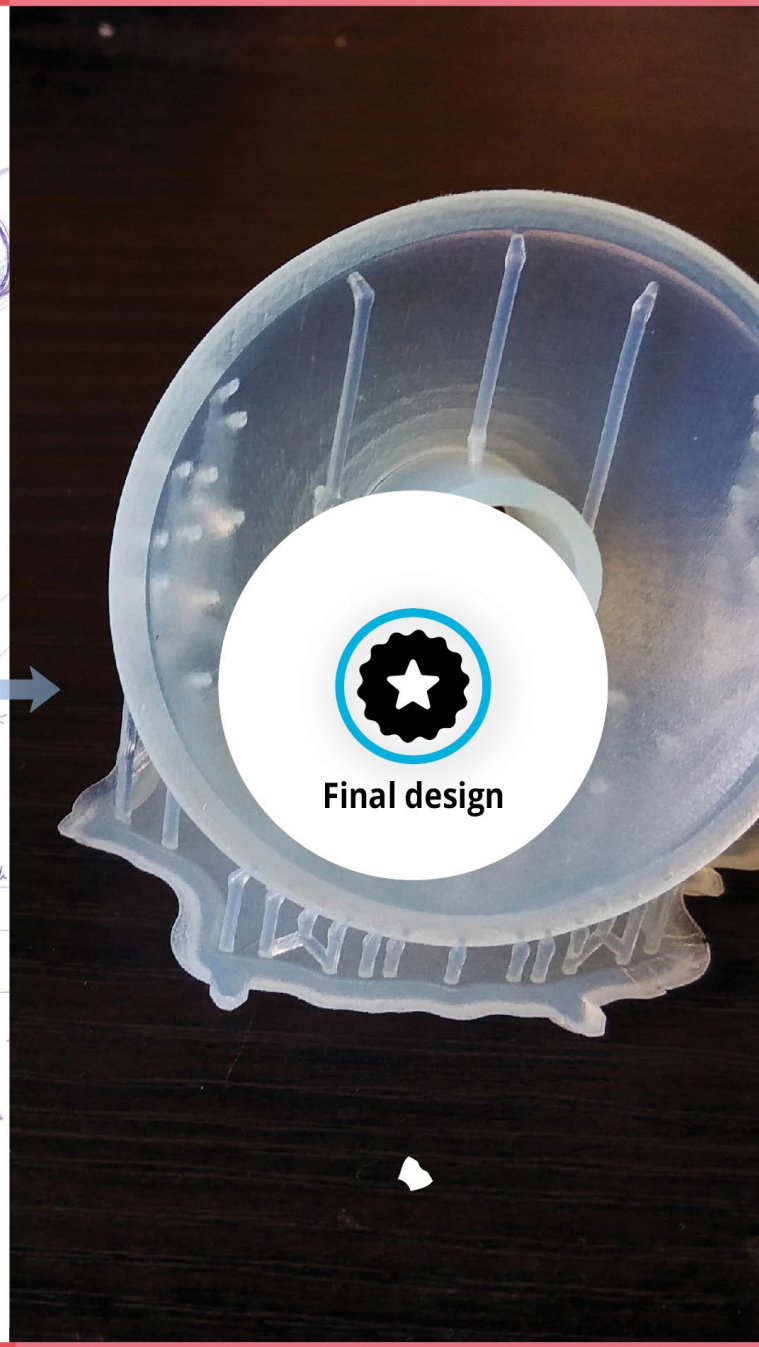


Design vision



Final concept



Final design

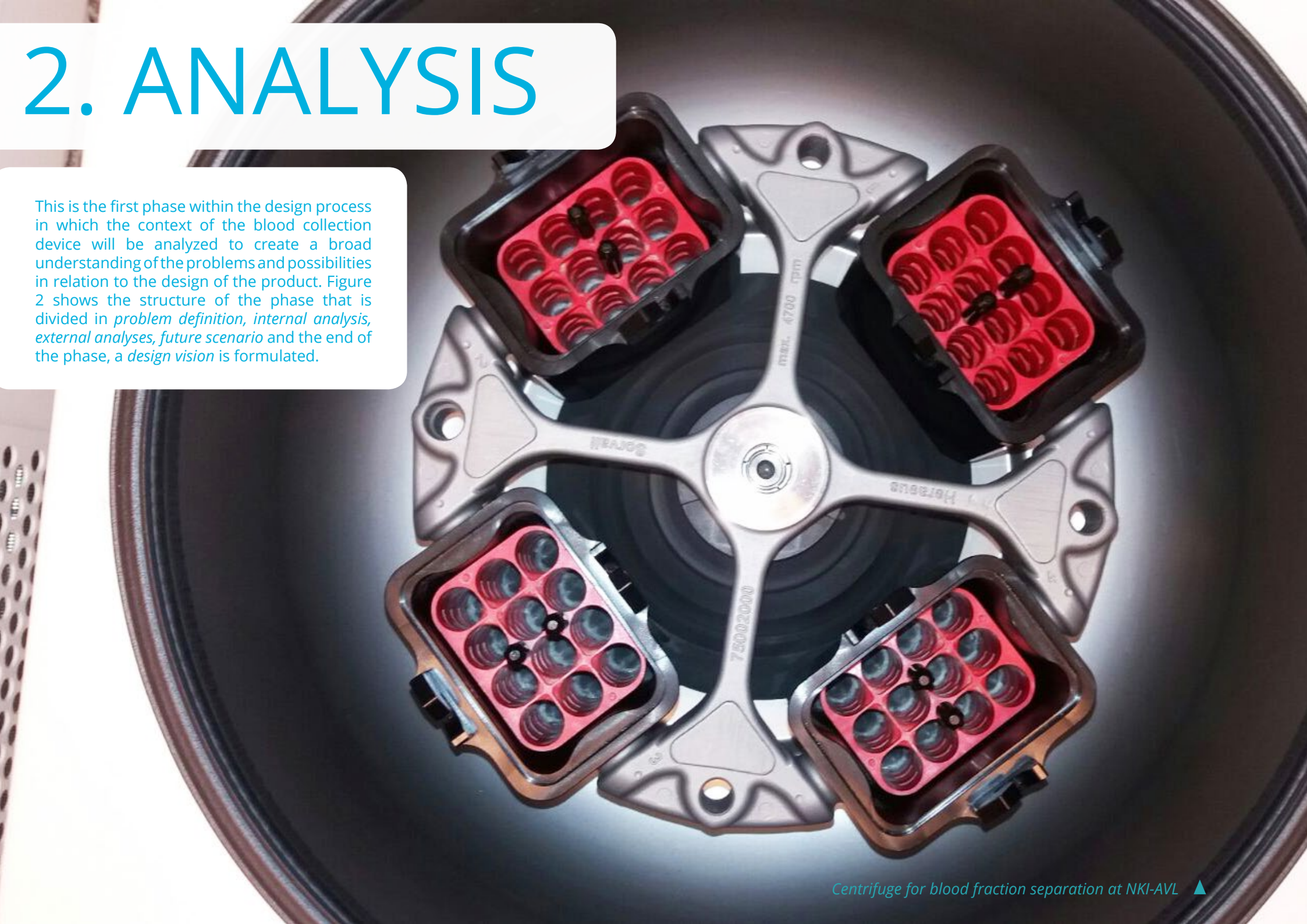
Analysis

Conceptualization

Embodiment

2. ANALYSIS

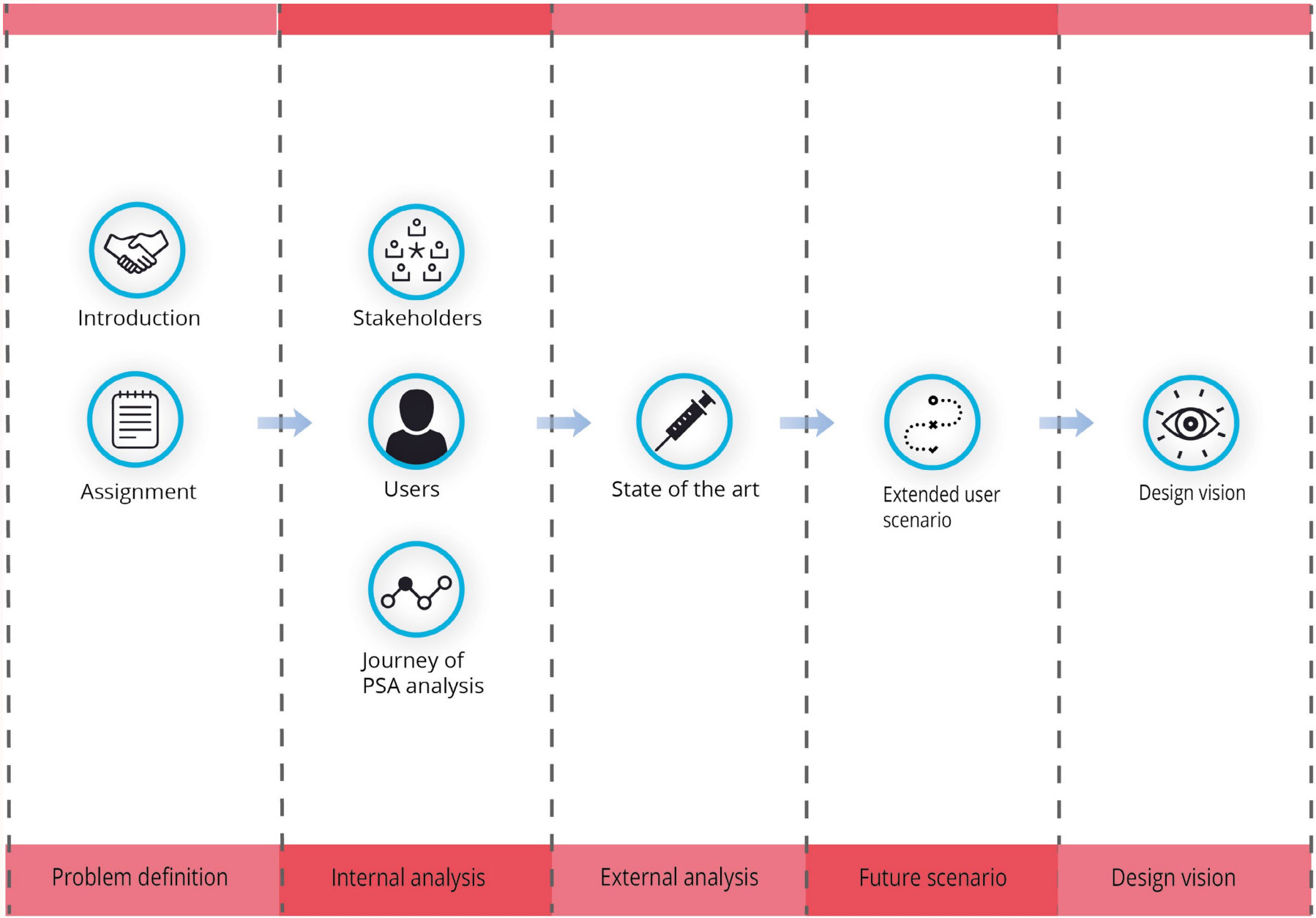
This is the first phase within the design process in which the context of the blood collection device will be analyzed to create a broad understanding of the problems and possibilities in relation to the design of the product. Figure 2 shows the structure of the phase that is divided in *problem definition, internal analysis, external analyses, future scenario* and the end of the phase, a *design vision* is formulated.



Centrifuge for blood fraction separation at NKI-AVL

Framework analysis phase

figure 2 - Framework analysis phase



2.1 Introduction

This chapter describes the scope of the graduation assignment and the context in which the project takes place. What are the problems in current practice and what kind of product is desired to design in order to optimize current situation.

Prostate cancer is the most common type of cancer for Dutch males. 1 out of 9 males is diagnosed with prostate cancer during his life. 48% Of the diagnosis is for men older than 70. From the European randomized study of screening for prostate cancer (ERSPC) became clear that screening for prostate cancer with PSA analysis and prostate biopsy could lead to decrease of disease specific deaths. However, this decrease is accompanied with an unacceptable amount of unnecessary analysis that leads to overdiagnosis and could cause unwanted side effects. The guidelines from "Integraal kanker centrum Nederland" (IKNL) are not to encourage PSA tests for asymptomatic men (IKNL, 2014).

The graduation project is done in collaboration with Nederlands Kanker Instituut and Antoni Van Leeuwenhoek hospital in Amsterdam (NKI-AVL). This collaboration is specialised in oncology in which they do research about the topic as well as analysing and treating various types of cancers. In this graduation report, NKI-AVL will be used as the name for the organisation.
The project focuses on the analysis of prostate cancer. In current practice, the patient needs to undergo a venipuncture that allows medics to analyse the blood sample on prostate cancer. This analysis is called a PSA test. These venipunctures are executed within the hospital or at local facilities by qualified personnel (figure 3).

However, venipunctures as procedure to collect blood samples have the following drawbacks:

- The patient needs to visit a blood sampling facility each time their PSA level needs to be measured. It takes time, money and effort for the patient to travel to blood sampling facilities.
- Sampling blood is labour-intensive which makes PSA analysis costly.

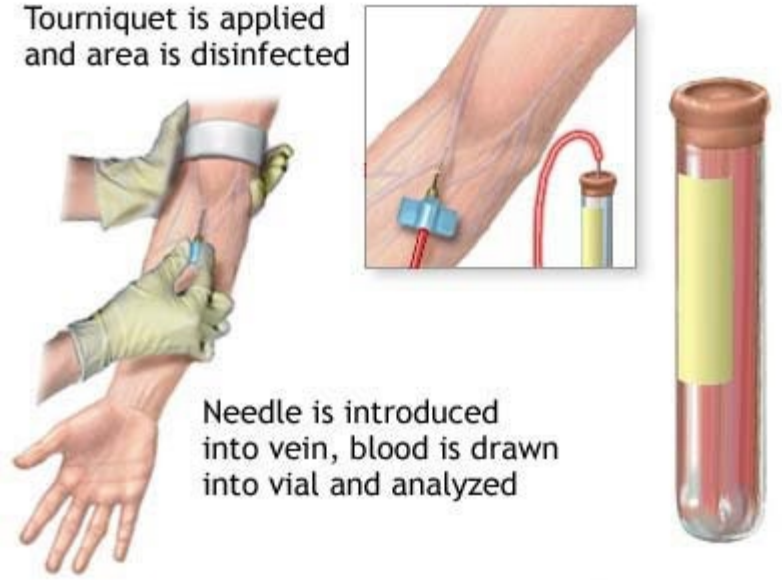


Figure 3 – venipuncture for blood sampling (Scripps, 2017).

These insights lead to the medical trend: movement of healthcare closer to home. There are already solutions to measure PSA at home (point-of-care test) (figure 4)

Most of these tests are developed in the UK and USA. Two types of PSA home tests exist;

1 - The point-of-care test, in which the patient samples his own blood and analyses the sample at home with a small device.

2 – A test in which patients sample their own blood, preserve it in a test tube and send it back to the hospital for clinical analysis. (Craig medical, 2012)

Figure 4 – Point of care PSA test (Self-test health kits, 2015)

The drawback of the first test is that the results lack accuracy. This type of test is often not suitable for measuring small percentages of PSA in the blood (Karim et al, 2007). Sensitive measurements are crucial in detecting early stage prostate cancer and monitoring developments during follow up tests

The test results of the second test are more accurate as the analysis of the samples is done within the clinical laboratory. However, the second mentioned tests are not user friendly. These kits consist of several components to sample your own blood, preserve it and send it back to the hospital. NKI-AVL experimented with this kind of tests but found the usability and user-friendliness not sufficient to implement this type of testing within their hospital and trials. Since the patients need to use the blood collection device approximately 5 times a year, a more user friendly solution is desired with improved usability.

Another drawback is that existing PSA home tests are not compatible with test equipment of the clinical laboratory. These home tests have dimensions that do not fit within the chemical analyser and are not user friendly according to NKI-AVL.
When blood sampling is done in external facilities, it could also happen that the systems between the two facilities lack unity which complicates the test logistics at NKI-AVL.

Research

The general clinical laboratory within NKI-AVL is currently doing a study to find out whether blood samples extracted from finger punctures deliver sensitive PSA values when analysed after the sample is hemolysed. It is expected by the clinical chemist that the outcomes will be as sensitive as the results from standard PSA analysing methods. The development of the blood collection device goes along with this research. It will be tested whether the device is capable of delivering blood samples that meet up to the required sensitivity values of PSA.

Problem definition & assignment

Current procedures to collect blood samples have the following drawbacks:

- Time money and effort to perform the test for patient
- Costs of a PSA test
- Reliability and accuracy of test
- Not compatible with equipment of NKI-AVL

The challenge is to design a blood collection device that could lower the amount of external blood sampling tests and lead to faster test logistics. In order to enable patients to collect their own blood at home without compromising patient's safety, accuracy, hygiene and ease of use, a blood collection device will be developed that is compatible with test equipment of NKI-AVL. The blood collection device should have ergonomic and technical features that will result in enabling patients to sample their own blood in a safe, accurate and hygienic way.

The blood collection device should:

- *Lower the amount of external blood sampling tests.*
- *Make test logistics faster at NKI-AVL*
- *Enable patients to collect their own blood at home without compromising patient's safety, accuracy, hygiene and ease of use*
- *be compatible with test equipment of NKI-AVL*

2.2 Stakeholders

This chapter gives insights in the organisation of Antoni van Leeuwenhoek. It clarifies where the organisation stands for and how it is structured. Stakeholders of the organisation and the future blood collection device will be mapped.

"The environment and sustainability are valued highly within NKI-AVL"

The Antoni van Leeuwenhoek hospital was founded in 1913 in Amsterdam and is both hospital and research institute (figure 5). The hospital is the only institute in the Netherlands that received the accreditation from the organisation of European cancer institutes. It is rated within the top ten Comprehensive Cancer Centers from Europe (cancer center that gets their support from the National Cancer Institute NCI).

Figure 5 - Buidling of NKI-AVL in Amsterdam (De Ploeg, 2015)

Legal structure

The organisation "Antoni van Leeuwenhoek" consists of a foundation that includes the Netherlands cancer institute (NKI) which is responsible for research and the Antoni van Leeuwenhoek hospital which is responsible for the treatment of patients. The two operate financially independent from each other although they form one foundation together. The reason is different funding sources for each of the organisations.

This graduation project finds an overlap in both disciplines as an ongoing research yet has to prove whether the analysis of finger-puncture samples provide equally trustworthy results as samples derived from venipuncture tests.

Vision of the company

NKI-AVL describes its vision to fulfill their mission in the following words:

"Conducting fundamental cancer research, translational research, as well as clinical, epidemiological, and psychosocial research of the highest quality."

"Providing state-of-the-art diagnostics, treatment, and nursing care as well as designing and developing new promising treatments and improving existing ones"

"Transfer of knowledge and skills through education and training of physicians, scientists and other professionals in the field of oncology." (R.Medema NKI-AVL, 2017)

The second citation matches the aim of the graduation assignment to develop an improved method in blood collection very well.
The environment and sustainability are also valued highly by the institute. Sustainable business is encouraged and adopted in the annual report. The hospital follows guidelines from MPZ (milieu platform zorg) which is a management system that stimulates and secures sustainable business (NKI-AVL, 2015).

Organizational structure

The hospital consist of 50 departments with their own expertise. The blood collection device will be relevant for stakeholders and several departments within the organization. These beneficiaries will be mapped in a stakeholder overview further on.

Stakeholders

NKI-AVL has various stakeholders. An overview of the major general stakeholders can be seen in figure 6. For a complete overview of all stakeholders involved see (NKI-AVL, 2015).

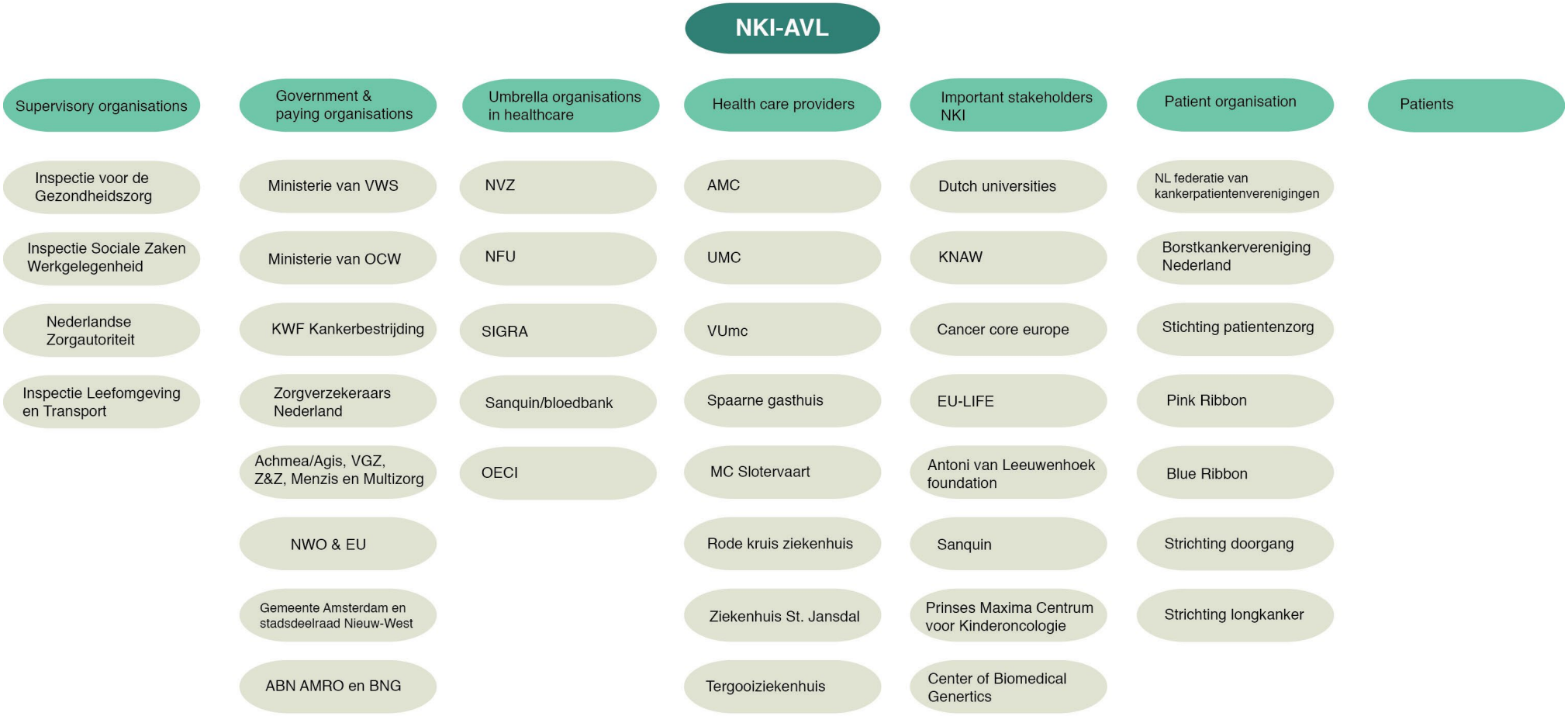
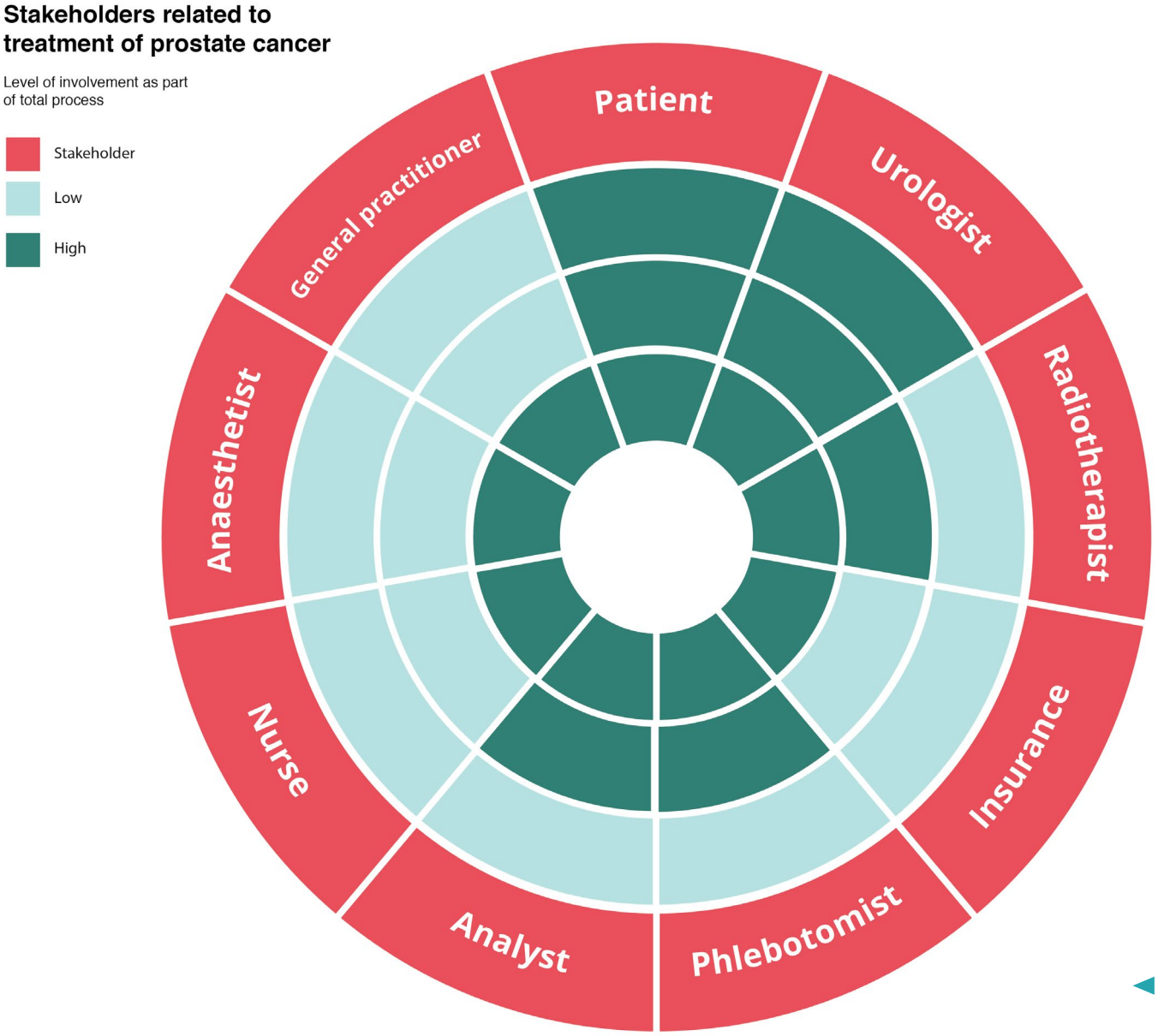


Figure 6 - General stakeholder overview NKI-AVL



Strakeholders - Treatment of prostate cancer
The overview in figure 7 visualizes the stakeholders that are related to the treatment of prostate cancer. It gives an indication about the level of involvement of the stakeholder as part of the total process. Chapter 2.4 will elaborate on these stakeholders in relation to the patients experience within the treatment of prostate cancer.

◀ *Figure 7 - Stakeholders related to treatment of prostate cancer*

"Stakeholder overviews are usefull tools to see for who value is created"

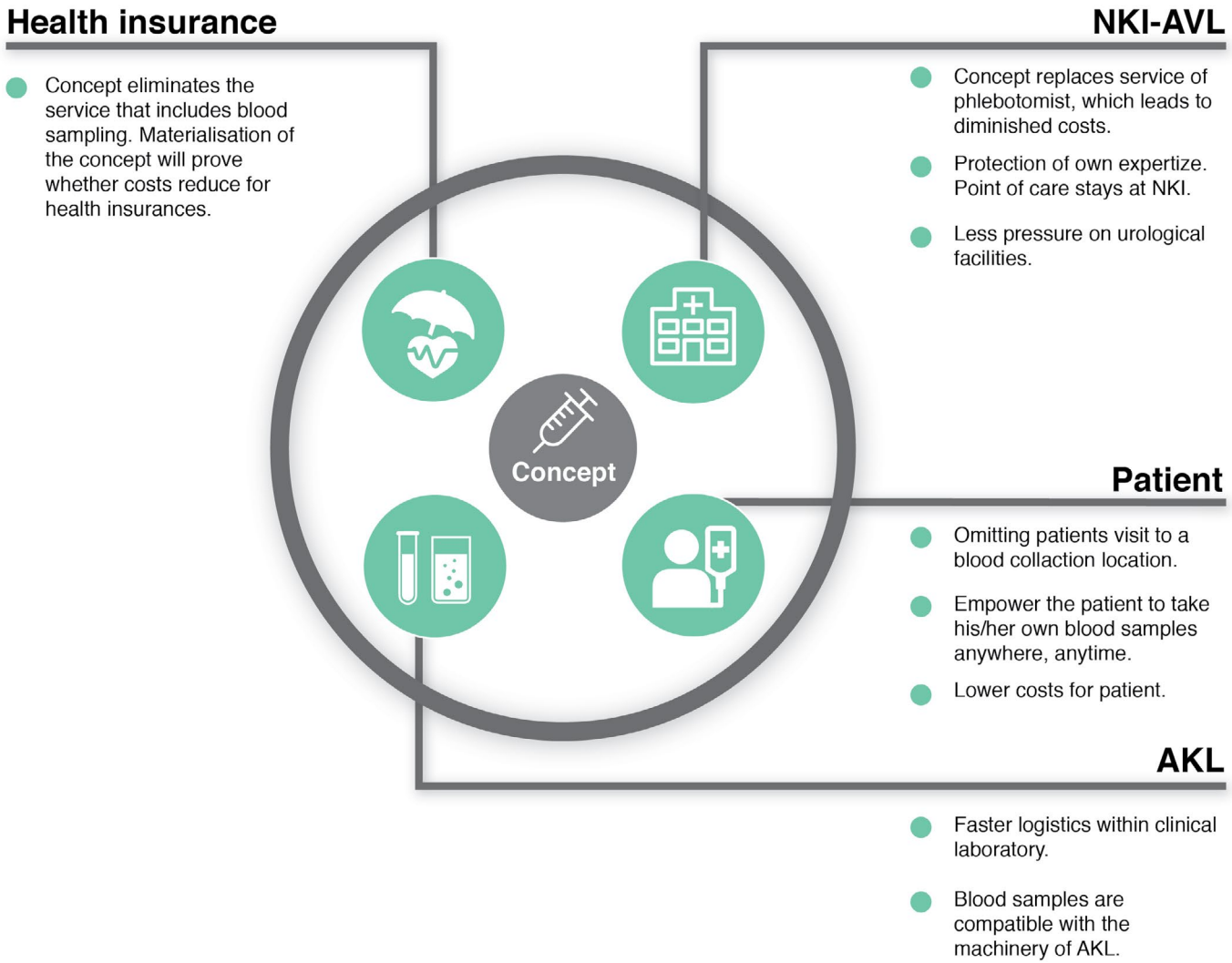


Figure 8 - Relevant stakeholders and benefits

Relevant stakeholders
Figure 8 gives an overview of the stakeholders relevant to this graduation project.

Conclusion
This chapter created an overview of current and potential beneficiaries of the blood collection device. The overviews can later on in the project be used to implement the blood collection device within the hospital and to formulate requirements for the development of the blood collection device. It can also be used to create a business plan for the device later in the project.

The blood collection device provides the most added value to the following stakeholders:

- *NKI-AVL*
- *AKL*
- *Patient*
- *Health insurances*

2.3 User

For the design of the blood collection device it is important to take the user into account in order to implement the right ergonomics and appearance. Especially the ergonomics are of great importance. The user should be able to use and understand the device when taking home samples. This chapter will zoom in on the user group, the user on a personal level and the interaction of the user with the blood collection device (figure 9).

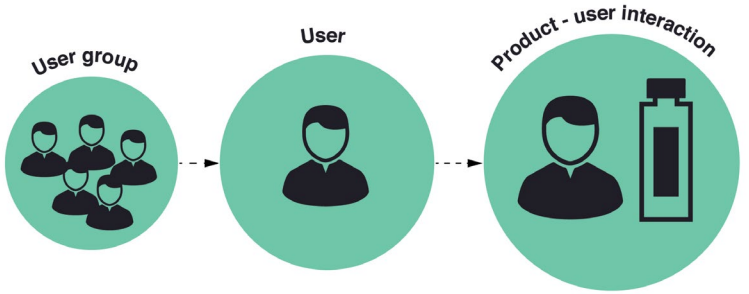


Figure 9 - Zooming in on the user

"The potential user of the blood collection device is a big group that will keep rising in the future."

Target group

50-80 year old men with prostate cancer

Comprises **>95%** of the patients

"In Januari 2015, 48% of patients were older than 70 years"

Figure 10 - Statistics of target group

The user group

The statistics for the target group are visualized in figure 10 & 11.

In January 2015, 77668 men in the Netherlands had prostate cancer, from which 48% was older than 70 years (IKNL / NKR, 2016). The amount of men diagnosed with prostate cancer is rising. 11500 men were diagnosed with the disease in 2011. It is expected that this number will rise to 17000 patients in the year 2020, which is related to the rising number of elderly men within the Netherlands. The prevalence of men with prostate cancer will rise as the mortality due to prostate cancer remains constant in absolute numbers. The ten years prevalence (number of men that is diagnosed at a maximum of 10 years before a measuring point) will rise from 60000 in 2010 to 106000 in 2020, which will put great pressure on urological facilities (IKNL, 2014).

The potential user of the blood collection device is a big group that will keep rising in the future. Data within NKI-AVL shows that the major group of prostate cancer patients are within the age group 50-75 years. Approximately 5 % is older than 80 years (Appendix G).

It is decided to focus on the age group of 50-80 year old man, as this group approximately comprises 95 % of the patients. Only patients who are thought to be mentally and physically fit enough to successfully use the blood collection device, qualify for the use of the blood collection device. It is the urologists responsibility to estimate whether the user qualifies. It can be assumed that patients over 80 years old are generally less fit than patients within the age range 50-80.

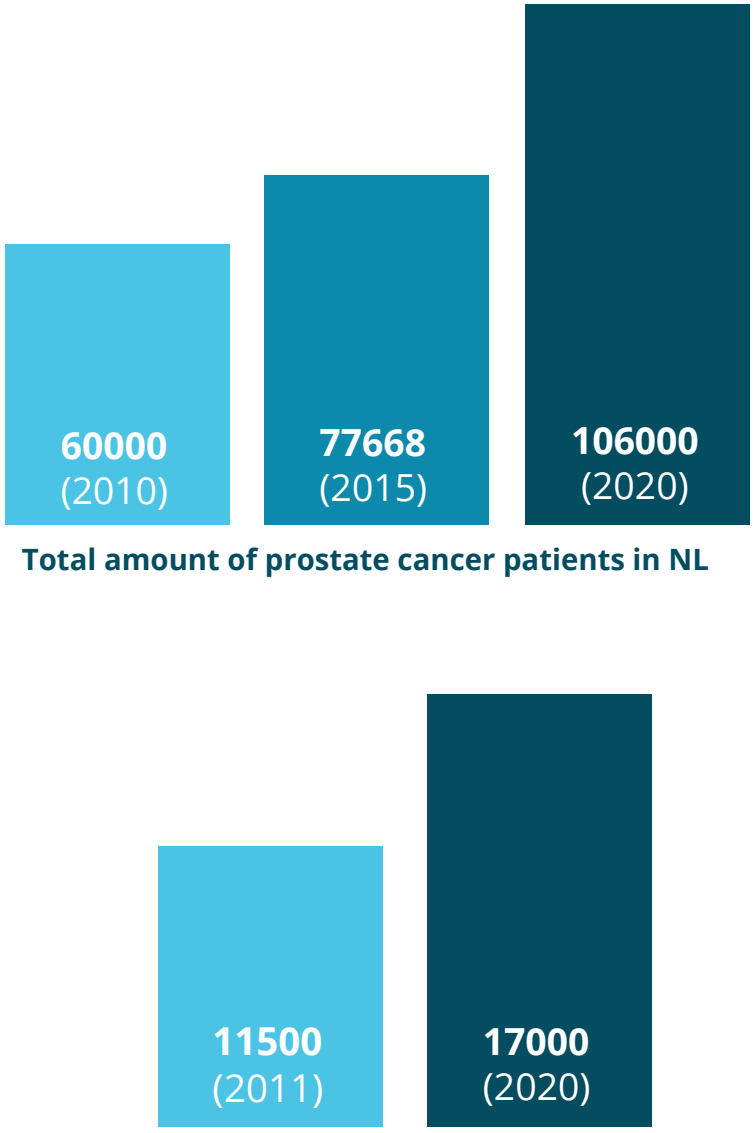


Figure 11 - Statistics of target group

Johan Huiskens

Age:	**72**
Gender:	**male**
Lives in:	**Alkmaar**
Patient:	**Prostate cancer**
Status:	**Married**

Values

- **Independent from environment**
- **Open for innovation**
- **Personal contact**

9 May, 2017

'Recently I discovered that something was wrong with me. It began with my difficulty to urinate when I visited the toilet 3 months ago. At first I tried to ignore the symptoms, as I found it quite awkward to talk about with my wife or children. I decided to tell my wife anyway. She told me that we needed to visit the general practitioner who lives next door. I agreed, and there we went a few days later. The doctor looked at me and told me that it was wise, considering my age and symptoms, to do a PSA test, which is an indicator of possible prostate cancer. The doctor took some blood and send it to the Antoni van Leeuwenhoek hospital. The results came in a few days later. My own doctor told me that I had an increased PSA value, which could mean that I had prostate cancer. My world turned upside down from that moment, because I knew that increased PSA was no good...'

"Prostate cancer patients seem to be open to the idea of a novel blood collection device."

"User wants to experience the same amount of trust during home sampling as they do experience inside the hospital"

▲ *Figure 12 - Persona of user*

The user

Latter paragraph described the user group for which the blood collection device will be designed. The "group" is eventually only relevant for production volumes of the final product. More relevant for the design of the product is the user on a personal level. This is the person that will actually use the device.
Prostate cancer patients seem to be open to the idea of the novel blood collection device. The idea of saving time and being independent appeals to them. Personality is something they value highly, such as personal contact with their doctor (Appendix E).

Persona

Figure 12 shows a persona that is written to give insight in the user that is related to the blood collection device. The information is gathered from interviews that were held with patients, a urologist and phlebotomists. The persona is not an actual person and no patient information is violated in the construction of this persona.

"It can take up to 6 hours of active time in current situation to do a PSA test "

User scenario for current situation

In order to gain understanding of current situation in which a patient visits the hospital for a PSA analysis, a visualization is made (figure 13).

Figure 13 - User scenario of current situation

Interaction with blood collection device

"The test person had difficulties in understanding the manual, spilled blood and the collection device fell over"

What is desired from the blood collection device in terms of product-human interaction. In order to make sure that it is clear and easy for the user to hold the collection device while sampling blood and puncturing the finger, a closer look to the target groups ergonomics would be useful in order to set ergonomic requirements for the development of the device. In order to find out what is the desired interaction of the blood collection device, a user observation is done for current blood sampling equipment to find out points of attention. Literature about ergonomics for elderly is consulted to determine threshold values for relevant ergonomics features of the blood collection device.

User observation

This user observation is meant to find out how a state of the art PSA kit is used by the target group. The test is done with a 66 year old male (appendix J). The observations (figure 14) are used to improve product human interaction. Relevant ergonomics were noticed during the observation. These ergonomics are analysed in next paragraph.

Figure 14 - user observations

Desired product-human interaction
The desired product-human interaction is visualized in figure 15 and 16. Various variables can be distinguished that give feedback towards the user during interaction with the device. Elaborated descriptions of these feedback variables with relation to the user can be seen in appendix O.

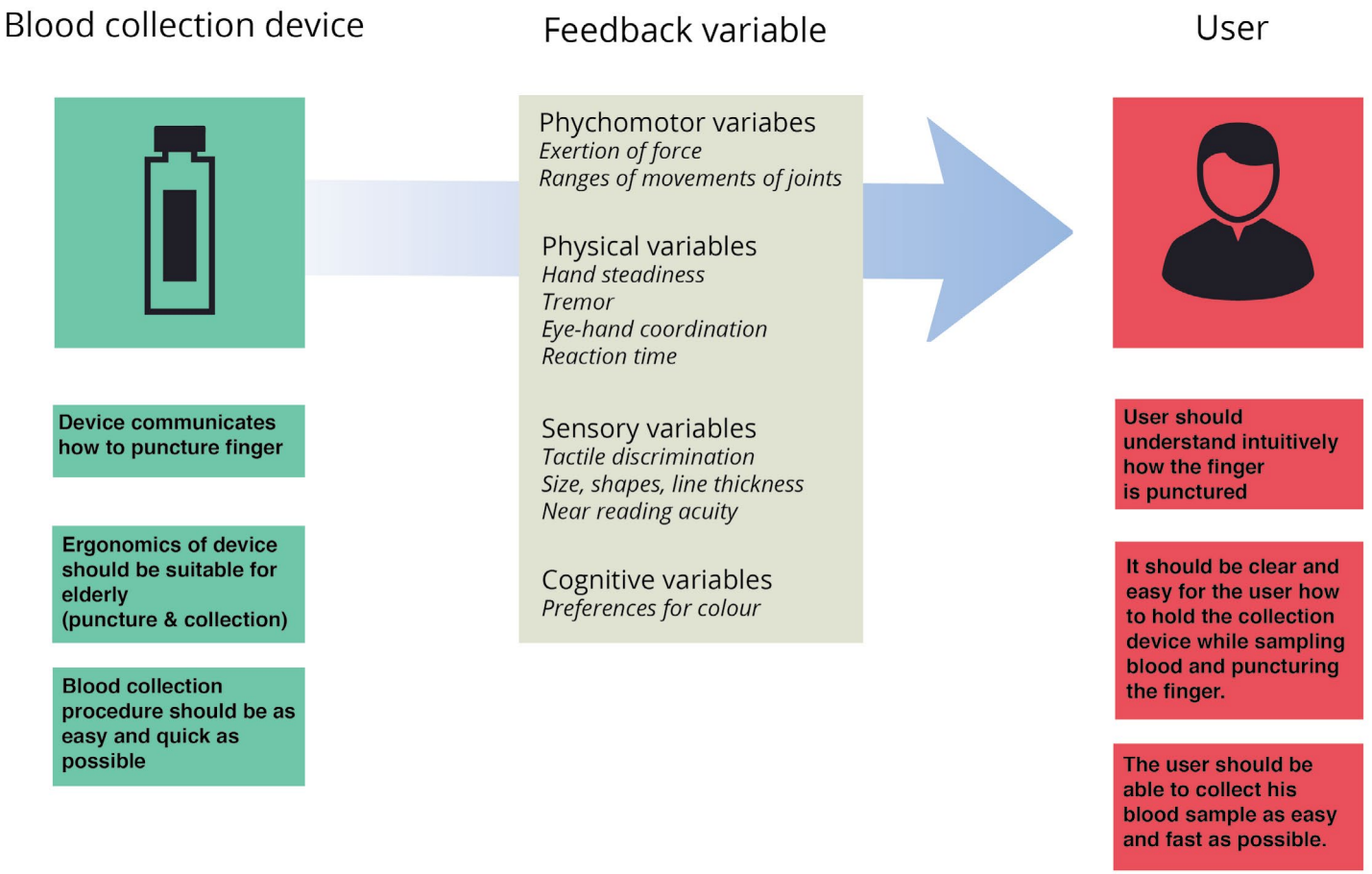


Figure 15 - Desired product-human interaction

Figure 16 - Ideal blood collection device

Ergonomics

The target groups ergonomics have their own characteristics, as the group is quite old. The ergonomics are split up in different variables that were observed during the user observation and are thought to be of importance during the design of the blood collection device. Appendix J gives an overview of relevant ergonomics for the target group. The final design of the blood collection device will need to meet up to these required ergonomics.

"The blood collection device will be designed for p 95 target group in terms of ergonomic features, such as force exertion and physical dimensions of the hand."

Dimensions

The blood collection device will be designed for p 95 target group in terms of ergonomic features, such as force exertion and physical dimensions of the hand. However, a margin is used because of the seriousness of the design context. Inaccurate use of the device could lead to falsificated measurement results. It is the responsibility of the blood collection device provider to judge whether someone is capable of performing a self-sample blood test.

Secondary user

When the blood collection device is send back to NKI-AVL for PSA analysis, another user appears in the scenario, the chemical analyst. This person needs to hemolyse, centrifuge the sample and places the sample inside the chemical analyser. These action require not high sensitive ergonomics. However, contamination is something to take into account, think for example about needlestick injuries that could occur. It is important to take the involvement of this secondary user into consideration during the design of the blood collection device.

Conclusion

This chapter focused on the user group, the user and the interaction of the user with the product. The analysis of these three user aspect leads to the formulation of user and user interaction requirements that are integrated in the list of requirement and will therefore be used as framework during the ideation phase of the project.

- *Target group: 50-80 year man with prostate cancer.*
- *The blood collection device should not require extensive use of hand muscles*
- *The blood collection device should not ask flexible movements of the wrist*
- *The blood collection device and hand should be stabilized to optimize performance*
- *The blood collection device should not merely use tactile feedback as means of communication*
- *User wants to experience the same amount of trust during home sampling as they do experience inside the hospital*
- *The manual should inform the user intuitively.*
- *No blood should be spilled during the sampling procedure*

2.4 Journey of PSA analysis

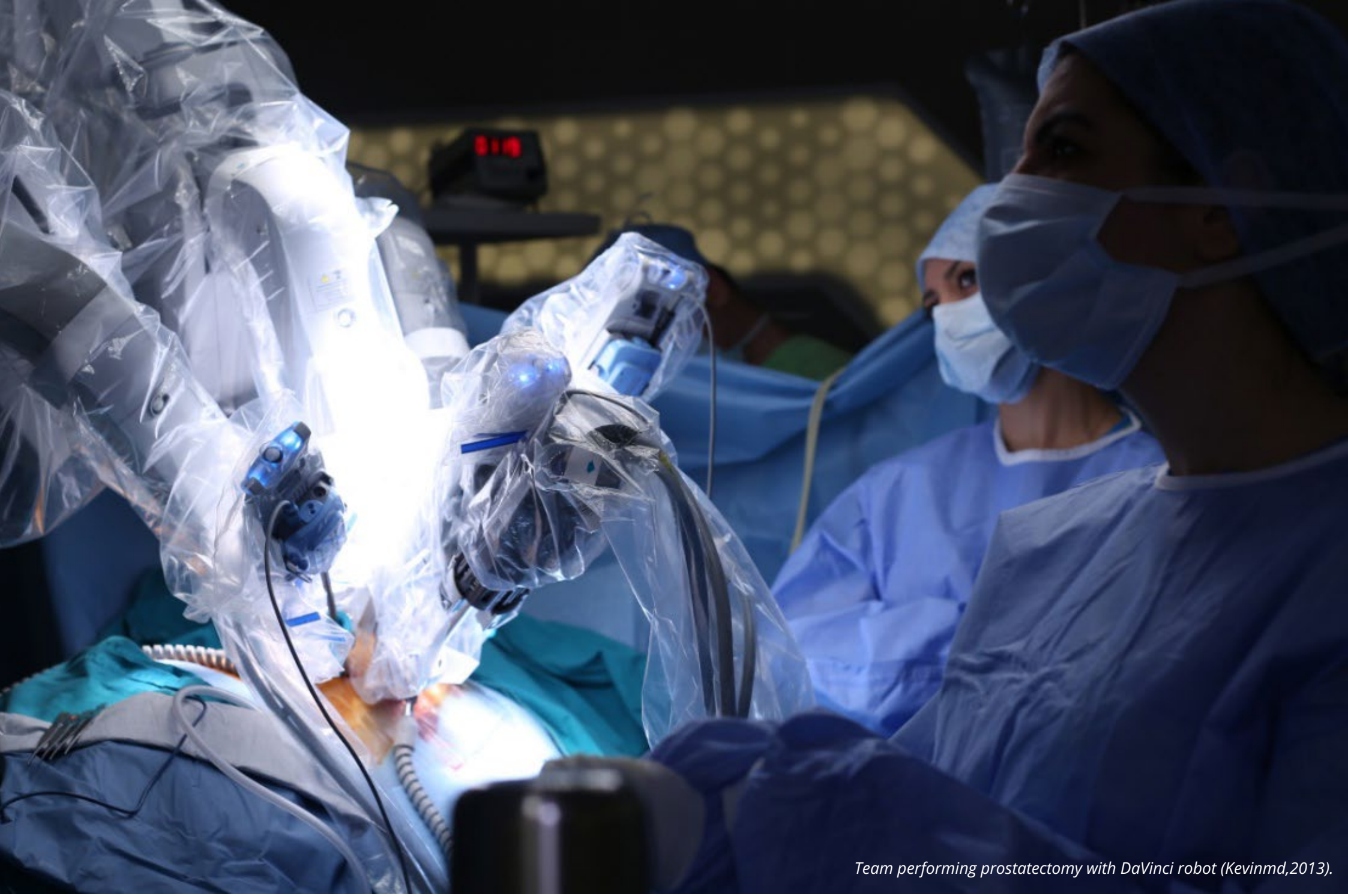
This chapter includes the process of prostate cancer treatment and narrows down to the follow-up phase in which direct stakeholders and actions within the process of blood collection in current and desired future situation are being analysed.

Journey of prostate cancer treatment

Figure 17 shows the different phases of prostate cancer treatment. All stakeholders related to the treatment of prostate cancer are mapped within these different phases to create an overview of the context in which the collection device will be developed. The last phase, “follow up” is highlighted. This phase is the most relevant for the project as the blood collection device will be used during the follow-up to monitor the patients PSA value.

Phase	Symptoms	PSA value	Prostate biopsy	Diagnosis	Prostatectomy	Recovery	Follow up
Stakeholders							
Patient	Patient notices that something is wrong due to symptoms within the prostate area.	Patient has an oppointment with GP to hear what his PSA value is.	Patient is unconcious when the prostate sample is taken.	Patient communicates with urologist and radiotherapist what treatment he wants.	Patient is unconcious when the prostatectomy is perfomed.	Patient needs to recover for a few days. He will be hospitalised for 24 hours.	Patient needs to visit the hospital to monitor his PSA value 5 times a year.
General practitioner	The GP examines the patient and suggests to do a PSA test.	GP communicates PSA results to the patient.					
Urologist			Urologist performs the prostate biopsy.	Radiotherapist and urologist discuss what would be the best treatment for the patient	Urologist performs the prostatectomy.	Urologist checks whether operation was succesfull	Urologist communicates PSA result and discusses treatment plan with patient.
Radiotherapist				Radiotherapist and urologist discuss what would be the best treatment for the patient	Alternative treament with radiation is an option.		
Anaesthetist			Anaesthetist makes sure that the patient is under general anaesthesia.		Anaesthetist makes sure that the patient is under general anaesthesia.		
Nurse			Nurse prepares the patient for surgery and takes care of patient after surgery		Nurse prepares the patient for surgery and takes care of patient after surgery	Nurse takes care of patient while being hospitalised	
Insurance	Costs need to be covered by the insurance.	Costs need to be covered by the insurance.	Costs need to be covered by the insurance.	Costs need to be covered by the insurance.	Costs need to be covered by the insurance.	Costs need to be covered by the insurance.	Costs need to be covered by the insurance.
Phlebotomist		A phlebotomist samples blood form the patient					A phlebotomist samples blood form the patient
Analyst		An analyst tests the PSA value of the blood sample and sends result to GP.					An analyst tests the PSA value of the blood sample and sends result to urologist.
Time		A few days	A few hours		A few hours	24 hours	6 hours

Figure 17 - Patients experience journey for the treatment of prostate cancer.



Team performing prostatectomy with DaVinci robot (Kevinmd,2013).

"The urologist decides whether a blood collection device is suitable for the patient"

Current & desired future situation

This paragraph focuses on the "follow-up phase" that has been highlighted in figure 17, as this is the phase in which the future blood collection device will be implemented . Figure 18 and 19 show current and the new journey of a PSA analysis within the follow up phase. These overviews have been created by observations of the context and by interviews and conversations with experts. Step 2 and 3 are parts of the journey which will be changed in the new situation. This journey focuses on all parts of the journey in order to map information that is needed for the design of the blood collection device that should fit with the new situation. This information will result in product requirements and wishes that are being listed in the list of requirements (appendix M). The process of the new situation is mapped in a process tree (appendix L). The process tree helps to create and structure the list of requirements.
Whether a blood sample by finger puncture could eliminate an initial blood sample by venepuncture is still a question mark which will be discussed with urologists and phlebotomists at NKI-AVL.

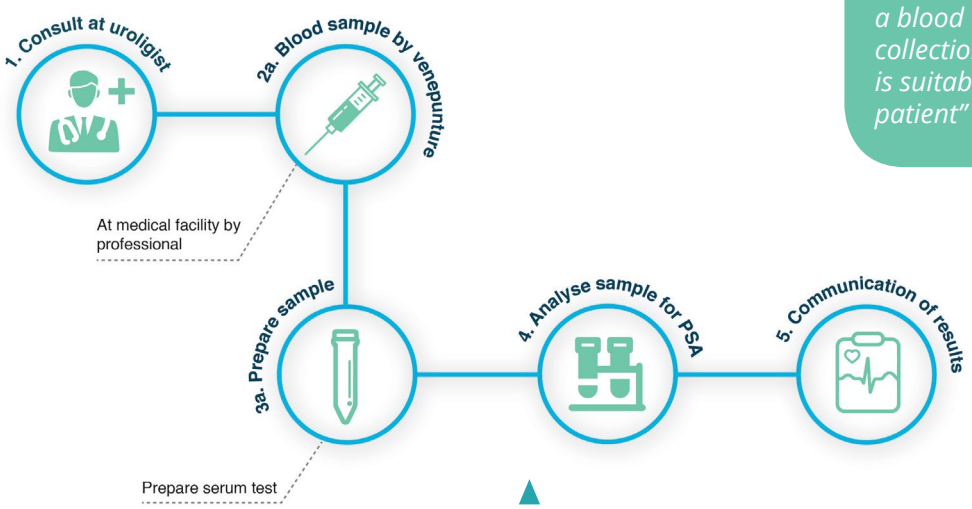


Figure 18 - current situation

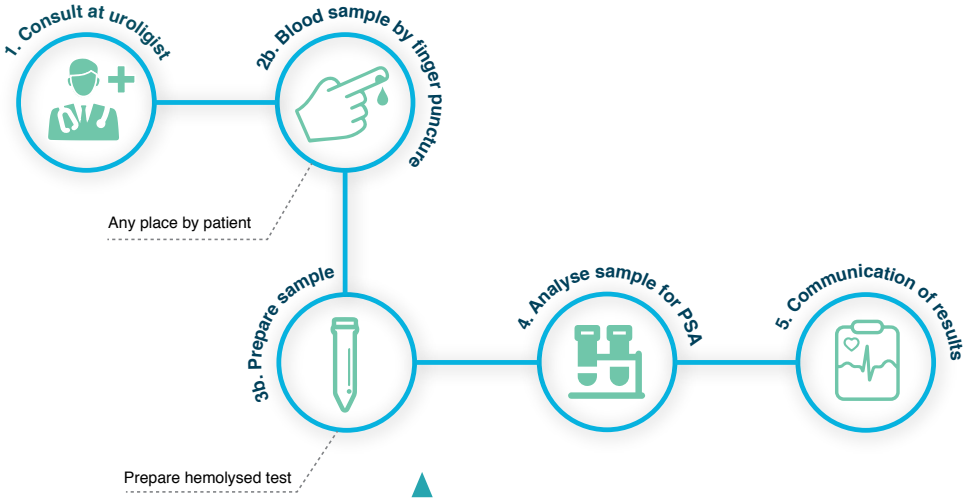


Figure 19 - Desired future situation

1.Consult at urologist

When a patient has problems or pain around the prostate, he will be forwarded to a urologist for further inspection of the symptoms. When the urologist suspects that the patient's symptoms are related to prostate cancer, either an appointment is made by the blood collection department or the patient receives a finger puncture collection device that enables him to test on PSA at home.
It will be the responsibility of the urologist to estimate whether the blood collection device is suitable for the patient. Approximately 95 % of the patients are between the 50-75 years old. A small percentage is older than 80 years (Appendix G - interview urologist).

2a. Blood sample by venipuncture

The venipuncture is executed within the blood collection department of NKI-AVL. The patients can visit the department without appointment. It depends on the moment of the day/week what time each patient has to wait. The venipuncture is done in a cubicle for enhanced privacy (figure 20)

Figure 20 - Phlebotomist in cubicle at NKI-AVL

The amount of blood that is sampled in PSA test tubes during venipuncture is 5 ml. The sampling time is about 2 minutes for a venipuncture. The test tubes (figure 21) contain an underpressure that allows the blood from the injection needle to enter tube easily when the phlebotomist injects the needle in the vein of the patient. It takes 10 minutes to transport a sample from the blood sampling department to AKL. The blood sample is placed in a plastic tube that is placed in a transportation pipe within the blood sample department. The tube is transported one floor up through the tube by pressure inside the tubes (figure 22). It takes 3 hours from initiation of the venipuncture until PSA data is received by the urologist. (Appendix F)

Figure 21 - Tubes for collection of blood for PSA analysis by venepuncture

Figure 22 - Transportation pipe for sample transportation towards AKL

2b. Blood sample by finger puncture

The finger seems the most logical place to take the blood sample as the hands are not covered by any cloths and are easily accessible. Exposure of the fingers is not considered controversial which means that samples could be taken in presence of other people. High density superficial capillaries in the skin make superficial low invasive sampling possible (Appendix B).
Extracting blood from the finger can be difficult. The finger prick is mostly used in scenarios that only require a tiny drop of blood, such as point-to-care devices. A minimum of 200 µl is needed for the PSA test, which is equal to 5 drops of blood. This minimum amount of blood is based on tube dimensions that are currently used within NKI-AVL. It might turn out that less sample is needed for the PSA test when dimensions of the new blood collection device allow diminished dead volume of the blood sample. For 200 µl amount of blood it is recommended to choose a high flow lancet that is more invasive than regular lancets. A blade (1,5 mm diameter x 2,0 mm depth) should allow a maximum blood flow of 500 µl by single puncture (BD, 2017). A lancet slightly shorter than the estimated depth should be used as the puncture depth is deeper than expected due to pressure that compresses the skin during puncturing. It is studied that pain increases with penetration depth. Thicker lancets were only perceived slightly more painful than thin ones. The depth of a finger prick should not exceed 2.4 mm, which makes a 2.2 mm lancet the longest length that is normally used (Fruhstorfer, 1999) (WHO, 2010).

3a. Prepare sample

For the preparation of a serum sample, it is desired for the red blood cells to coagulate. Most of the tubes in which the samples are stored, contain a coagulant that accelerates the coagulation of the red blood cells. The tubes that are being used are able to coagulate blood in 5 - 30 minutes. (H.Duijn, 2017)
After the blood is coagulated, the blood needs to be centrifuged in order to separate the serum from the clotted blood. It takes 10 minutes to centrifuge the blood sample until it is ready for a serum test. NKI-AVL uses the “Heraeus Multifuge 1S-R Centrifuge” (figure 23). The machine rotates with 2500 RPM for a serum sample.

Figure 23 - Heraeus Multifuge 1S-R Centrifuge

“Pain especially increases with penetration depth.”

"EDTA is added to the container of the finger puncture sample to prevent the blood from coagulation."

3b. Prepare sample

In the desired future situation, it is desired to create a hemolysed blood sample instead of a serum sample, as a hemolysed sample requires less blood from the user. It is desired for the sample that it is not coagulated, therefore an antigoagulant (EDTA) is used. When the blood sample arrives at the logistic point, it needs to be hemolysed. Hemolysation means that the red blood cells need to burst open to free its hemoglobin into the plasma fraction of the sample. Free floating hemoglobin in the plasma fraction results in a transparent red appearance of the liquid. Hemolysation can be accomplished by various techniques. AKL rarely uses hemolysed samples. An easy way to hemolyse a blood sample is to freeze the cells which results in rupture of the cell membrane. The samples could be stored in refrigerators that are present in the laboratory of AKL.

After hemolysation, the samples need to thaw after which they will be centrifuged in the Heraeus Multifuge 1S-R Centrifuge that separates cell debris from the rest. The settings for the this sample are different than for the serum sample. The centrifuge will rotate at 3100 RPM and 1700 g. It is desired that the dimensions of the blood collection device match with the rack in this machine, otherwise additional gear in needed to make the samples fit the centrifuge. Figure 24 shows the centrifuge rack. Dimensions can be seen in (Appendix H)

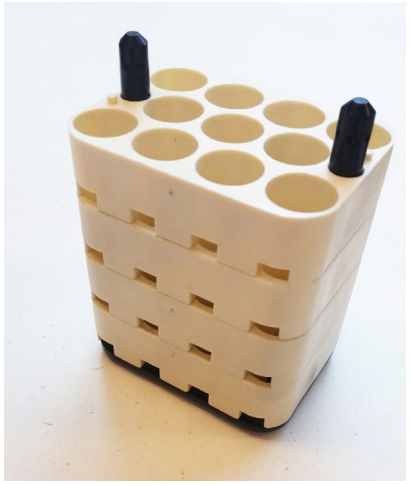


Figure 24 - Centrifuge rack

4. Analyse sample for PSA

When the sample is prepared in the clinical laboratory, it is ready to be analysed in the chemical analyser of the hospital. Other chemical analysers that are widely used will also be taken into account to make the design of the blood collection device also operational for other facilities. NKI-AVL makes use of the "Roche Cobas 6000 E-module analyser" (figure 25), which will be discussed in this paragraph.

The analysis of the samples is done in 18 minutes. The total time from venepuncture sampling and results is approximately 3 hours. PSA tests do not have the highest urgency which results in slower priority within the chemical analyzer. The sample, including samping materials, will be thrown away after PSA analysis for hygienic purposes.

Figure 25 - Roche Cobas 6000 E601 -module (Dotmed, 2017)

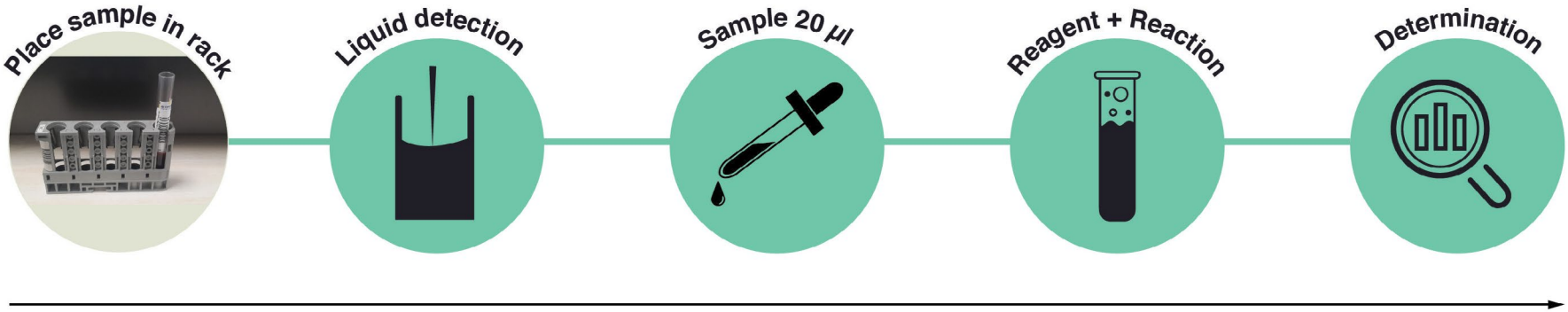


Figure 26 - Test procedure steps of chemical analyser

Working principle
The logistics within the chemical analyzer consist of several steps. The first two steps are important for the design of the blood collection device. Figure 26 gives an overview of the steps within the analyzer (Cobas, 2012).

Place sample in rack
Before a blood sample can be analysed, the sample must be placed in a rack that has fitting dimensions to the chemical analyser. NKI-AVL uses a Hitachi calibration rack which has been visualised in figure 27. In current situation, it happens that the blood samples are placed in another tube or pipetted in another tube in order to make the dimensions right for the chemical analyser. For the design of the blood collection device, it is important to take the dimensions of this rack into consideration. For the full dimensions of the Hitachi calibration rack, see (Appendix A).

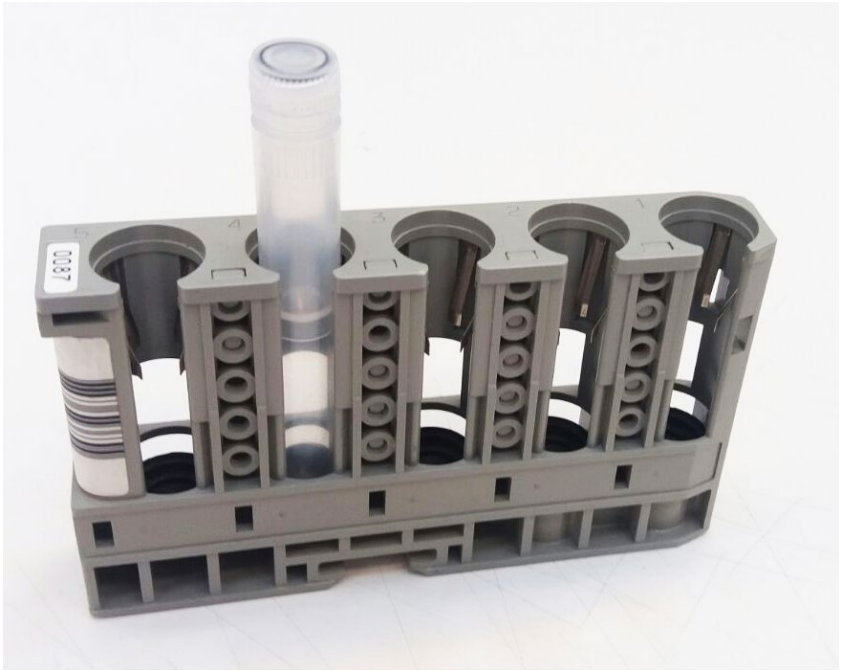


Figure 27 - Hitachi calibration rack

Liquid detection
At first, the blood sample is identified by scanning a label on the container. Then the chemical analyser detects the surface of the liquid by emitting an electromagnetic pulse. When liquid is detected, the machine lowers the needle a few millimeter to make sure that the needle is actually inside the liquid (figure 28). This is important. Sampling a bit of air along with the liquid could lead to incorrect results. NKI-AVL noticed that containers that were too small, resulted in failure of the analyser. This has to do with electromagnetic pulses interfering with the sides of the containers. Because it is unclear

"The container should be broad enough and the buffer zone high enough to prevent machine failure"

what tube dimensions were accepted by the analyser and what not, a test is conducted to find out what type of tubes would be best (Appendix C). As a result: The diameter of the containers should not be too small and deep in order to prevent machine failure. Superficial detection of the liquid passed without failure.

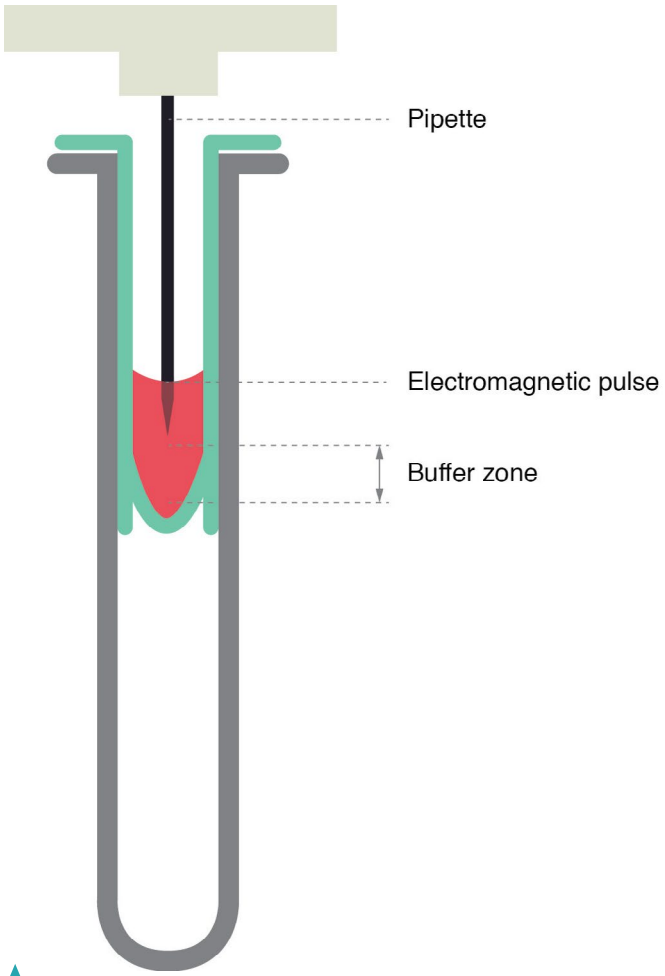


Figure 28 - Pipetting blood sample

Sample 20 µl
The chemical analyser pipettes a sample of 20 µl from the blood sample, which is placed in another smaller blood container. The pipetting is done a few millimeter underneath the liquids surface which results in a buffer zone (dead volume) within the blood container (figure 28). This buffer zone is needed to make sure that the needle does not accidentally touches the bottom of the container. This could happen when a sample contains a smaller amount of liquid than expected.

Reagent + reaction
Various reagents are aspirated in the blood sample to react. The type of reagents and reactions are not relevant for the development of the blood collection device.

Determination
After the reaction takes place, the analyzer is able to measure the PSA concentration within the following sensitivity range: 0.003-100 ng/mL. The analyzer sends the results for the specific blood sample automatically to the urologist.

5. Communication of results

The urologist will contact the patients either by appointment or by telephone after the chemical analyzer has send the PSA results. The urologist and patients can discuss further steps in the patients treatment.

Conclusion

This chapter gave insight in current and the desired future situation related to PSA testing. The analysis resulted in a better understanding of the actions that take place within these scenarios. This led to product requirements that are useful during the conceptualization phase of the project

Greater scope

For the design of the blood collection device it is interesting to do research in other chemical analyzers that are big players in the market. Roche, is considered the worldwide market leader for chemical analyzers. The main concern is to design for this brand, as NKI-AVL's analyzers are from this brand. However, it is interesting to see whether other systems can be implemented as well. It is found that other major chemical analyzers require a minimum dead volume between 50 and 100 µl (CAP Today, 2016), which makes the blood collection device also compatible to these analyzers.

- *200 µl blood is needed for a PSA test*
- *The finger is the best location to sample this amount of blood.*
- *It is desired to use a lancet with the following dimensions: 1,5 mm diameter x 2,0 mm depth to ensure sufficient blood flow*
- *It is desired to make the container as small as possible to make dead volume as small as possible without interfering with the electromagnetic pulse of chemical analyzer.*
- *EDTA is added to the container to prevent coagualation of the blood sample.*
- *The device should be a diposible for hygienic purposes.*

2.5 State of the art

Latter chapter described all actions within PSA analysis in the follow-up phase of prostatic cancer's treatment. This chapter zooms in and analyses the procedure of performing a finger puncture and defines its subactions. Market research is done for each separate action to find solution that are present and available in current market. This overview gives an understanding of solutions that exist and will be both informative and inspirational for the development of the future blood collection device.

This analysis focuses on devices for blood collection related to the finger puncture. Medical devices that are related to venipuncture are not taken into account.
The finger puncture home collection of blood can generally speaking be divided in different sub-actions (figure 29):

- Creating a sterile sample environment in which the finger is cleaned and prepared for sampling.
- Puncture an opening in the finger which enables the blood to be sampled.
- Stimulating blood flow
- Collecting the blood in a medium that conserves the sample until analysis.
- Transport from sampling location towards the hospital in which the analysis takes place.

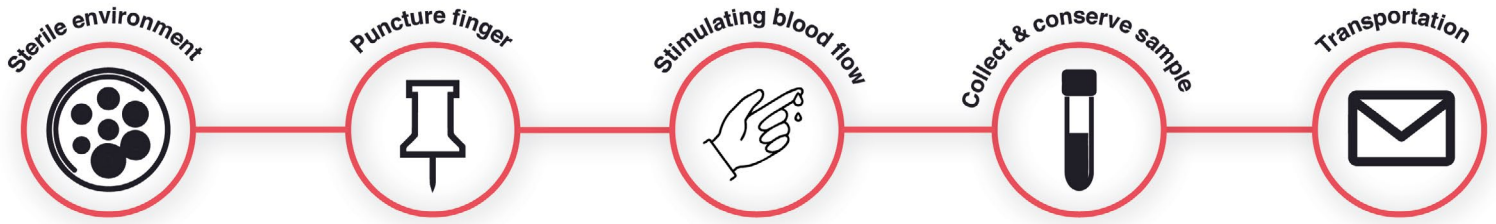


Figure 29 - Sub-actions of finger puncture blood sampling at home

First an overview is made from different types of existing PSA home sampling kits that integrate all steps described in latter text. Then medical products related to the other subactions are explored.

PSA test

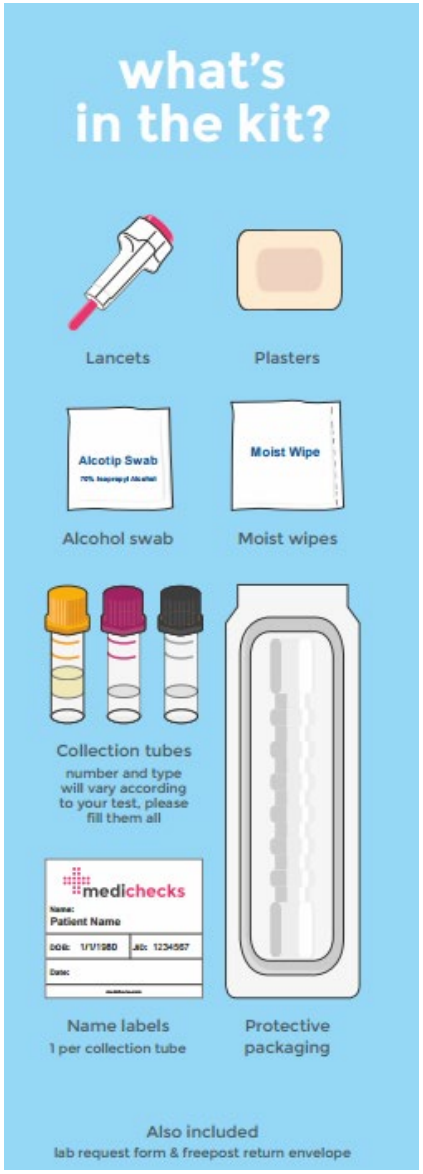
Two types of PSA tests can be found, namely point-of-care tests and PSA tests in which the blood samples are being analysed in medical facilities.

PSA test (analysis in medical facility

This test contains sterilizing equipment, multiple lancets to puncture the finger, containers to store the blood samples, labels to document the samples and instructions on how to go through the sampling procedure. Also protective packaging is provided to transport the sample to a medical test facility (figure 30), (figure 31). Another PSA test has been reviewed as well (The Doctors Laboratory Limited, 2017). This developer offers an instruction video to the patient to help him through the process. The example test kits contain a lot of different components that are needed to complete the PSA test. The blood collection is done by gravity-flow in which the blood drips from the finger into the sample container.
NKI-AVL has experimented with this type of collection but found this technique not sufficient as it requires accurate motorics from the patient, which is not always feasible considering the target

group. Another PSA test (figure 32) follows the same principles as the others, except for the blood collection/storage part. The patient drips blood on a paper filter medium and sends it back for analysis. The first three tests make use of stabilizing liquid that is pre delivered in a blood collection container. The patient's blood is mixed with a stabilizing liquid for two reasons: To protect the blood during travel towards the medical facility and to make the total volume of the sample bigger to make the analysis possible. The test in figure 32 does not make use of a stabilizing liquid. However, the paper filter with the dry blood sample is mixed with a liquid inside the hospital to absorb the blood from its medium.
Both cases described, lead to diluted PSA samples. Diluted samples contain a smaller serum fraction than samples that have not been diluted. A smaller serum fraction within the sample results in less accurate PSA measurements.
NKI-AVL wants to perform an analysis based on the hemolysate of the blood sample, which prevents dilution due to the fact that all the whole bloods components are used during the analysis.
Compromising in test sensitivity is something that is not desired by NKI-AVL.

Figure 32 - PSA home test with filter paper (Mijnlabtest, 2017) ▲



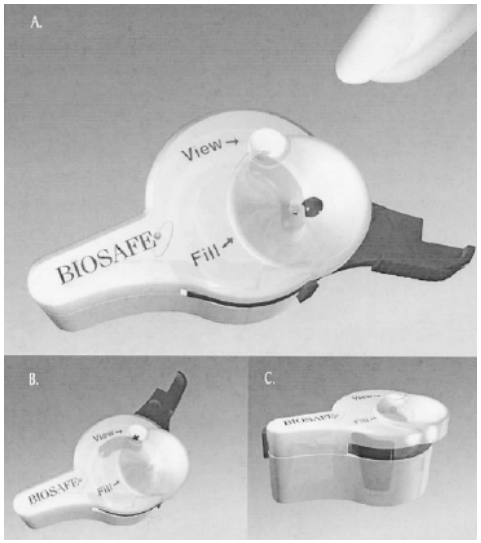


Figure 31 - Biosafe collection kit (Biosafe, 2002) ▲

◄

Figure 30- PSA test kit from Medichecks (Medichecks, 2017)

"Point of care tests are not sensitive enough for NKI-AVL"

"NKI-AVL doesn't want to compromise in test sensitivity"

"The device should have a safety system that prevents needle stick injuries"

Point-of-care PSA test

These type of PSA test are offered by a lot of different companies on the internet. The idea of point-of-care PSA tests sounds quite promising. You could test and measure the results in minutes without being dependable on others (figure 33). The patient pierces himself with a lancet and drips a few drops of blood in the opening of the device. Indication marks on the device communicate the PSA presence and level to the patient.
An evaluation was made of the analytical abilities of such devices (Karim, 2007). The same level of sensitivity on low PSA measurements as laboratory test could not be achieved, which make them not that useful as a follow up test to monitor the development of PSA.

Figure 33 - PSA home test (Karim, 2007)

Sterile sample environment

The patient must first make sure that his hands are sterile to avoid contamination of the blood sample. An easy way to sterilize the hand is with an alcohol swab

Puncture for an opening

Lancets

Lancets are the most common tools to puncture the skin in order to sample blood from the patient. Lancets are devices that press a sharp tiny blade into the skin (figure 34). These devices are standard equipment for finger blood sampling and are sold in different appearances in which the working principle stays the same. NKI-AVL uses lancets with varying blade depths. Patients with a lot of callus on the finger require a blade that punctures deeper than an old patient with thin skin. Most lancets have an integrated safety system in which the needle is only exposed once, when the button is pressed. This way needlestick injuries can be prevented during usage. It is estimated that annually 25000 needlestick injuries take place in the Netherlands from which 85 % take place within the healthcare sector (RIVM, 2008). An American study shows that the finger prick is listed as 3th major cause of needlestick injuries within non-hospital care settings (figure 35). It is important to take this type of injury into account during the development of the blood collection device. The injury can both apply to the patients as the caregiver.

Figure 34 - Lancet (Sarstedt, 2014)

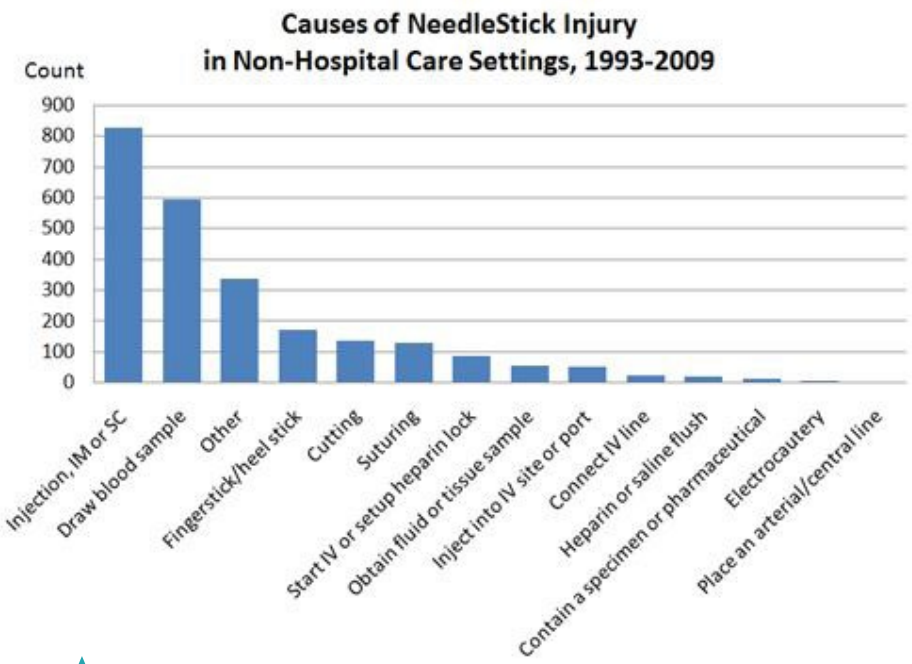


Figure 35 - Causes of needlestick injury in non-hospital care settings in 1993-2009 with 2638 respondents (International Healthcare Worker Safety Center, 2012)

Stimulate blood flow

A patient's slow blood flow can have multiple causes. For example, the hematocrit value can be high or he has cold hands, it is recommended to stimulate the blood flow of the patient. It can be hard to extract 200 micro liter blood from a finger puncture. Blood flow stimulation can be done in various ways.

Warm water

Placing the (cold) hands in warm water is often used by professionals and home tests to stimulate the patient's blood flow.

Pressure

Extra blood can be extracted when an underpressure around the punctured finger is created. Several tools in the market are able to create such a pressure (figure 36). The tool can also be used to draw blood from other (less easily bleeding areas) on the human body.

Figure 36 - EZ-Vac (Diabetes in control, 2014)

Collect & conserve sample

The blood needs to be collected after a puncture is made in the finger. This has to be done in a sterile and secure way. Puncturing the skin releases thromboplastin, which activates the process of coagulation, which is something to take into account when designing a collection device. Contamination with other materials than the blood sample is also unwanted as it can affect the quality of the test.

Capillary blood collection

Capillary action is an effective way to transport blood from the finger to the container. Most capillary blood collectors are sprayed with an anticoagulant to prevent coagulation of the blood during collection and storage. When the container is filled with blood, the capillary tube is removed from the container and the bottom lid is removed and placed on top of the container to secure the blood sample (figure 37).

"Pressure can damage cells during blood sampling, which is a reason that this method is not often used. However, damaged cells are not a problem for the new system as the cells in hemolysed samples will be damaged anyway "

Figure 38 - Capillary collector (Safe-Tec, 2016)

Figure 37- Capillary blood collector (Sarstedt, 2014)

Figure 38 shows a variation on the capillary collection tube. This tube draws blood by capillary action. The user is able to remove the blood within the dead volume of the tube by squeezing the upper reservoir.

Gravity-flow blood collection

This is the most straightforward method to collect blood. The user has to hold the tube against the finger to collect the blood after the finger has been punctured (figure 39). The upper part of the container is often scoop-shaped to make the collection easier.

Figure 39 - Gravity flow blood collector (Sarstedt, 2014)

Novel solutions

The market also offers solutions that are not commercially available yet. The Hemolink (figure 40) is such a device with a new blood collection technique that could be used in the near future. The device does not puncture the body but it creates such an under pressure on the skin that it enables the blood to travel through the skin right into the collector.

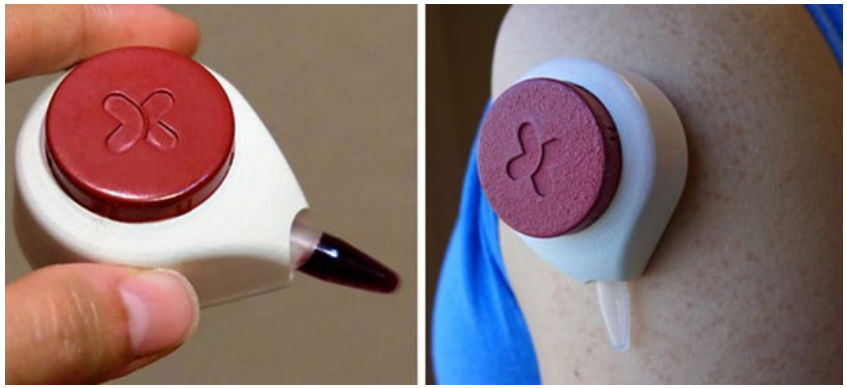


Figure 40 - Hemolink (Newatlas, 2015)

Theranos is a controversial American pharmaceutical developer that became famous for its nanotainer, which is a collection container that measures slightly more than 1 cm. These containers can be filled by pressing the containers into a device that collects blood by capillary action (figure 41). The nanotainer is criticized for its quality in blood sample measurements (J.Belluz, 2015)

Figure 41 - Nanotainer and collection device (Pharmaphorum, 2016)

Transportation

After a blood sample is collected and stored in a container, it must be send to the medical facility in which it is analyzed. It is important to stabilize the sample in order to prevent cellular debris, to maintain the samples quality and to prevent contamination. It is desirable to transport the sample as quick as possible from the sample location to the medical facility. The packaging of in-vitro-diagnostica needs to be in line with the regulations described in UN 650 (IATA, 2015).

Comparison

A state of the art PSA test kit is used during a user observation to find out how users interact with the system. During this sessions, product-user interactions are observed and discussed with the users which will be relevant when designing the blood collection device. (Appendix K).

"The Theranos collection device is a good example of a product that embodies easy blood collection and storage in an integrated way"

- *Point of care test kits are not accurate and ergonomic to the user. The future blood collection device can make a difference here.*
- *The blood collection device needs to make use of a lancet in order to make the puncture due to the complexity of hygiene and needle stick accidents.*
- *Pressure, capillary action and gravity are the available methods to collect the blood sample. The blood collection device should make use of one or multiple of these methods as collection method.*
- *Novel solutions seem too far fetched for the blood collection device as they have not been validated.*

This chapter gave insights in state of the art medical devices related to finger puncture blood collection. Above described design implications have been added to the list of requirements (Appendix M).

2.6 Extended user scenario

A better understanding is created of the context in which the blood collection device will function, the stakeholders that are involved, possible sample techniques that can be used and about the user of the device. An extended user scenario is created that integrates this knowledge and insights from latter analyses in order to map what problems can be expected during usage of this future device and what solutions might solve these problems. These solutions are translated to product requirements.

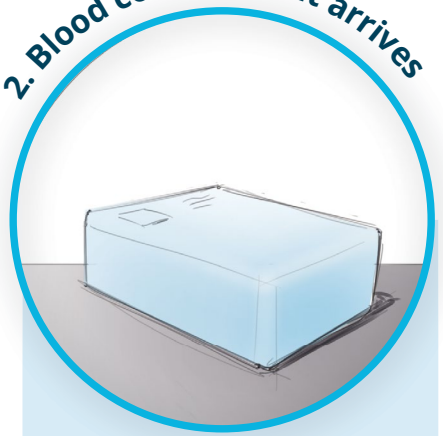
The procedure of blood collection is divided in 12 steps. Each step describes the specific action, problems and possible solutions.

- 1. Action
- 2. Possible problems within action
- 3. Possible solution

1. Call from urologist

- Urologist tells patient that his PSA level needs to be measured.
- Patient can forget about the doctors call. Critical information should not be discussed here. Time between call and PSA sampling is too long
- Patient does not answer the phone.
- Make sure that the patient receives his test kit automatically after the call
- Call should only be an announcement of the “already” send sampling package.

2. Blood collection kit arrives



- Package arrives by mail. Patient picks it up and leaves it on the table.
- Patient stores package somewhere and forgets about it.
- Patient lack human interaction and needs to be motivated to collect the sample
- Patient does not recognize the package as the PSA collection kit.
- Make in the appearence of the package clear that it is about PSA measurement.
- Set a deadline that the sample needs to be taken before a certain date.
- Make the appearence approachable and easy to use / understand.

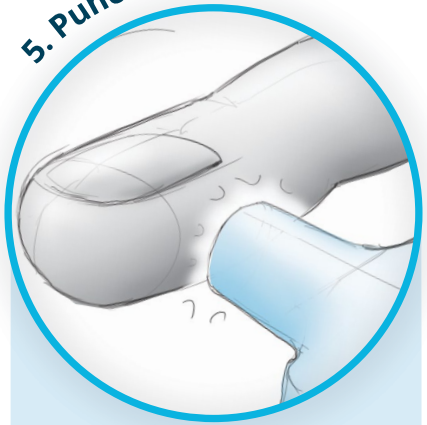
3. Collect information

- Patient opens package and is able to understand how the sampling procedure is executed.
- Patient is unable to understand the procedure.
- A critical step is misunderstood.
- Patient is analfabetic
- Patient feels insecure / incompetent.
- Patient is not able to read in Dutch / English
- Use icons instead of text. Keep it visual
- Product design is easy / minimalistic
- Integrate animation / clip in which a doctor explains the process.

4. Prepare finger for puncture

- Patient holds finger under warm water and sterilizes finger
- Patient washes with cold water instead of warm water.
- Patient wipes wrong finger for sterilization.
- Patient waits too long between warm water and the puncture.
- Make very clear that the water needs to be warm. Quantify “needs to be 40 degrees”.
- Add multiple sterilization wipes.
- Description should make clear that the finger needs to be punctured direct after the warm water.

5. Puncture finger

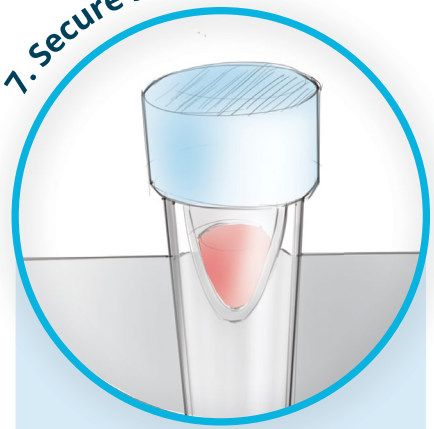


- A small needle punctures an opening for blood flow by pressing a button.
- The patient punctures the wrong part of the finger
- The patient hold the lancet not in the right orientation which results in a bad puncture.
- Clear indication in manual what the puncture location should be.
- No other possible way of puncturing. The dimensions of the design guide the patient towards the right puncture location.
- only one orientation is possible because of design dimensions

6. Collect bood and create blood flow

- Patient both pressures the finger and collects blood at the same time.
- Patient is unable to perform both motorics at the same time.
- Patient spills blood and makes a mess due to too many required motorics.
- collection container falls over.
- Patient is unable to collect blood due to tremor.
- Patient is not quick enough in sampling of the blood which results in coagulation of blood.
- Patient is not able to sample enough blood due to too small puncture.
- Make sure that one hand is free during sampling.
- Make collection container stable.
- Make blood collection inlet big like a funnel.
- Make sure that an anti coagulant is used as an impregnation to prevent coagulation.
- Make sure that multiple punctures can be made when desired (without losing track of hygene).

7. Secure sample



- Patient secures sample and makes sure that it is ready to send by mail.
- Patient doesn't close sample in the right way, which makes it leak.
- Sample gets contaminated with environment while closing.
- It should not be possible to close the sample in a wrong way.
- The design of the container should make sure that the user can not touch the inner part in which the sample is stored.
- The design should make sure that no foreign materials are able to enter the blood sample.

8. Send sample by mail to NKI-AVL

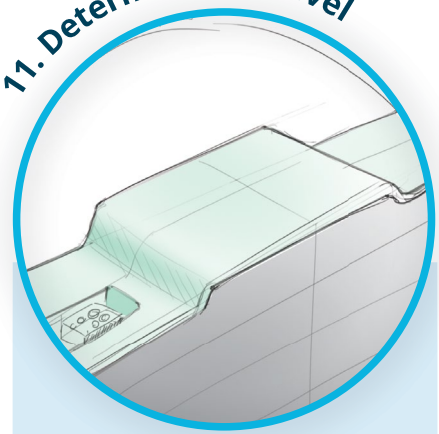
- Patient sends sample back to NKI-AVL.
- Patient posts package during the weekend which is bad for the sample quality.
- Possilble leakage could be harming for mail-distributors.
- Only use mail distributors that operate all days of the week.
- Explicitely inform the patient only to send the sample during working days.
- Use special biospecimen packages.

9. Hemolyse sample

- Samples arrive. Analysts place them in a refrigiator to hemolyse the sample.

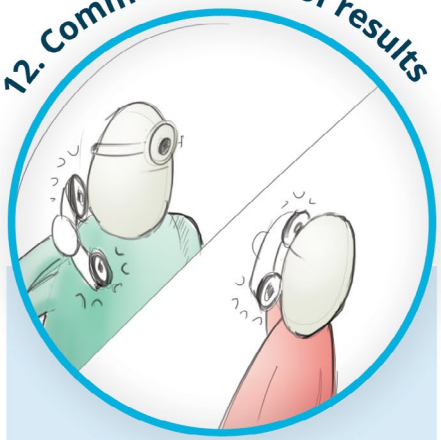
-

11. Determine PSA level



- Analyst places sample in a rack which is then placed inside the Cobas E-module chemical analyser.
- The blood samples do not fit within the rack of the analyser.
- The analyst takes of the lid and spills the blood sample.
- The sample dimensions fit the dimensions of the centrifuge.
- Lid design is done in such way that abrupt opening of the container cannot happen.

12. Communication of results



- Urologist checks results from analyser. Results are forwarded to the patient.
- Patient wants personal contact while PSA values are being discussed
- Urologist might not have the time to personally contact the patient.
- Make automated communication of results personal by service.

"it takes about 30 minutes of active time to perform a PSA test in the new situation."

The blue icons are a direct solution for the possible problems that might occur during the future procedure of blood collection. These solutions have been translated to requirements that can be found within the the list of requirements (Appendix M).

2.7 Design vision

This chapter gives an overview of challenges that originated during the analysis phase. A design vision is formulated and an introduction is given to the next phase of the project.

Challenges

All the research that is done can be confined to several challenges that will be formulated in this chapter. Each challenge can potentially be solved with solutions that will be presented during the conceptualization phase of the project. These challenges together are the workable list of requirements. For the full list of requirements see appendix M.

1. Create a non-invasive blood flow
In order to collect the blood sample for a hemolyzed analysis, it is needed to take at least 200 µl blood from the patient's body. The challenge is to collect this blood sample in a way that is as quick, non-invasive and painless as possible.

2. Collection of 200 µl blood
It is needed to collect at least 200 µl blood in order to perform a PSA analysis for the hemolyzed sample. The challenge is to collect the blood in a way that is as fast and easy as possible. The time limit has to do with coagulation of blood. It is important to make this task motorically easy as the user groups motorics are deteriorated due to age.

3. Ergonomics and usability fit the user
This challenge is partly overlapping with latter described challenges. The general way of creating a non-invasive blood flow and the collection of blood need to fit the users ergonomics while being easy to perform in terms of motorics and cognition.

4. Conservation of 200 µl blood
When the blood has been collected, it needs to be stored in a medium in order to be transported towards NKI-AVL. The challenge is to maintain the blood's quality while being contained and transported. This means that the blood needs to be contained in a sterile way with zero chance for contamination. It must not coagulate and it is preferred that the cells remain undamaged.

5. Integration
It is preferred to come up with a design that integrates the creation of a non-invasive blood flow, the collection and the conservation of blood in one design. This eliminates the difficulty of all procedural steps that are currently needed in order to sample blood.

6. Design integrated with NKI-AVL chemical analyser
The dimensions of the blood collection device need to fit the dimensions of the chemical analyser within NKI-AVL and preferably also similar analysers that are located at in different clinical laboratories.

Vision

My design vision is the following:

"Design a blood collection device that is adjusted to the ergonomics of the user while being compatible with the chemical analyser at NKI-AVL. The use of the device should give the user the same amount of trust as is experienced within the hospital. Bring the trust that is experienced within the hospital to the patients home"

What is next

Conceptualization phase

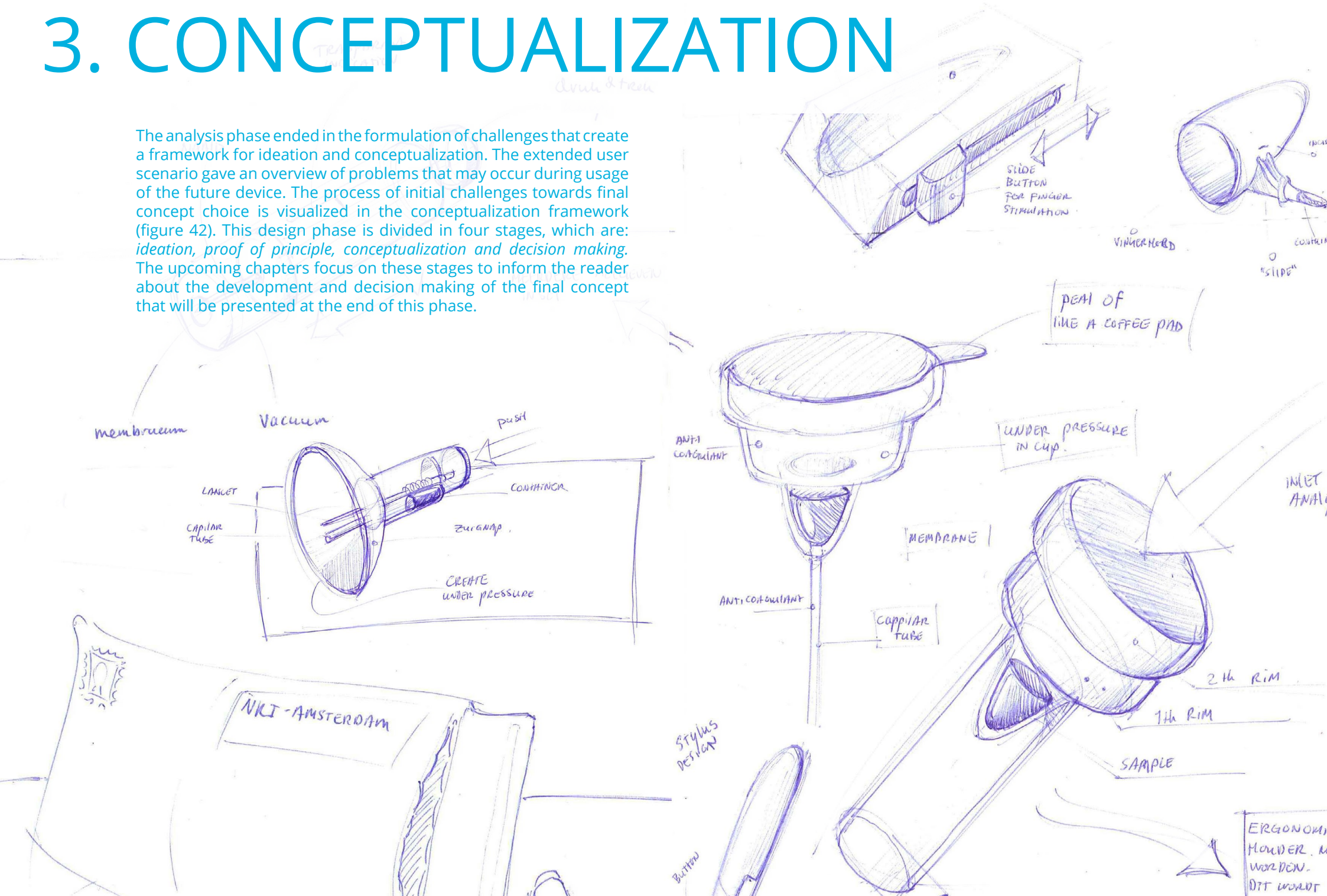
This report led to the formulation of various wishes and requirements that will be used as a guideline during the conceptualization phase. The conceptualization phase will end in the creation of a few concepts that fit the vision and meet up to the challenges that are described in this chapter.

Summary of the analysis phase

- *Description of assignment*
- *Stakeholder analysis*
- *User analysis*
- *Journey of PSA analysis*
- *Market research*
- *Extended user scenario*
- *Design vision*

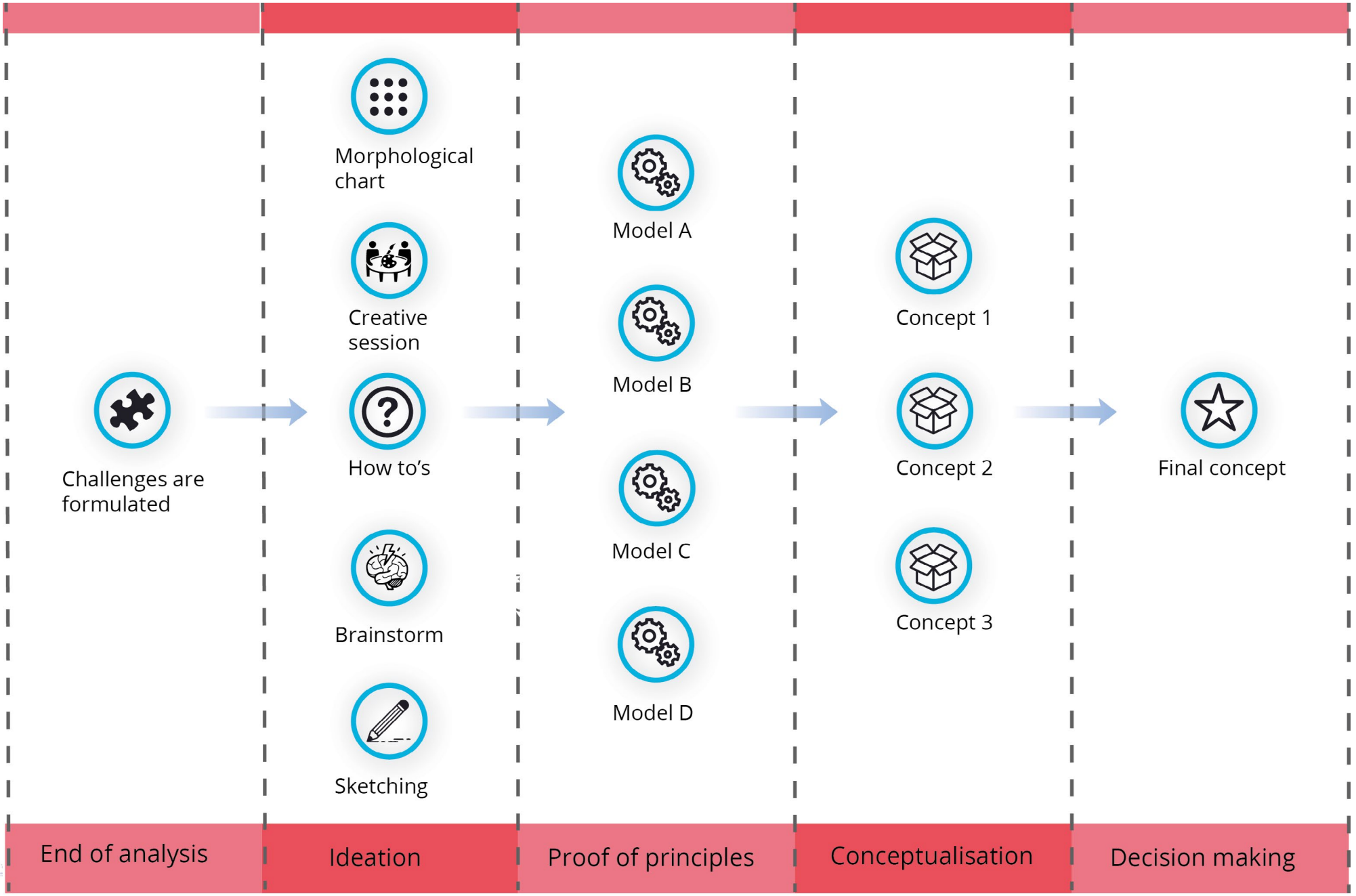
3. CONCEPTUALIZATION

The analysis phase ended in the formulation of challenges that create a framework for ideation and conceptualization. The extended user scenario gave an overview of problems that may occur during usage of the future device. The process of initial challenges towards final concept choice is visualized in the conceptualization framework (figure 42). This design phase is divided in four stages, which are: *ideation, proof of principle, conceptualization and decision making.* The upcoming chapters focus on these stages to inform the reader about the development and decision making of the final concept that will be presented at the end of this phase.



Framework conceptualization phase

Figure 42 - Framework conceptualization phase



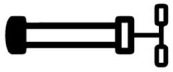
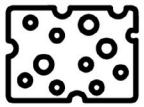
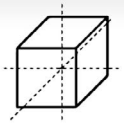
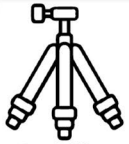
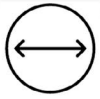
3.1 Morphological chart

A morphological chart is a tool that gives an overview of different problems that should be solved by the future design (van Boeijen, 2014) . Possible solutions are mapped for these problems. Concepts will be constructed by combining different solutions from different sub problems.

The analysis report ended with an overview of challenges that need to be taken into consideration during the ideation phase. These challenges are used within a morphological chart to find out possible solutions. The following 5 challenges are described and placed in a morphological chart (figure 43):

- **How to create a non-invasive blood flow?**
- **How to transport blood from puncture to container**
- **How to integrate the device with equipment at NKI-AVL?**
- **How to avoid spilling blood?**
- **How to make the dead volume of the collection container as small as possible?**

These five challenges are obviously not the only points of consideration. This selection contains the major challenges that need to be solved and are therefore used as guideline for ideation.

Problems	A	B	C	D	E	F	G
1 How to create a non-invasive blood flow?	 Warm water	 Pushing					
2 How to transport blood from puncture to container?	 Gravity flow	 Capillar action	 Under pressure	 Sponge	 Micro needle	 Like Lamprey fish	 Like mosquito
3 How to integrate the device with equipment at NKI-AVL?	 Adjust design to dimensions	 Design additional equipment					
4 How to avoid spilling blood?	 Stability	 Container attached to finger	 Funnel shaped inlet of contrainer				
5 How to make "dead volume as small as possible?	 Small diameter of container	 cone shaped container					

▲ *Figure 43 - Morphological chart*

The possible solution within the morphological chart will be briefly described in this chapter:

1A - Warm water
The blood flow increases highly when the patient places his hands in warm water. This is a widely used technique before performing a finger puncture to start the blood flowing to the fingers.

1B - Pushing
When a puncture in the finger is made, the blood does not always flow out. Pushing movements from the finger up till the puncture stimulate blood flow.

2A - Gravity flow
In this technique that is also described in chapter 5, the patient drops the blood in a container by means of gravity. It is the most straightforward way of collecting blood.

2B - Capillary action
This technique uses capillary action to transport blood from the puncture towards the container. This technique can also be seen within plants when they transport water up their vessels.

2C - Under pressure
Underpressure can "suck" the blood from the puncture towards the container. This could for example be done by releasing vacuum, but also via inhalation through the mouth.

2D - Sponge
The working principle of a sponge is basically a capillary network that traps liquid inside the medium. This network of capillaries could be used to "suck up" and contain blood. The question arises however how to release the blood from the sponge after it has been absorbed.

2E - Micro needle (figure 44)
This is a new technique in which the needle is very small in diameter which means that the patient feels almost nothing from the puncture. Multiple micro needles are used at ones to be able to be functional. However, this technique is still rather expensive which makes application for single use purposes doubtful.

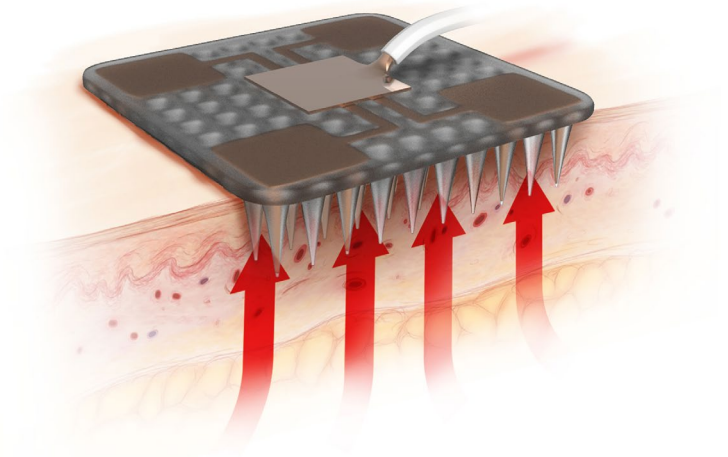


Figure 44 - Multiple microneedles at work (UCD Medical Device Design Group, 2015)

2F - Lamprey fish (figure 45)
Also called the vampire fish, lives from the blood of other animals. The mouth of the fish functions as sucking cup and attaches itself to the victim by underpressure. An array of sharp teeth penetrate the skin and the underpressure makes sure that the blood flows inside the Lamprey fish. An efficient way of collecting blood. However, not directly applicable to the blood collection device as the victim often not survives a visit from this predator.

Figure 45 - Lamprey fish (State of Michigan, 2017)

2G - Mosquito (figure 46)
Mosquitos have the ability to collect blood with the aid of a very small sting. The sting is flexible and can move around cells to find that small vein which the mosquito likes to drain. Humans are not able to feel the sting of a mosquito, the itchiness that is experienced after a bite is a result of the anticoagulant that is injected to prevent the blood from solidification. Flexible micro needles still seem a bit far fetched but are interesting to keep in mind as nature already invented the perfect way to collect blood in a painless way.

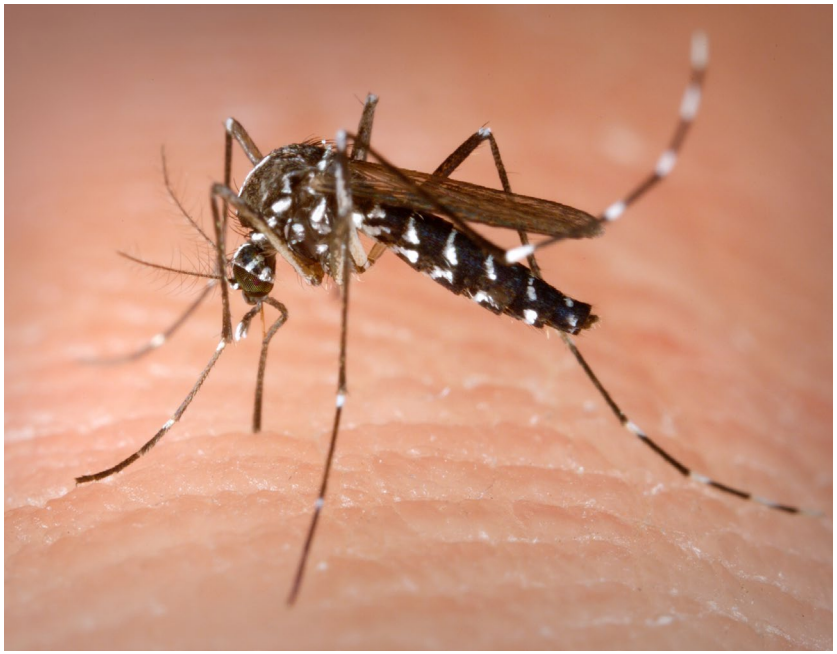


Figure 46 - Mosquito (State of Victoria, 2017)

3A - Adjust design to dimensions
In order to integrate the device with equipment at NKI-AVL, the dimensions of the concept can be adjusted to the design of the equipment such as the centrifuge and the chemical analyser.

3B - Design additional equipment
An alternative solution could be the additional design of equipment in which makes the concept compatible with equipment of NKI-AVL such as the centrifuge and the chemical analyser.

4A - Stability
Stability of the collection device would diminish the chance of spilling blood during the collection process as the container with blood is less likely to fall over.

4B - Container attached to finger
It is difficult to spill blood when the collection container is directly attached to the finger as the blood can only flow in the direction of the collection container. All movements are possible during the collection without spilling blood.

4C - Funnel shaped inlet of container
Making the diameter of the inlet bigger will result in a bigger “target” to aim on during the collection of blood. The bigger the inlet, the easier the aiming will be, especially taken in mind that tremor occurs by some users.

5A - Small diameter of container
The smaller the diameter of the container, the smaller the dead volume of the blood sample will be. An optimum should be found in this dimension as the chemical analyser cannot handle too small diameters due to interference of emitted electromagnetic pulses during detection of the blood sample.

5B - Cone shaped container
A cone shape results in a lower dead volume as the lower part of the container becomes small. It should be examined what the optimal cone slope would be for the smallest dead volume while the analyser remains operational.

- *Solutions indicated in challenges 2 & 4 need exploring in order to be able to implement in a concept proposal. The other solutions seem straightforward and could therefore be implemented right away.*

- *Biomimicry seems promising as nature has developed the most efficient way to draw blood from its host. However, natures method in blood drawing is rather invasive for the host which makes imitation of these techniques impossible or very expensive (micro needles).*

3.2 Creative session

A creative session is a organized in order to come up with various creative ideas, generated by a lot of different people and perspectives. The session starts with a problem statements that is given by the problem owner, which is in this case NKI-AVL . The purpose of the session is to come up with ideas and provide solutions for the problem owner in order to solve the given problem. The facilitator uses various type of creative methods to trigger creativity within the group.

Two creative sessions have been organized within the faculty of Industrial design engineering. The facilitating has been outsourced by two facilitators that both lead a research group of eight students (figure 47). The facilitators have been briefed in order to inform them about the problem (Appendix N). The focus within the project was rather technical and practical until now, which is the reason to focus more on the emotional aspects of the development of the blood collection device that is also described in the design vision. The creative session focuses on trust and confidence. The problem statements that were given to the research group are the following:

"How to create trust/confidence within patients during home sampling for a PSA test?"

"How to bring the feeling of trust/confidence that is experienced during blood sampling in the hospital to the patients' home"

The main conclusion was that trust and confidence should be integrated in the whole journey/user scenario. Possible solutions are:

1. Inviting the patients to the hospital to do the first blood sampling together in a type of class, where a doctor is available to give instructions and introduce you to the kit.

2. Involve people around you so they can help you plan and perform the sampling. Make it something in which relatives can be involved and help out. This also increases the confidence and trust in the home environment.

3. Respect the importance of testing but present it as a simple routine. Make the kit look professional but still simple, let it stepwise speak for itself and prevent any distractions.

4. Make the blood sampling kit personal. Give it the experience like the different components were specially selected for you. This could be done by putting your name on it, or have a message in it from your doctor or nurse. Maybe you could also personalise it or select one kit from different options etc.

5. Give visual indication and direct feedback on the device. Show by colour indication if the blood is right and give a signal when enough blood has been drawn. (Might be good to make it a closed system where blood is not visible or should be measured by the patient themselves)

6. Hand it in personally at package counter when sending it. The aftercare of the package is also a part of the trust and confidence. You are sending a piece of you into the mailbox and you want it to be safe. Also the use of a track and trace code would work, or a confirmation when arrived at the hospital.

- *The creative session led to interesting solutions and inspiration concerning the implementation of trust and confidence in the design of the blood collection device.*

Figure 47 - Impressions of creative sessions at TU Delft

3.3 How to's, brainstorms, sketching .

How to's, brainstorming and sketching are techniques that have been done simultaneously. Small brainstorm sessions where executed within NKI-AVL and at the faculty of industrial design engineering. Sketching was used to visualize ideas during these creative techniques.

Figure 48 shows a sketch that was a result of a How to brainstorm session about ways to avoid spilling blood. Figure 49 shows an example of explorative sketches throughout the ideation process. A full overview of sketches can be found in appendix Q.

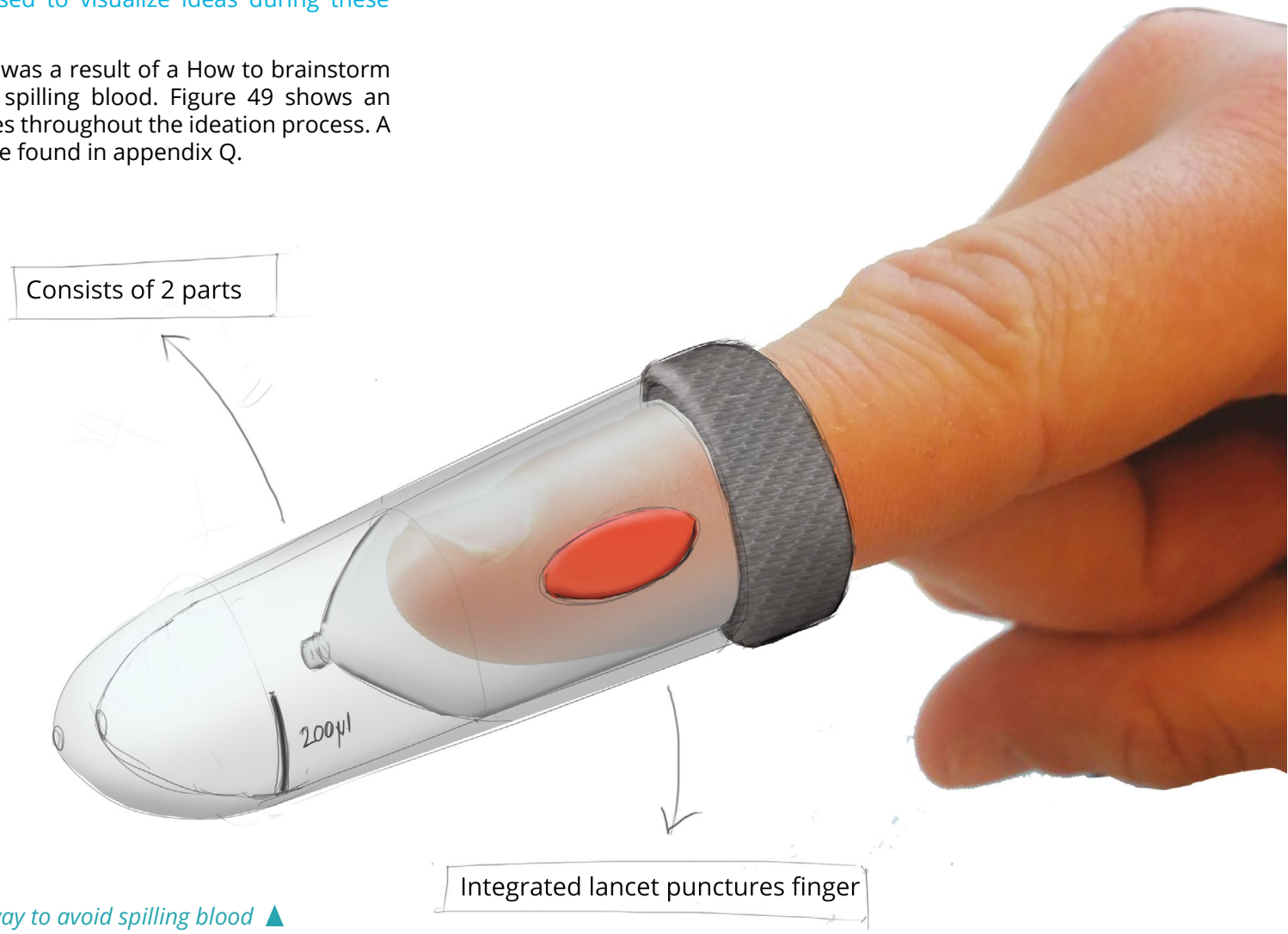


Figure 48 - Sketch of a possible way to avoid spilling blood ▲

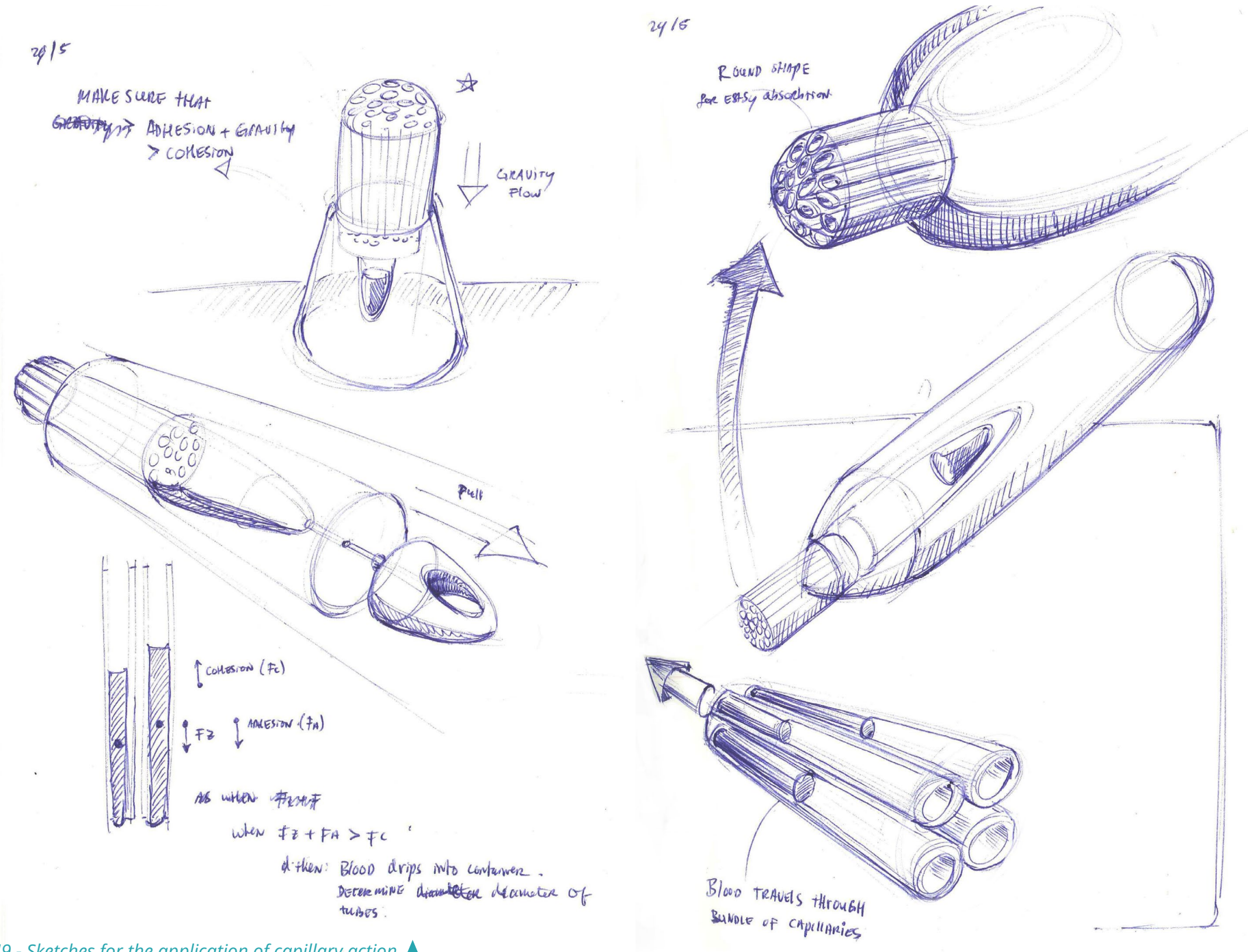


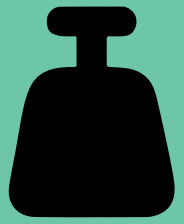
Figure 49 - Sketches for the application of capillary action ▲

3.4 Proof of principles

This chapter tests whether certain solutions that where proposed during the ideation phase are feasible and usable to integrate in a concept.

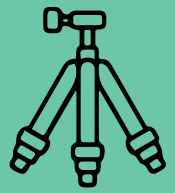
A selection of five principles is chosen from the ideation phase (figure 50). These solutions where seen as potentially successful. However, they were not proven to work for the blood collection device. The following principles are tested with the aid of models A,B,C,D. This chapter describes the tests that have been done for each model. The insights that have been gained during these tests will be used to validate which working principle(s) is the most promising and therefore suitable to integrate in concepts.

Gravity



Model A1
Model A2
Model A3

Stability



Model C1

Capillar action

Model A1
Model A2
Model A3

Model B1

Pressure

Model B1

Finger hat

Model D1
Model D2

Figure 50 - five principles that have been tested in this chapter

Capillary action & gravity test 1- model A1

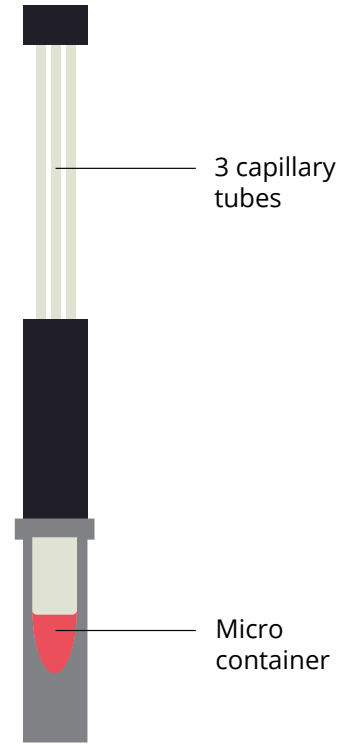
User uses the model to transport blood by capillary action.

The model consists of 3 capillary tubes that are held together by tape.

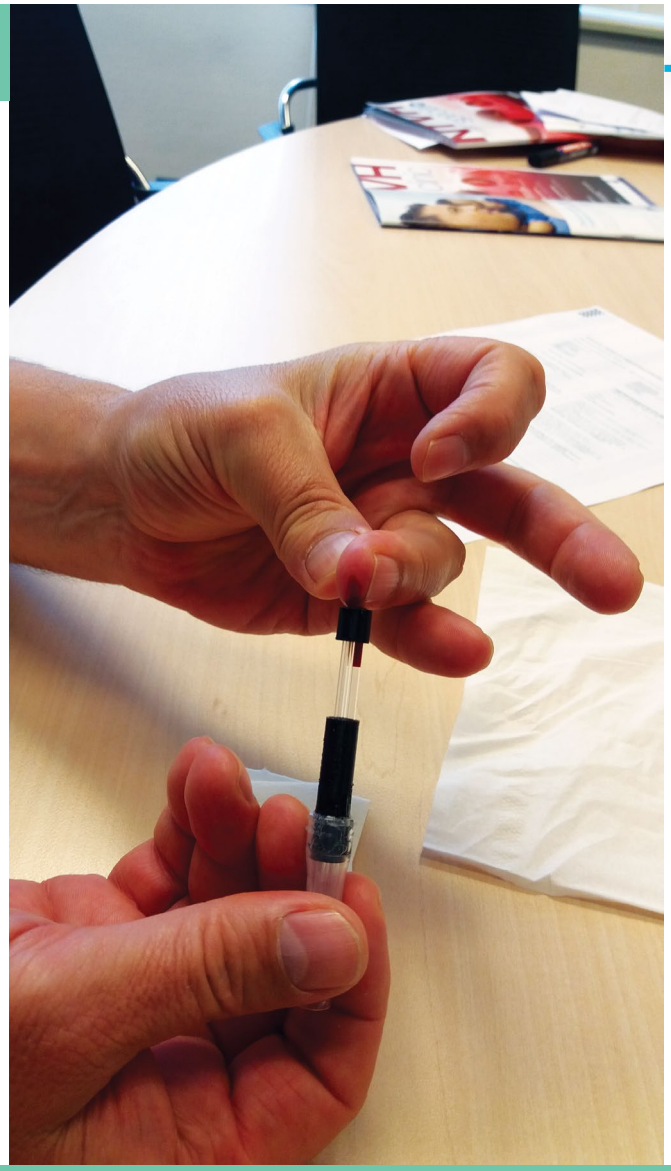
Insights:

- The tubes should be held closer together without space in between as this causes unwanted capillary forces which results in blood flow outside the tubes.
- The tubes should be closed at one of the sides after blood is collected to prevent the blood from flowing out.

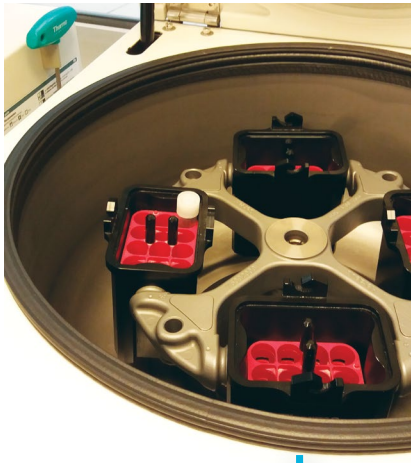
Capillary action & gravity - test 2 - model A2



Model A2

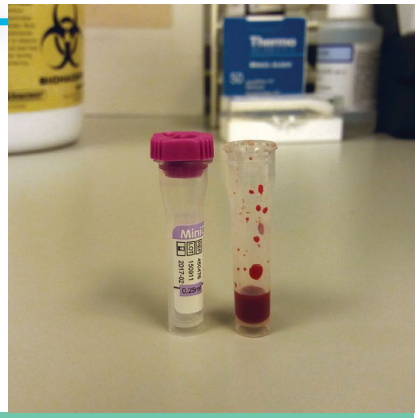


User collects blood by capillary action



Model is centrifuged with 10 G.

All blood is centrifuged in a microcontainer



Insights:

- The user uses two hands to sample the blood which makes pushing difficult.
- The centrifuge can be used to push the blood from the tubes inside the micro container.
- There is no clear feedback / indictation whether the user samples enough blood for a PSA test as the blood both is collected in the capillary tubes as in the micro container.
- Capillars are effecitive in transporting blood from the finger to another medium.
- An optimal diameter for the capillary tubes should be determined.

Capillary action & gravity - test 3 - model A3 (1)

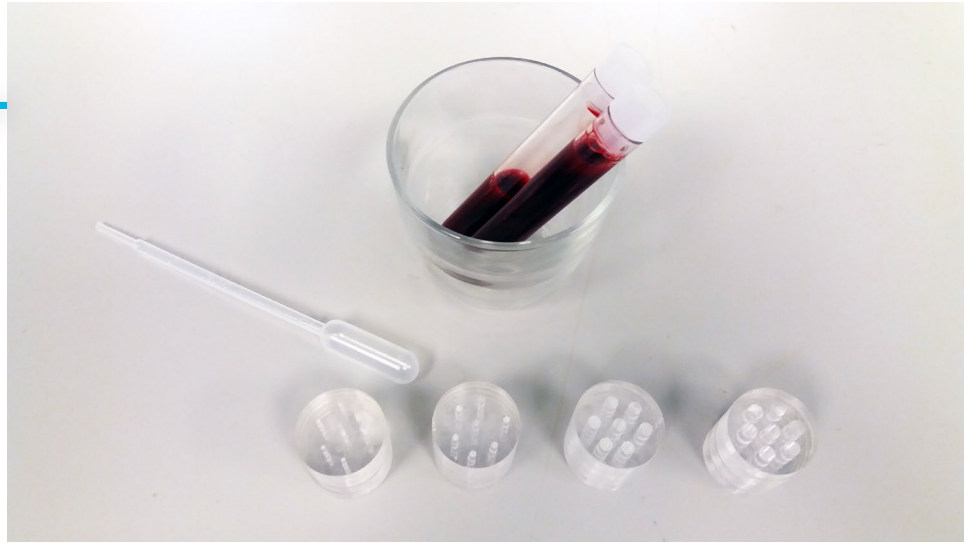
Model with capillary tubes (1mm)

Model with capillary tubes (2mm)

Model with capillary tubes (3mm)

Model with capillary tubes (4mm)

Test materials:
Four models with varying tube diameters are used in the test to find relations between capillary and gravitational behaviour.
Capillary forces are important to guide the blood sample from the finger into the tube.
Gravitational forces are important for the blood to leave the tube.

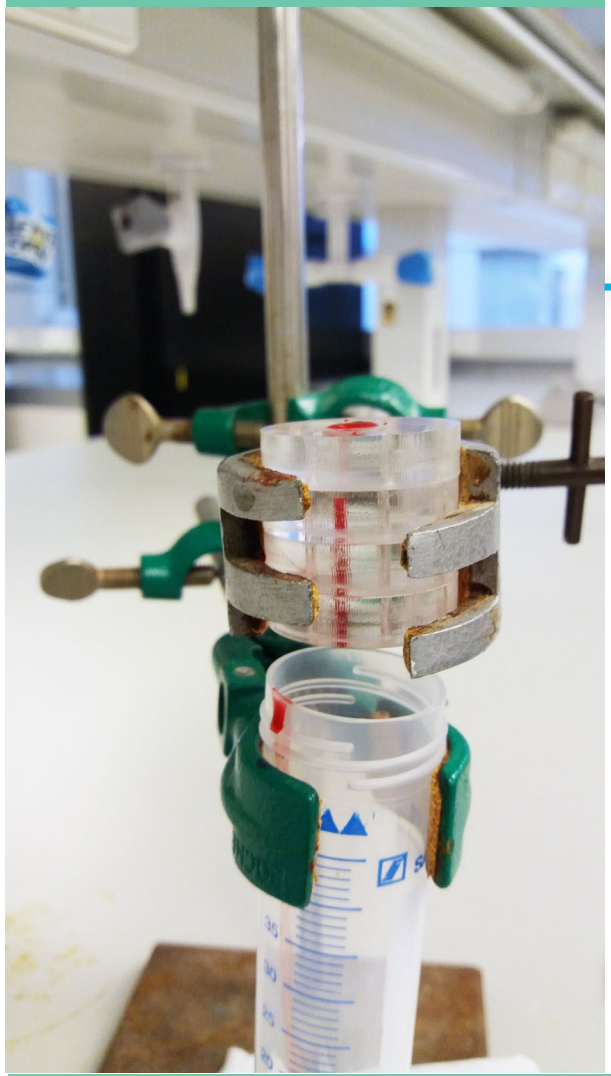


This setup is used to perform the test. A pipette is used to place the blood on the capillary tubes.

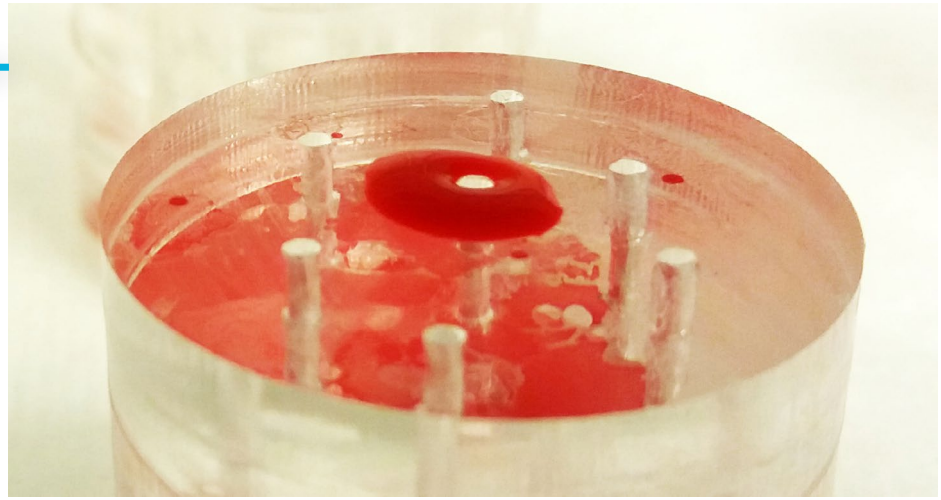
Insights:

- The smaller the diameter of the tube, the larger is the capillary force within this tube, however the harder it is for the blood to leave the tube due to limited gravitational forces. This observation sounds logical as capillarity is the product of adhesion, cohesion and gravity.

Capillary action & gravity - test 3 - model A3 (2)



Observation
The shape of the tube inlet resulted in a lot of surface tension and loss of blood sample.



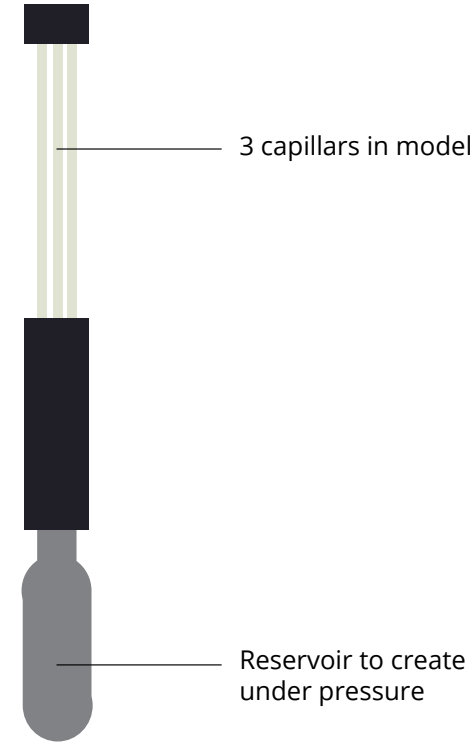
Blood is travelling through the capillary tubes into the container.

A second test is merely used to test capillary forces of the different diameters. The model is placed in a pool of blood to measure how high up the blood is able to travel against gravity.

Insights:

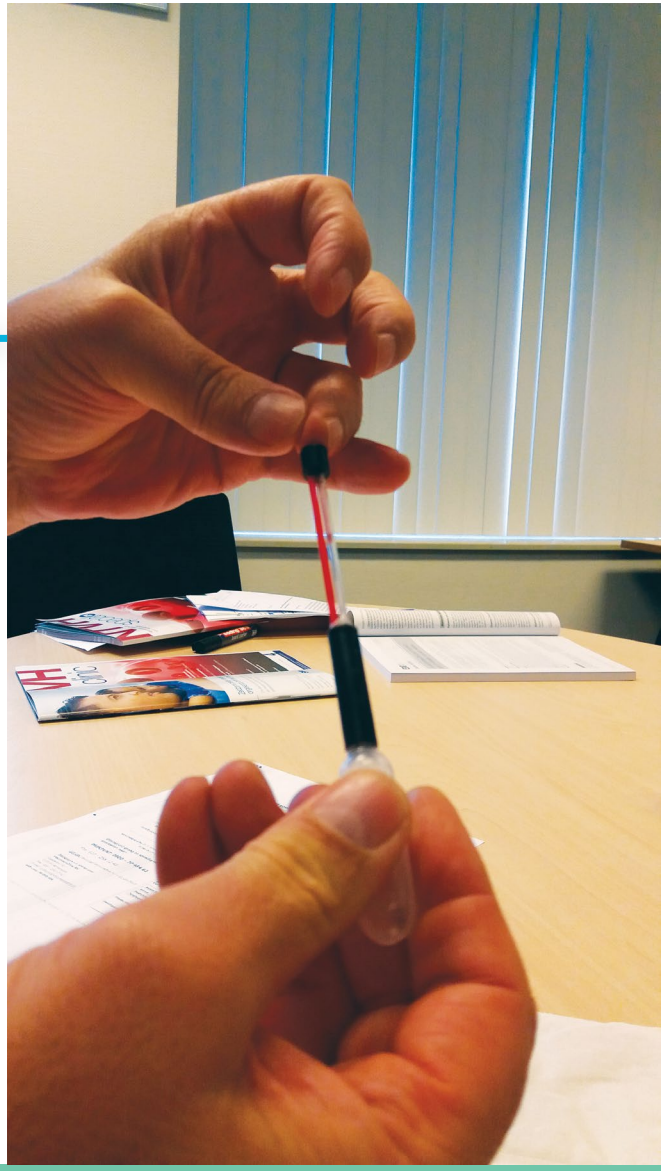
- The shape of the inlet and outlet of the capillary tube are important, as surface tension prevents the blood from entering and leaving the tubes. Adjusting the inlet/outlet shape could potentially be a solution.
- It was observed that the capillar forces within the center tube of the models worked the best in comparison with the other tubes. It is not clear yet what the reason is of this behaviour.
- Optimal dimensions of the capillar tube should be determined. It should be able guide the blood from the finger into the capillar tube and flow in the container as fast as possible while keeping the blood sample loss as small as possible.

Capillary action & underpressure - test 1 - model B1



Model B1

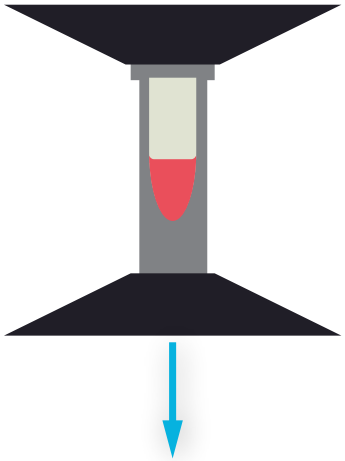
User presses the reservoir to create an underpressure that is used to transport the blood from the finger towards the capillary tubes.



Insights:

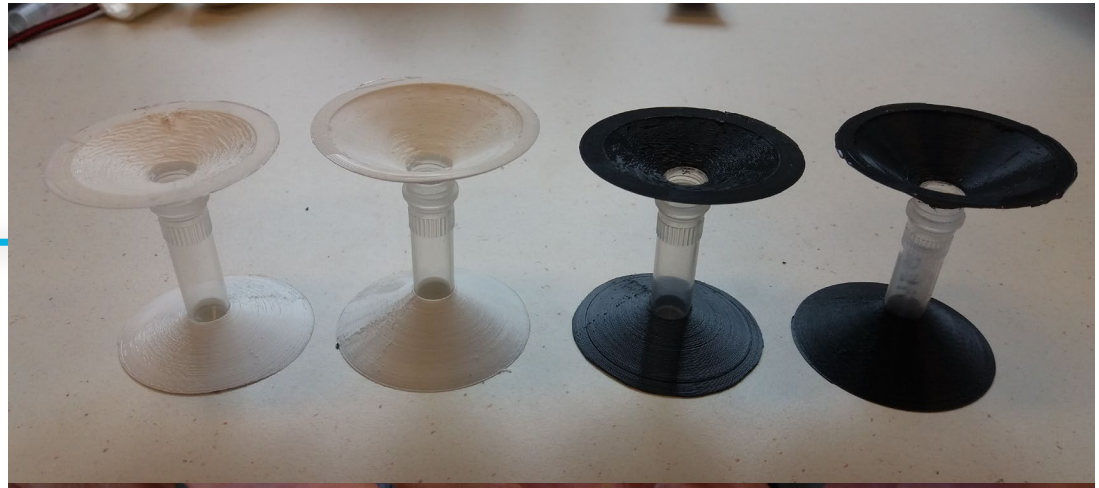
- The user used two hands to perform the sampling which makes it difficult to push the blood out the finger.
- The pressure can be used only onces. When blood is trapped in the capillar tubes, the user cannot squeeze the reservoir anymore as the blood will return its way back to the finger.
- The capillary action works effectively in transporting the blood from the finger to the capillary tube.

Stability - test 1 - model C1

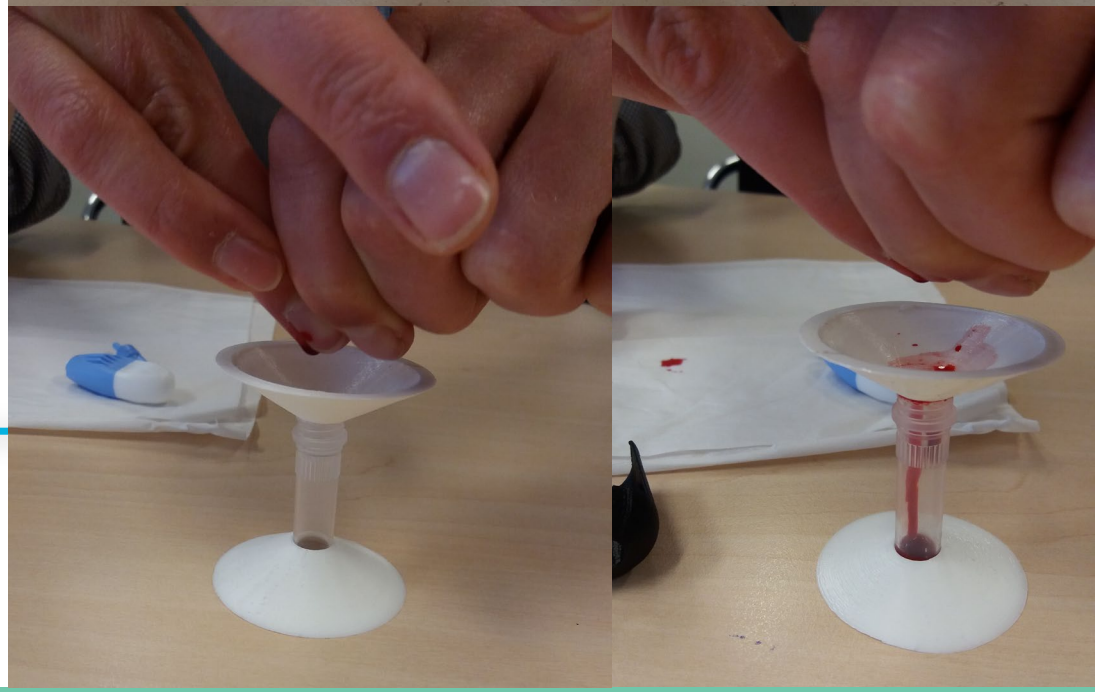


Stability model (C1) to test for stability and sample accuracy.

Two type of models are made with the funnel steepness as variable.



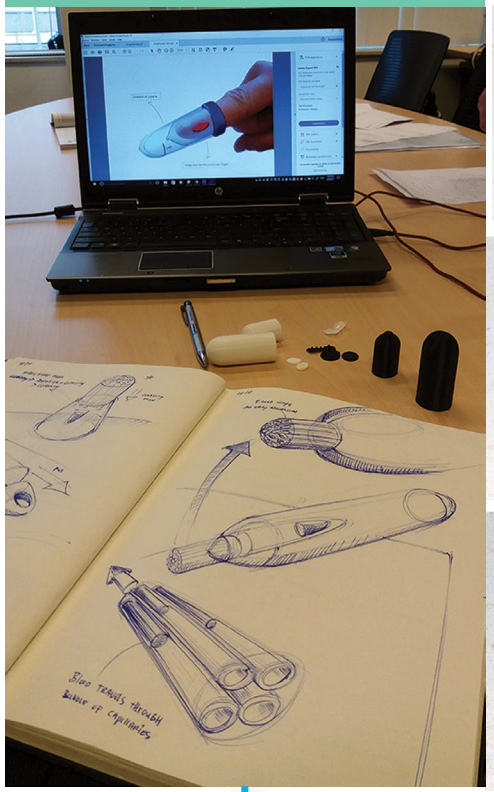
User uses both hands to push out blood samples within the model.



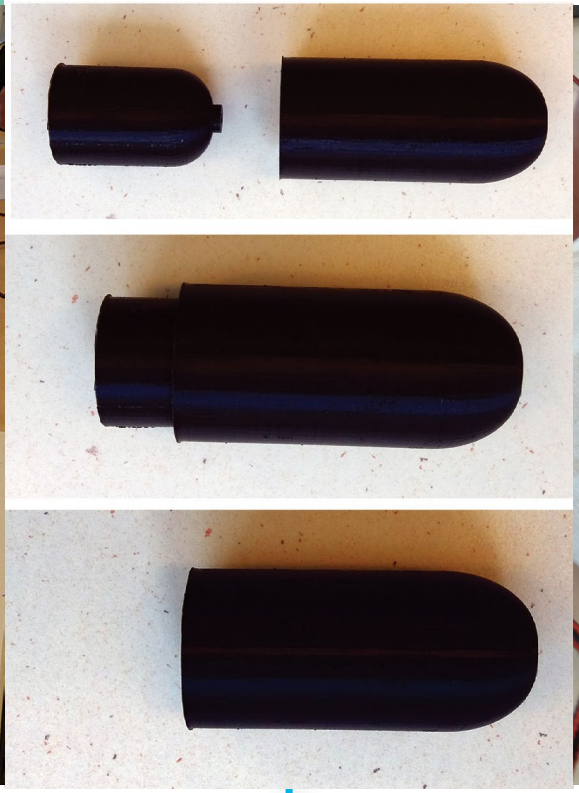
Insights:

- The stable basis makes sure that the user is able to use both hands during the sampling process.
- The steeper slope of the funnel is desirable to guide the blood towards the container.
- Blood does not drop easiliy from the finger due to high viscosity. It is recommended to guide the drop of blood inside the container.
- The user was able to fill the container with blood, it took some effort though to transport the blood from the finger tip towards the container.

Finger hat - test 1 - model D1



Testing finger hat principle



Model of finger hat. Two models are present; a white and black one.

User punctures himself and places the finger in the finger hat.

The result of the user test when the user takes out his finger.

Insights:

- Pushing for blood flow should be done on the finger tip. Pushing lower than that does not work.
- The outlet of the model was too small for the blood to go out
- The space between the model and the finger causes capillary forces which prevented the blood from flowing in the desired direction.

Finger hat - test 2 - model D2

Micro container.

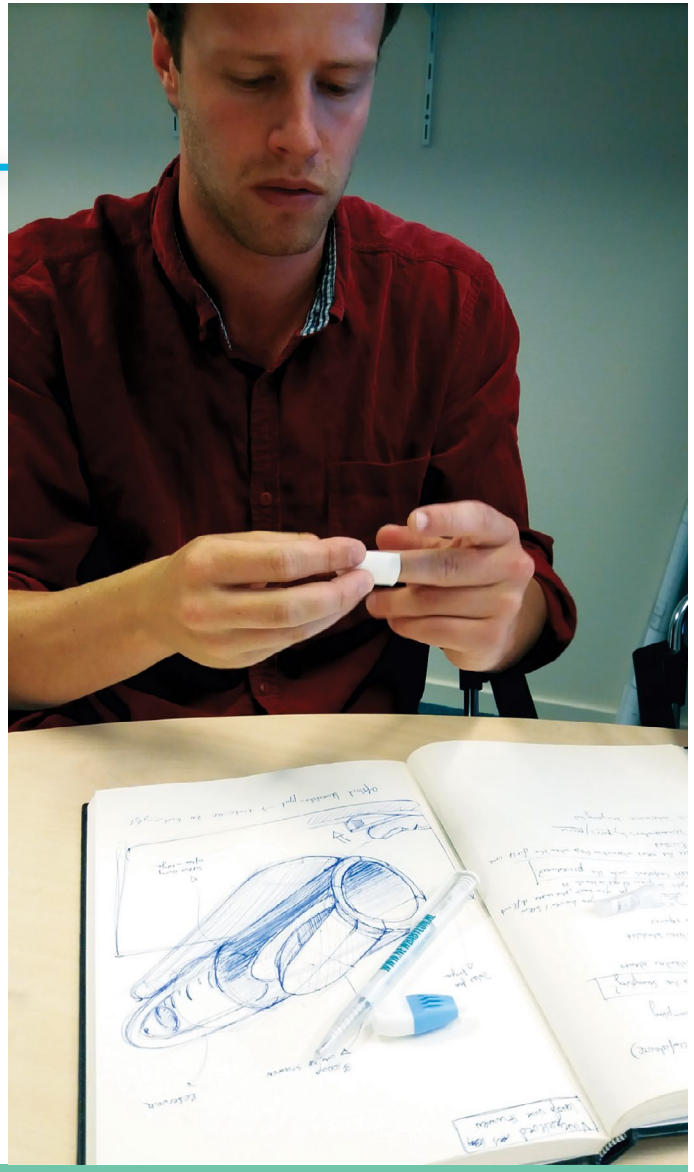
Gutter to guide bloodstream to outlet.

Flexible material that allows pushing of the finger.

Finger hat model D2

Result of the finger hat after usage.

User uses the new finger hat model.



Insights:

- Blood is trapped in the finger hat due to unwanted capillary forces between the hat and the finger.
- The lower part of the hat should be completely open.
- The puncture location and outlet of the blood stream should be on the same location
- The distance between the puncture location and storage should be as small as possible

Conclusion

The test of principles were important to find out what worked and what did not. The principles that have been validated can now be used in the construction of concepts that are described in next chapter.

Finger hat

The principle in which a finger hat is used to collect the blood sample was harder to apply than expected due to the bloods viscosity and unwanted capillary action. however, when the lower part of the hat is completely open it should work.

Stability

The stability test worked well. A stable base at the bottom of the container made sure that the user had both hands free to sample the blood. Also the funnel shaped upper part was considered useful as that prevented unwanted drops to be spilled on the table.

Pressure

The use of pressure was not very successful as under pressure can only be applied once. After pressure is gone, new pressure should be created which is possible but takes more complex design constructions.

Gravity

Gravity is an easy way of collecting a blood sample, the only disadvantage is that gravity alone results in slow blood sampling due to the high viscosity of blood.

Capillar action

Capillary action is a useful principle to collect blood samples. It is simple in its design but effective in transporting blood due to high adhesive forces. The only drawback is the stagnation/loss of blood in the tube during sampling.

3.5 Concepts

This chapter presents three concepts that are the result from the ideation and proof of principles described in latter chapters. The most promising principles have been combined in order to create feasible concepts that form the best solutions to the formulated challenges.

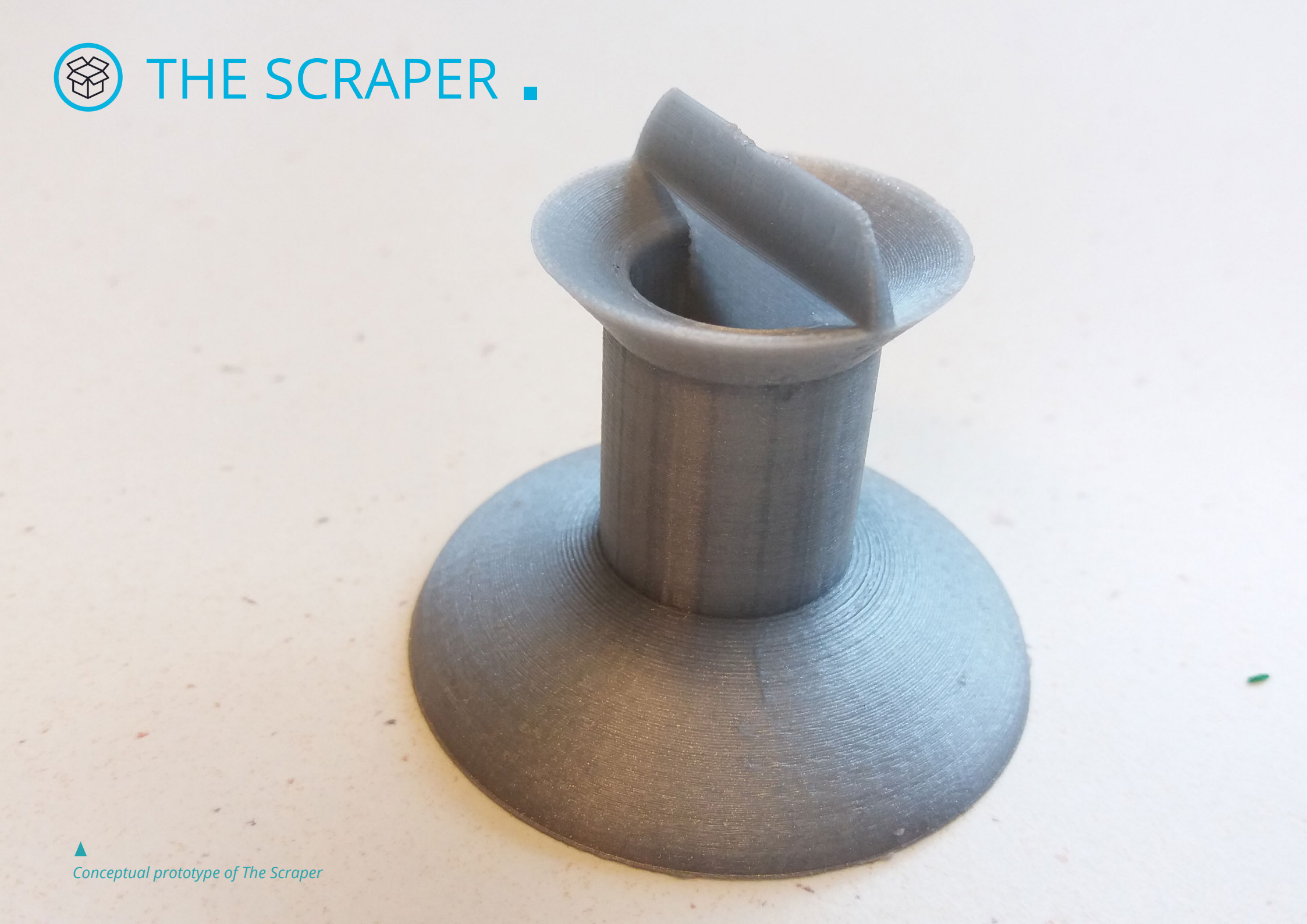
The concept description will show the reader how the concept is constructed, what components it contains and how it will be used in combination with the user.

At first *The Scraper* is presented

Secondly *The Thimble* is presented

At last but not least, *The Capillar* is presented

THE SCRAPER .



Conceptual prototype of The Scraper

How is it constructed

This concept is a combination of different principles that were tested and observations that were made during the analysis phase. The idea of "scraping of' the blood drops from the finger inside the container was observed at an existing product (figure 51). The bowl shaped top was found to be useful when aiming blood in the container, which prevents blood sample spilling. The concept is simple in its design which make the usage and understanding easy for the user.

Figure 51 - Microvette 200 uses the rim of the container to scrape of the blood sample (Medicalexpo, 2017)

Scenario

Figure 52 shows the scenario of The Scraper's user. After the container is filled with the user's blood sample, the user disassembles the container and places a cap on top to seal off the sample. After that, the sample is ready for mail towards the hospital for analysis.

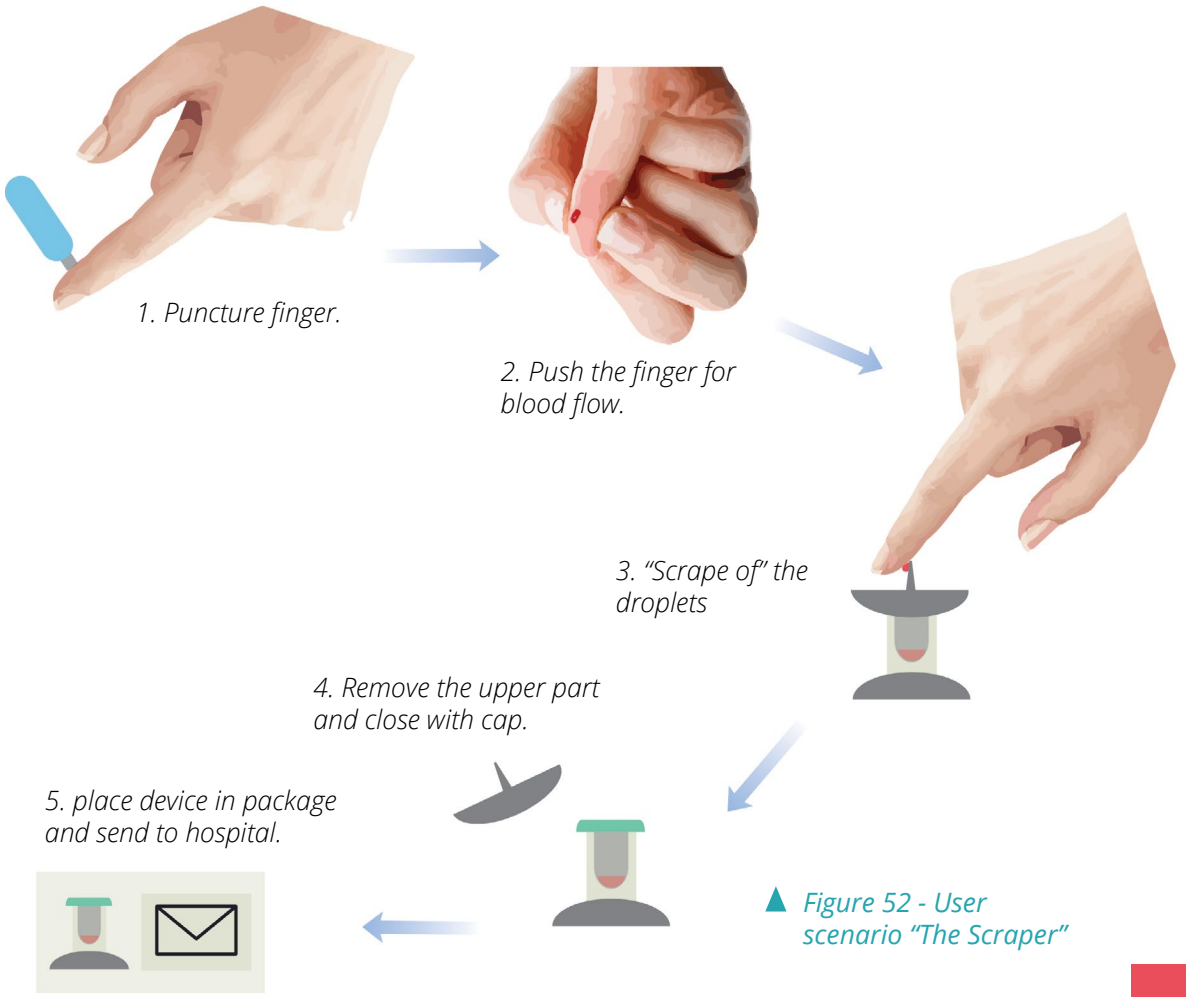


Figure 52 - User scenario "The Scraper"

Components

Figure 53 shows the components of The Scraper, 3 components can be distinguished. Figure 54 shows the use in more detail.

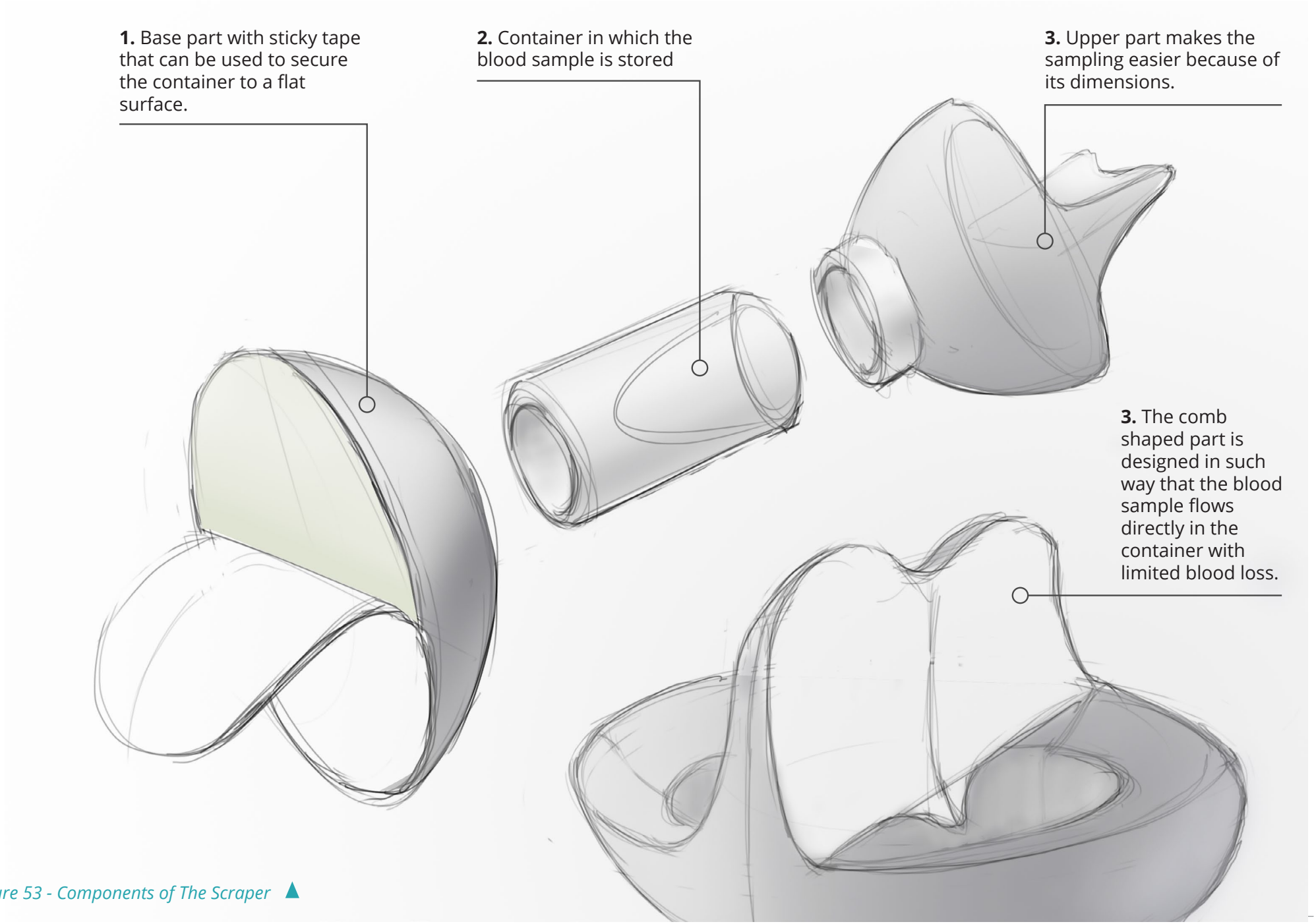
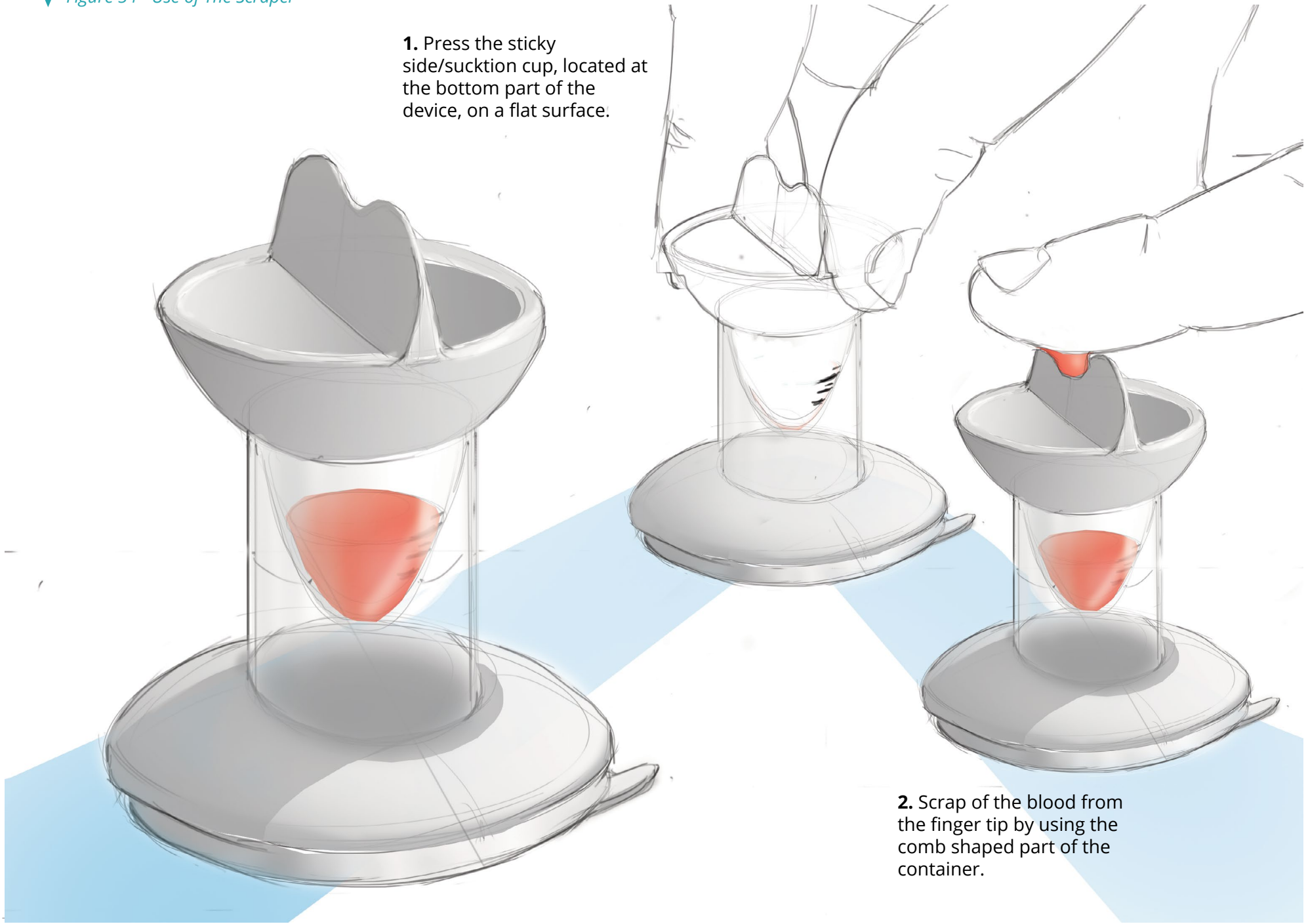


Figure 53 - Components of The Scraper ▲

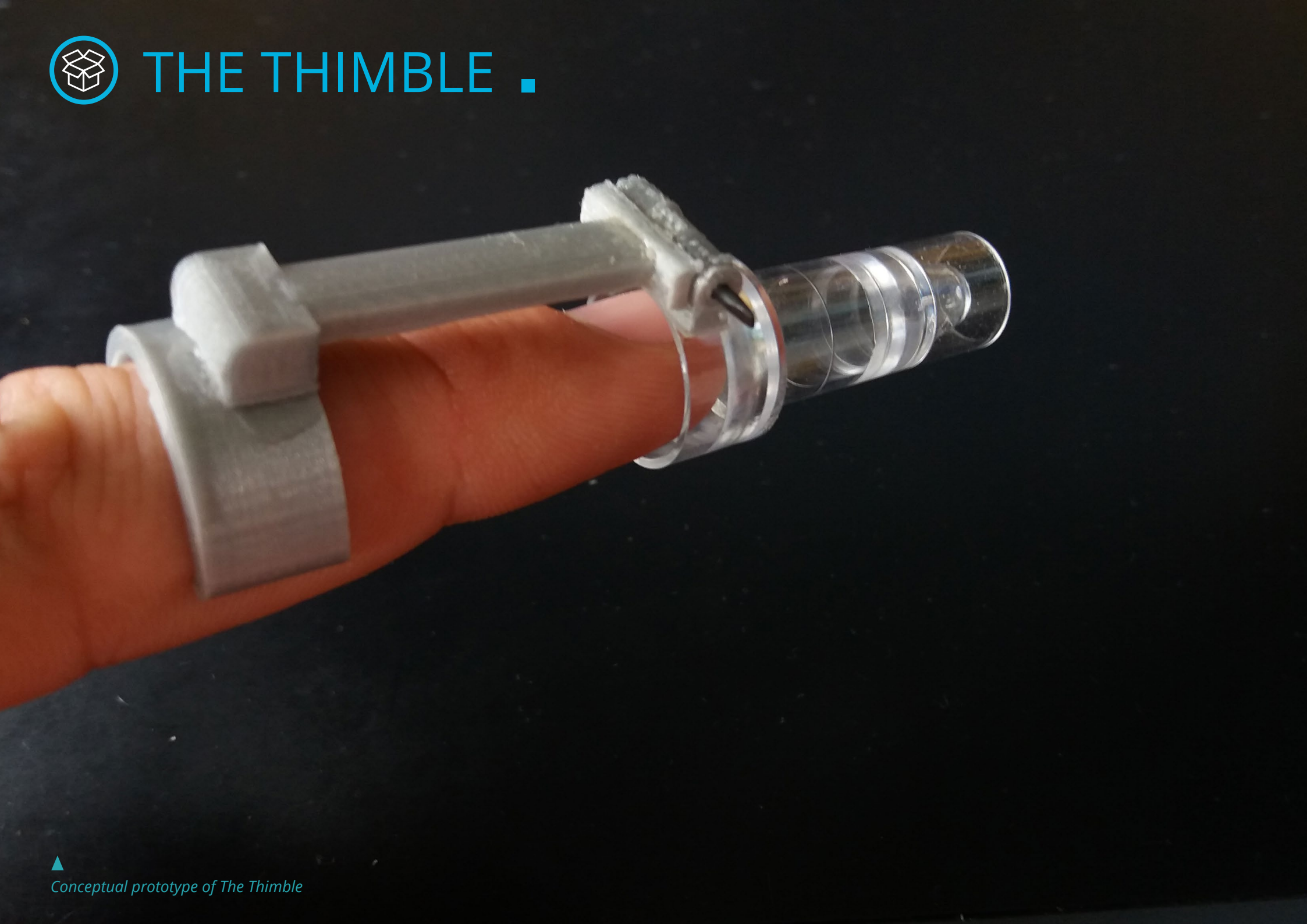
Figure 54 - Use of The Scraper

1. Press the sticky side/sucktion cup, located at the bottom part of the device, on a flat surface.



2. Scrap of the blood from the finger tip by using the comb shaped part of the container.

THE THIMBLE .



▲
Conceptual prototype of The Thimble

How is it constructed

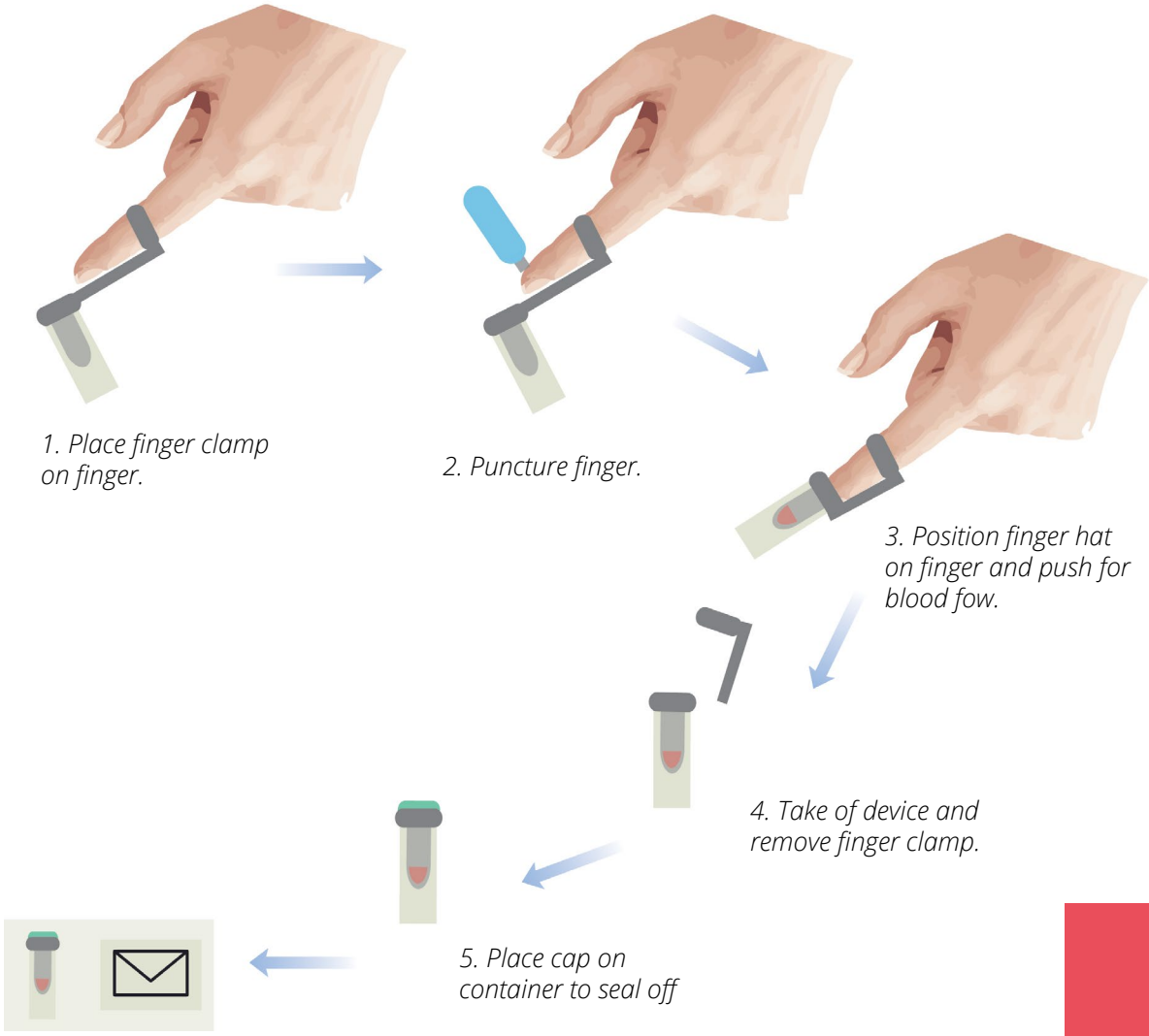
This concept is derived from the idea of using a finger hat as a way to collect blood. The big advantage is the fact that both hands can be used to collect blood while the user can push the finger to enhance blood flow. Two variations of the concept are presented; One makes use of capillary tubes as a way of transporting blood, the other makes use of gravity and straw as blood guider towards the container. The user can position The Thimble by adjusting the hinge that connects the finger hat with the finger holder. Figure 55,56,57 show the concept and the way it works.

Components

The Thimble consist of two major components which is the finger hat in which the blood will be contained and the finger clamp that makes sure that the device is secured on the finger of the user. The clamp is a flexible component which makes sure that it is able to fit to finger dimensions of p95 users.

Scenario

The user first places The Thimble on the finger, then a puncture is made in the finger after which the user positions the finger hat on top of the finger. The blood will flow inside the container when the finger is pushed. When the container is filled with 200 microliter, the device can be taken of. The finger clamp can be removed and a cap is placed over the container to seal of the blood sample (figure 58).



▲ *Figure 58 - User scenario "The Thimble"*

Figure 55 - Visualisation of The Thimble

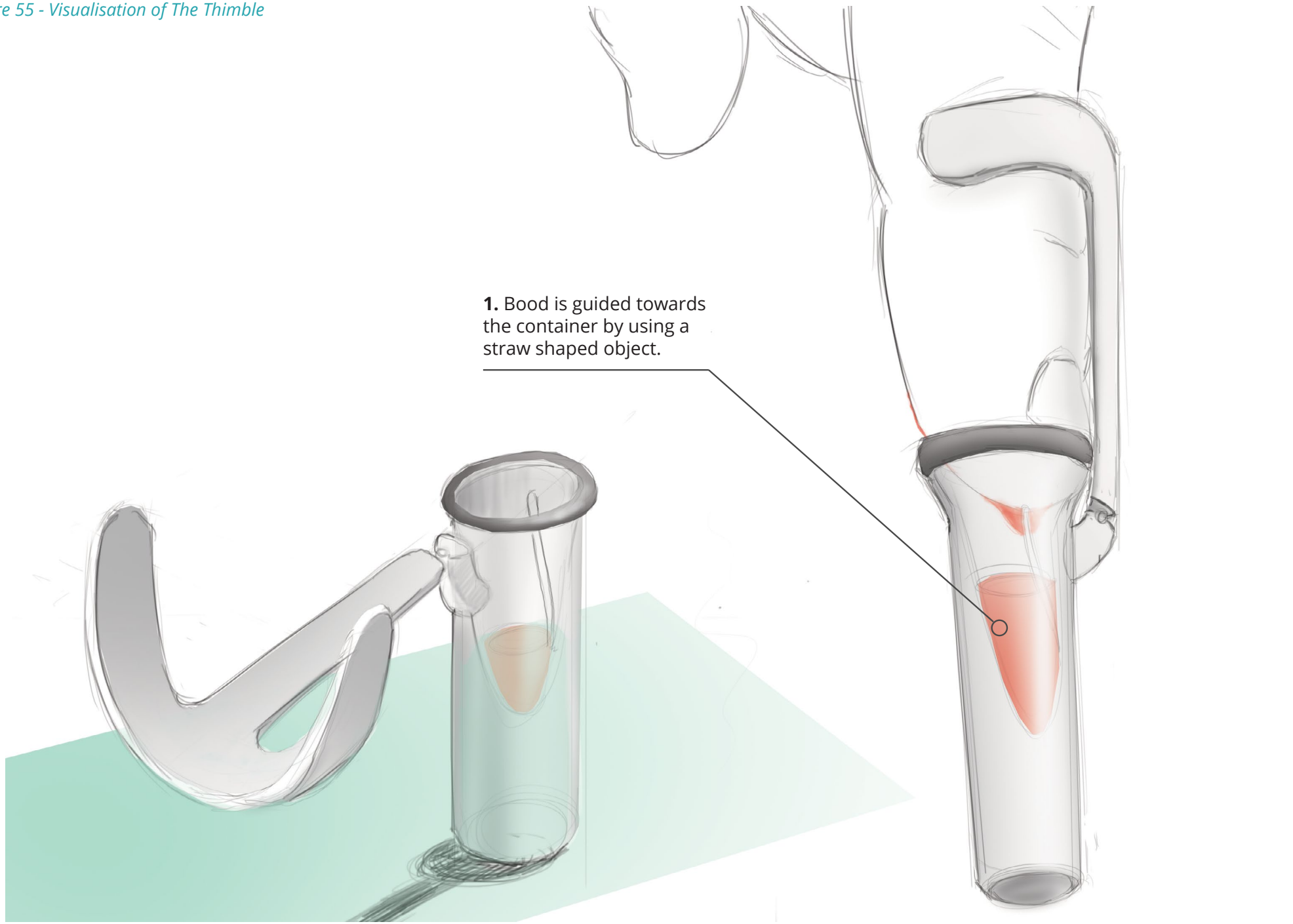


Figure 56 - Visualisation of The Thimble

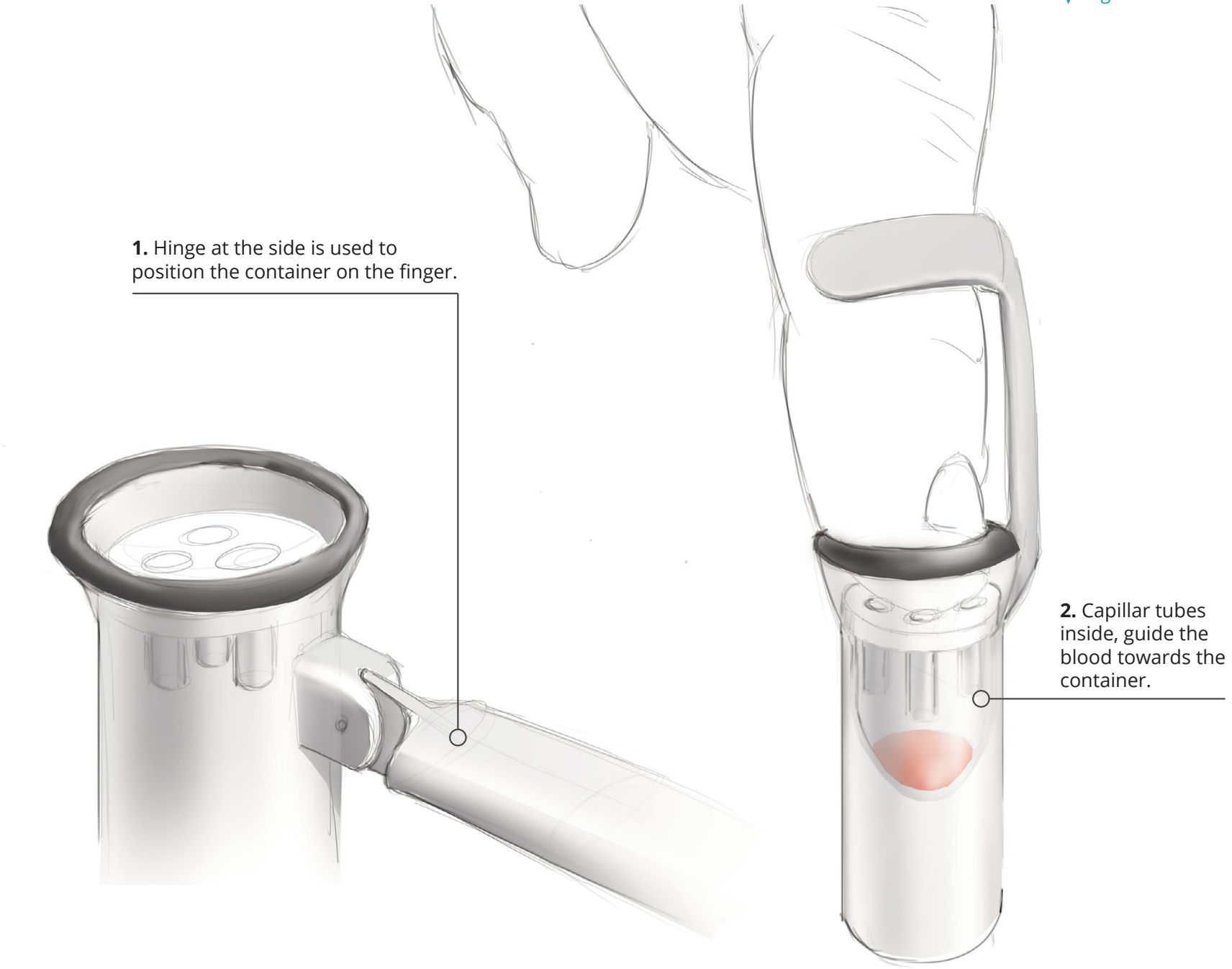
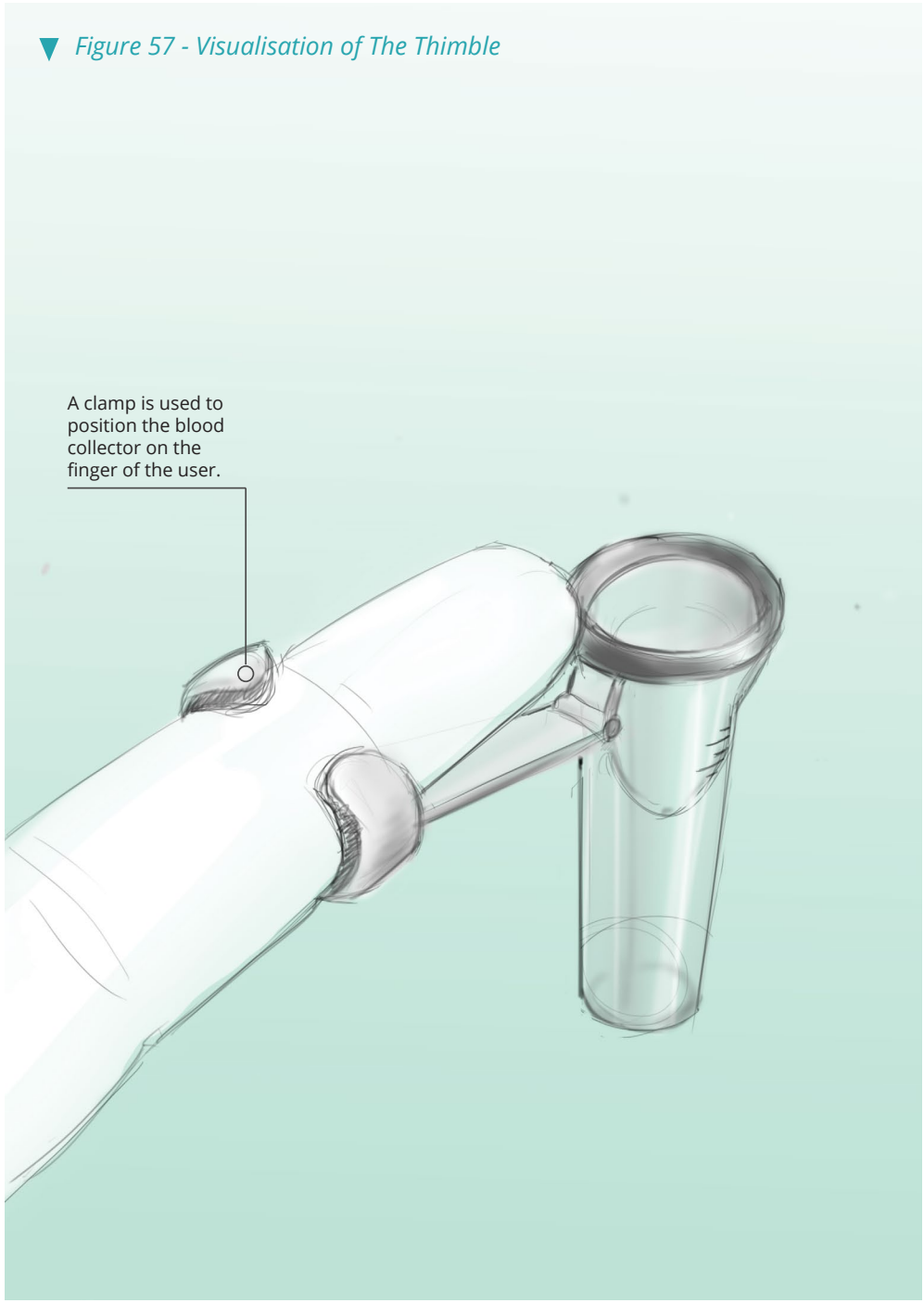
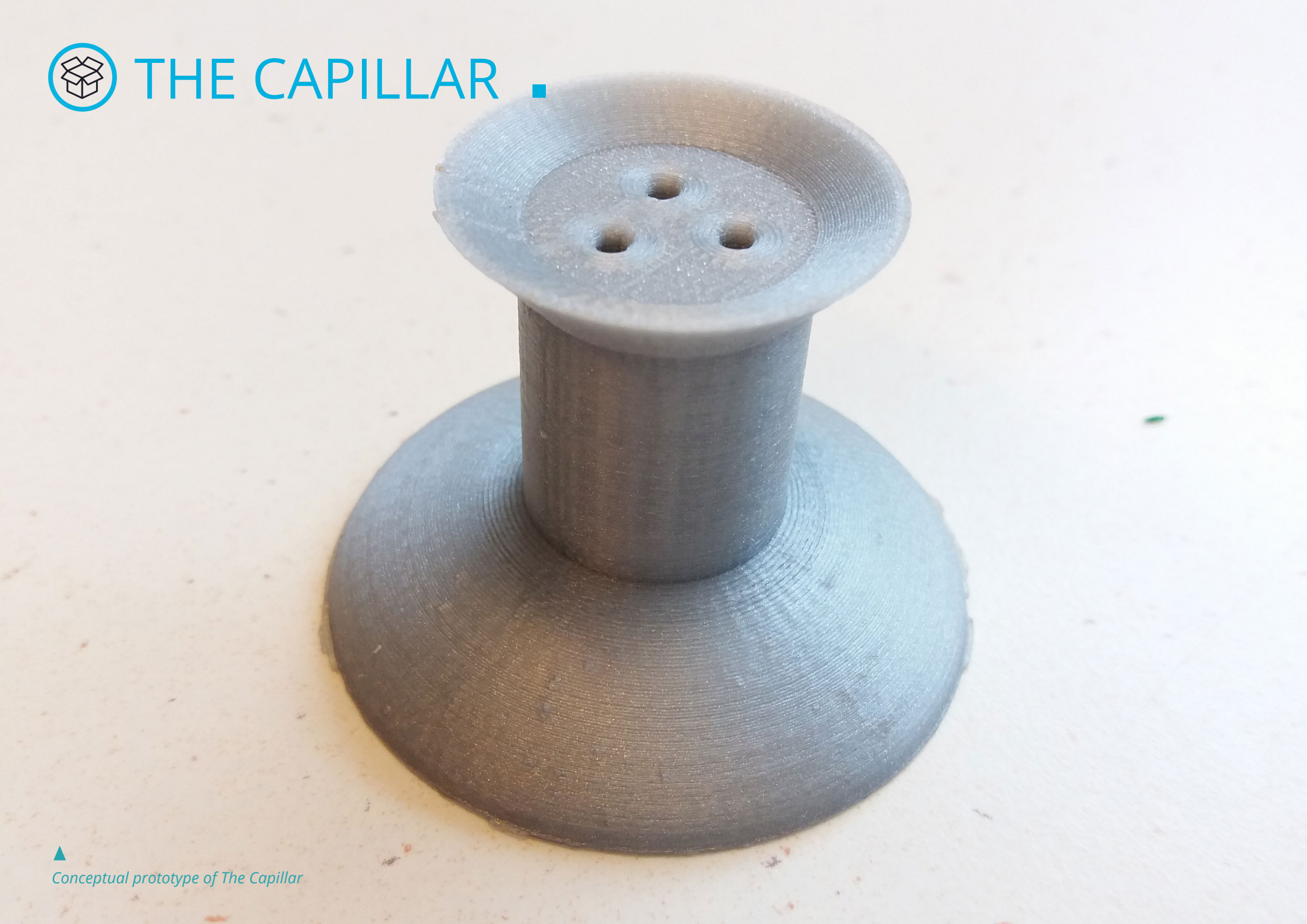


Figure 57 - Visualisation of The Thimble



THE CAPILLAR



Conceptual prototype of The Capillar

How is it constructed

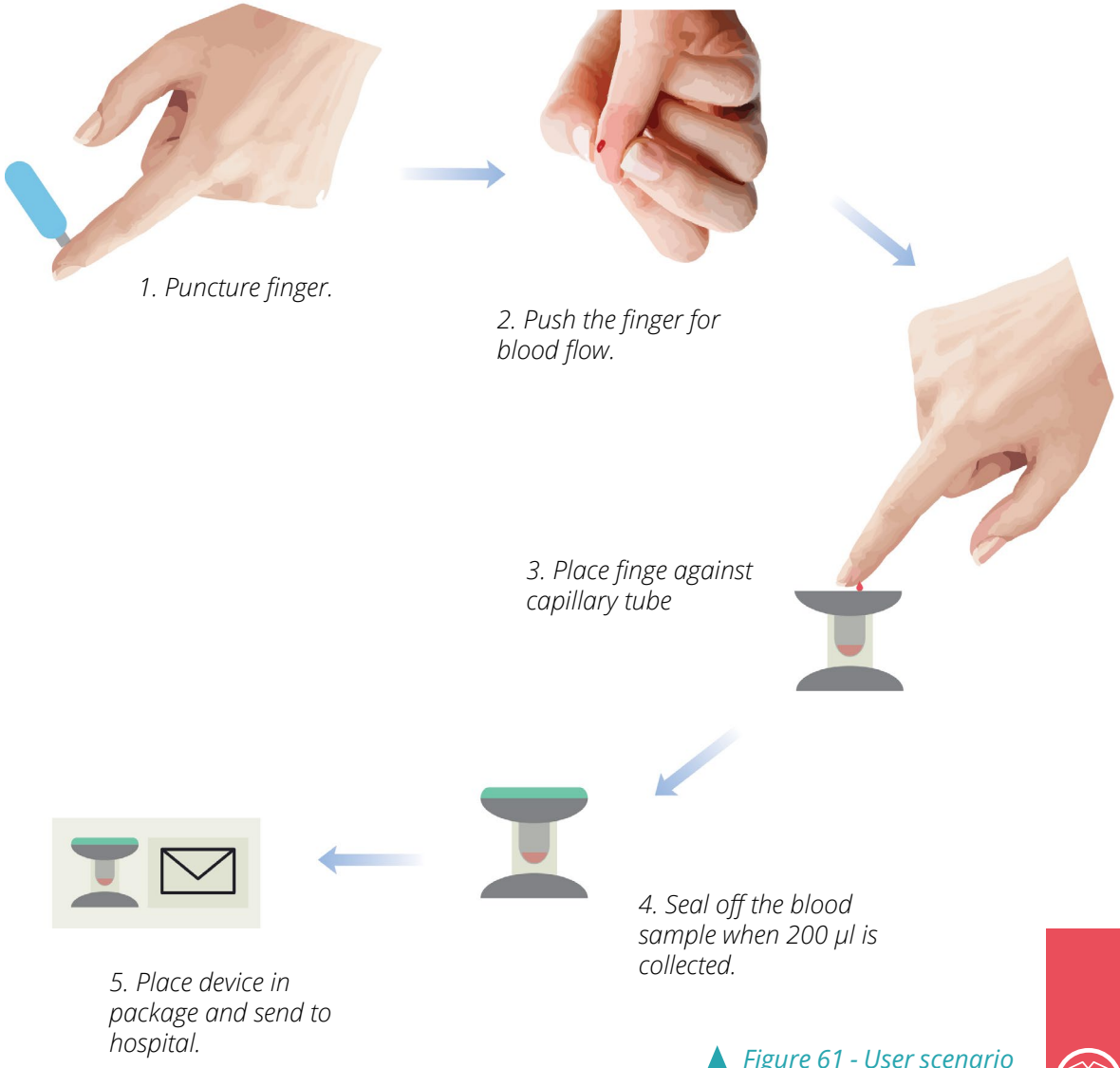
This concept is created by using capillary action as technique to transport the blood sample. The advantage of capillary action is that even small amount of blood is sucked away from the finger surface by the amount of surface tension inside the tube. This makes the sampling process easy to perform. Figure 59,60 show the concept and the way it works.

Components

The Capillar consists of three components; The upper part in which the blood is sucked from the finger and transported towards the container. The middle part, which is the container, collects and preserves the blood sample. The bottom part is the base which makes sure that the device is stable during the sampling process.

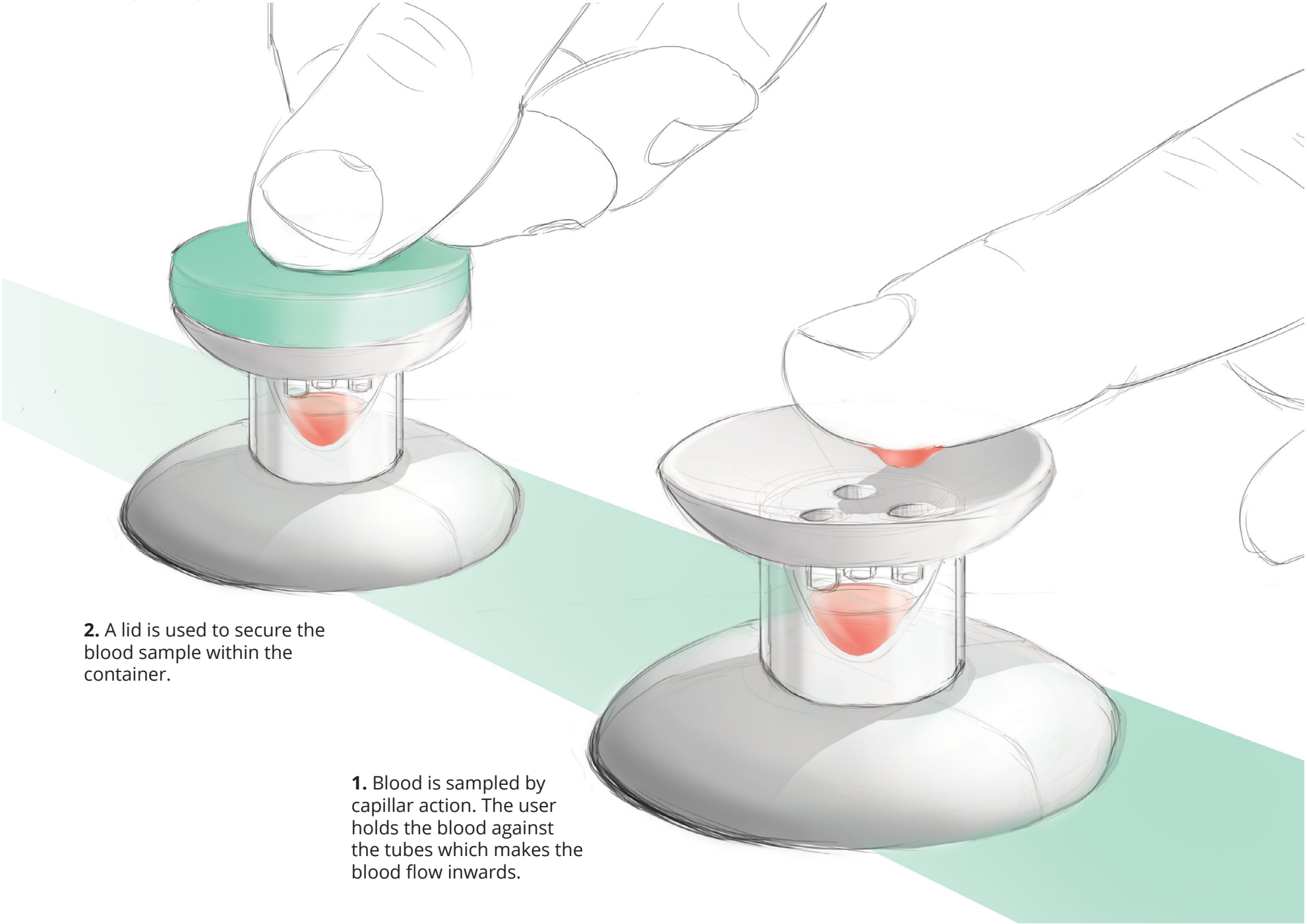
Scenario

The user has to puncture himself after which he places his finger on the upper part of the device. The capillar tube will suck the blood from the finger. Gravity makes sure that the blood sample falls inside the container. After the sampling is done, a cap is placed on top of the device to seal off the blood sample (figure 61).



▲ *Figure 61 - User scenario "The Capillar"*

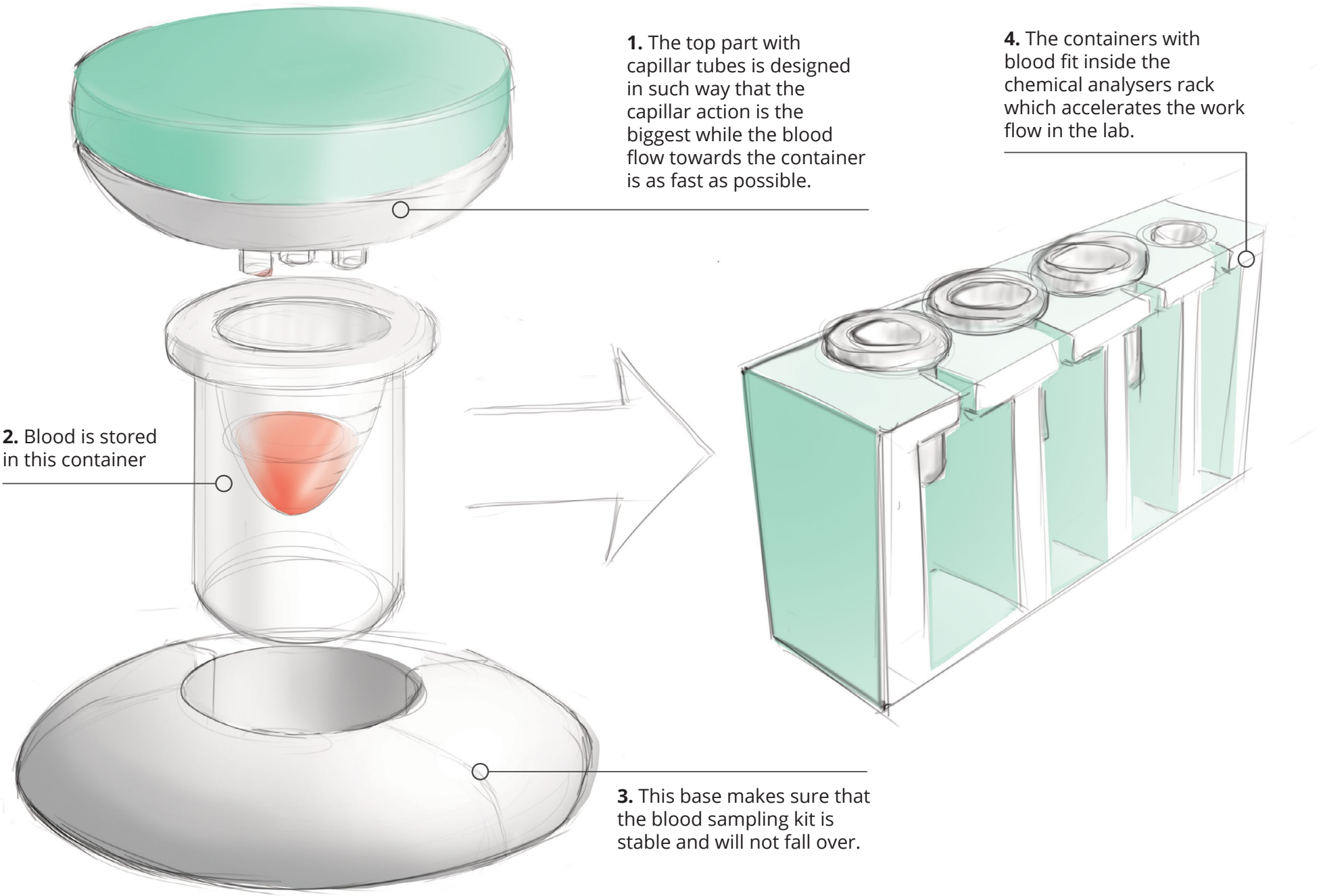
Figure 59 - Visualisation of The Capillar



2. A lid is used to secure the blood sample within the container.

1. Blood is sampled by capillar action. The user holds the blood against the tubes which makes the blood flow inwards.

Figure 60 - Visualisation of The Capillar



THE CAPILLAR .
variation

Conceptual prototype of The Capillar variation

The Capillar variation

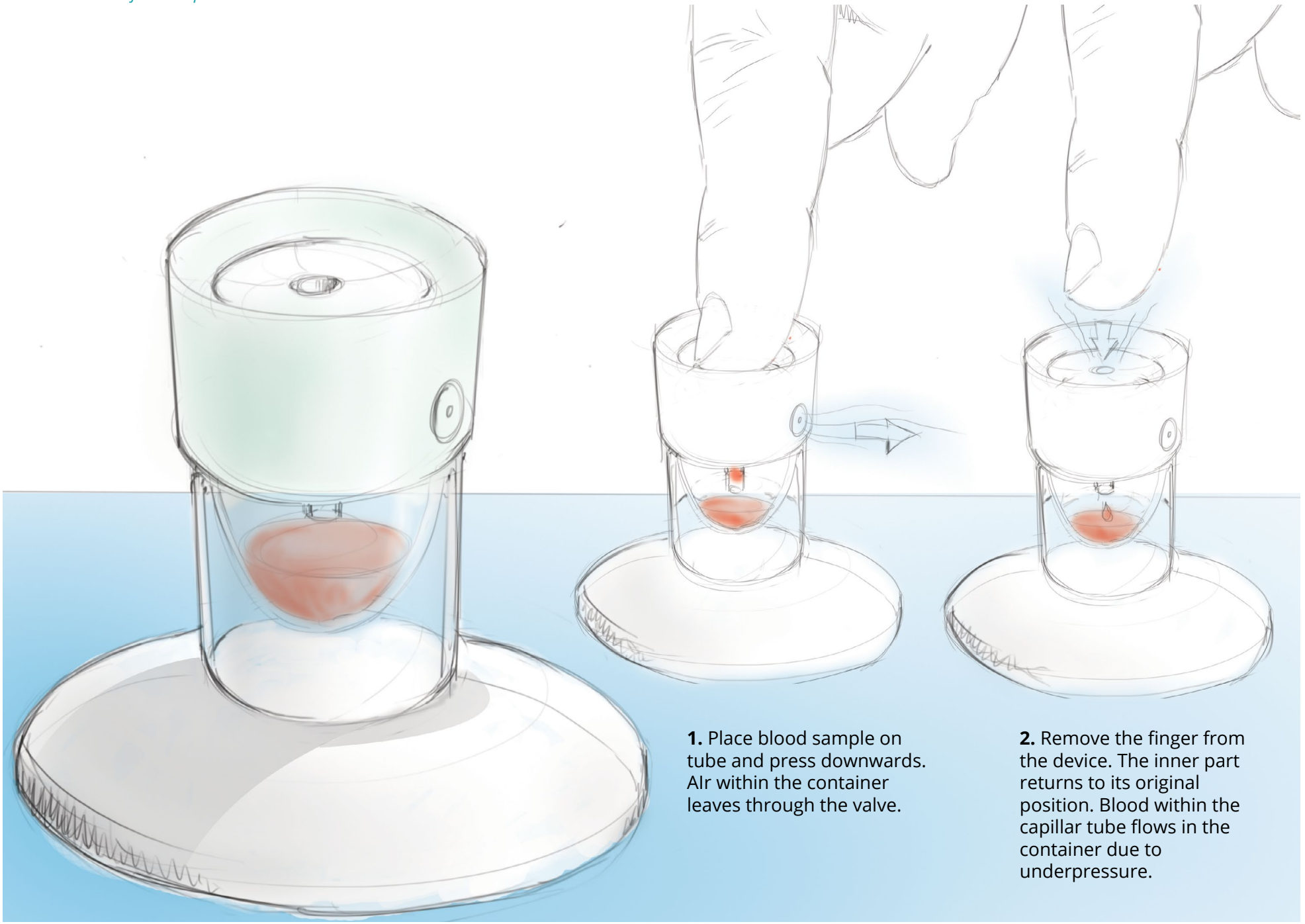
This concept is a variation on previous concept. This variation is made because there is an uncertainty on how much blood volume will get stuck in the capillar tubes during sampling. This is something that is undesired as the blood volume that is needed should be as small as possible to make the burden on the patient as low as possible.
This concept makes use of under pressure to release all blood that gets possibly stuck in the tubes during sampling.

Figures 62 & 63 show the working principle of the concept.

Materials (general)

The Scraper and The Capillar should be made from the same type of material as the way of transporting blood is quite similar. The upper part of the device should be made from a hydrophobic type of plastic that transports the blood as fast as possible towards the capillary tubes. The material should not react with the blood and anticoagulant that is present in the device. The Thimble is different in its set up. The clamping part should be made from a elastic material that can adjust to the shape of different users. During the embodiment of the final concept these materials will be examined more in detail.

Figure 62 - Visualisation of The Capillar variation



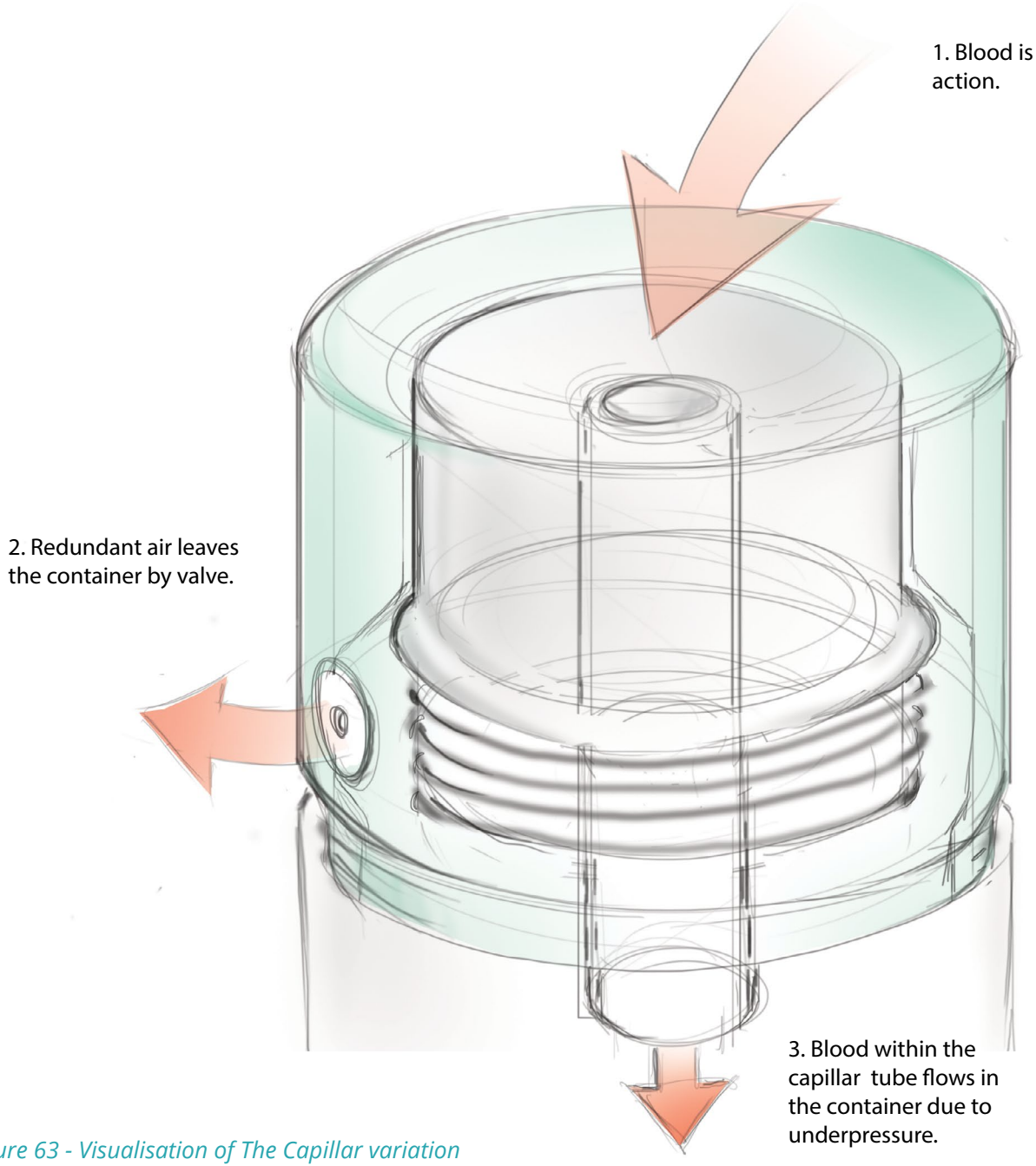


Figure 63 - Visualisation of The Capillar variation

- *These three concepts with their prototypes form a tangible proposal to the formulated challenges from the end of the analysis phase. They are meant to convince the stakeholders of their added value and feasibility.*

3.6 Decision making process

This phase decides what concept that was proposed is the most desired and worth developing further during the embodiment phase. The decision making process is described in this chapter.

Concept Presentation

The conceptualization phase ended in a presentation at NKI-AVL to present the concepts to the board of TU Delft and to AKL. All concepts were presented and the people attending the presentation were asked to participate in the decision making process of the final concept at the end of the presentation (figure 64).

Figure 64 - Participants are involved in the decision making process.

Criteria

The participants were asked to rate the concept on the following design statements by giving scores rating from 1 to 5:

1. *Feedback to user on how much blood is sampled (200 µl) is good*
2. *The amount of blood loss during sampling is low*
3. *The use of the device is intuitive (easy to understand)*
4. *The design is feasible (easy to develop and implement)*
5. *The device is easy to use*
6. *The 200 microliter blood is quickly sampled (speed of action)*
7. *The chance on contamination of blood sample is low*

These design criteria are a review on the design vision and are major points in the workable list of requirements. For the full questionnaire that was given to the participants see appendix U. For the scores that were given by the participants for each criteria and concept also see appendix U

Concept choice

Figure 65 shows the scores that were given to the different concepts by the participants of the concept presentation. The Scraper and The Capillar were rated better than The Thimble. The rating was meant to start a discussion between the participants that could lead to a communal decision of the final concept. The following conclusions were drawn for each concept during the discussion.

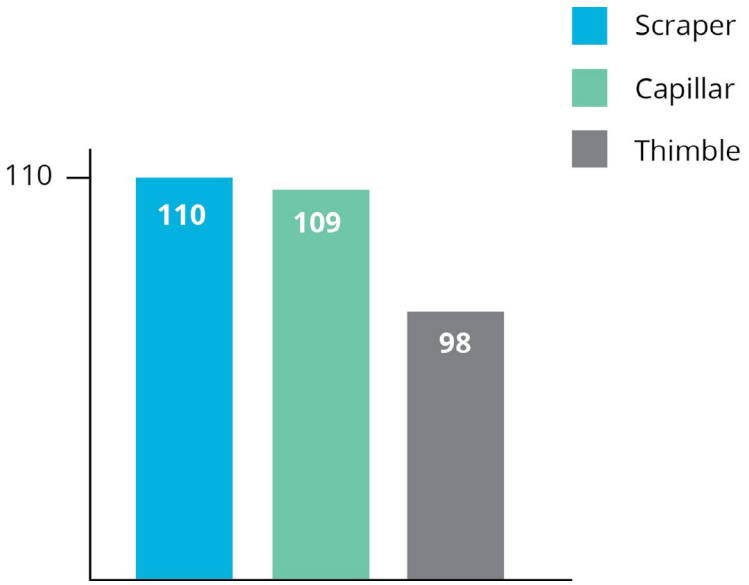


Figure 65 - This graph shows the scores of the different concepts

The Scraper

The Scraper seems to be a feasible and promising concept. The lowest score is given on the contamination of blood sample as "scraping the finger" could lead to unwanted cellular debris inside the sample. This concept is the most straightforward, basic and looks the most on existing products for blood sampling.

The Thimble

The Thimble is the concept that differs the most from the other two. The concept seems less feasible due to the fact that it needs to be clamped on the finger which requires that the device should be adjustable to all type of ergonomics in order to be operational. The sampling itself seems to be doubtful as well, as the puncture in the user's finger needs to be done on exactly the right location, a puncture too close to the nail would result in sampling failure.

The Capillar

The Capillar is the concept that has a lot of similarities with the Scraper. The big difference is the way it transfers blood from the puncture towards the container. The concept looks promising as capillary action accelerates the sampling process. The backup concept can be used when it turns out that the dead volume, as result from stagnated blood inside the capillary tube(s), is too large.

Final concept

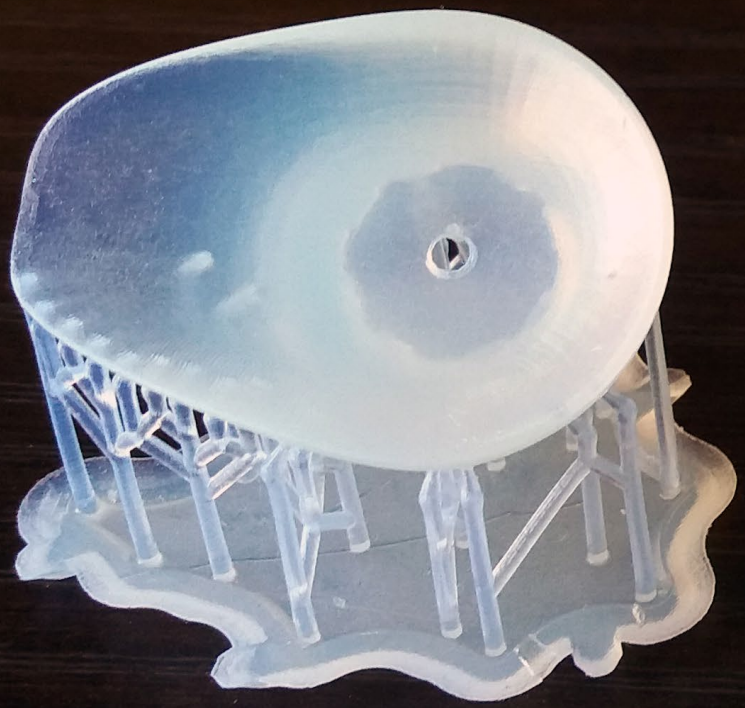
It is decided to continue with **The Capillar.** The concept requires less actions from the user and is seen as a more innovative way of sampling blood in comparison with the Scraper. During the discussion some modifications were discussed for the Capillar.

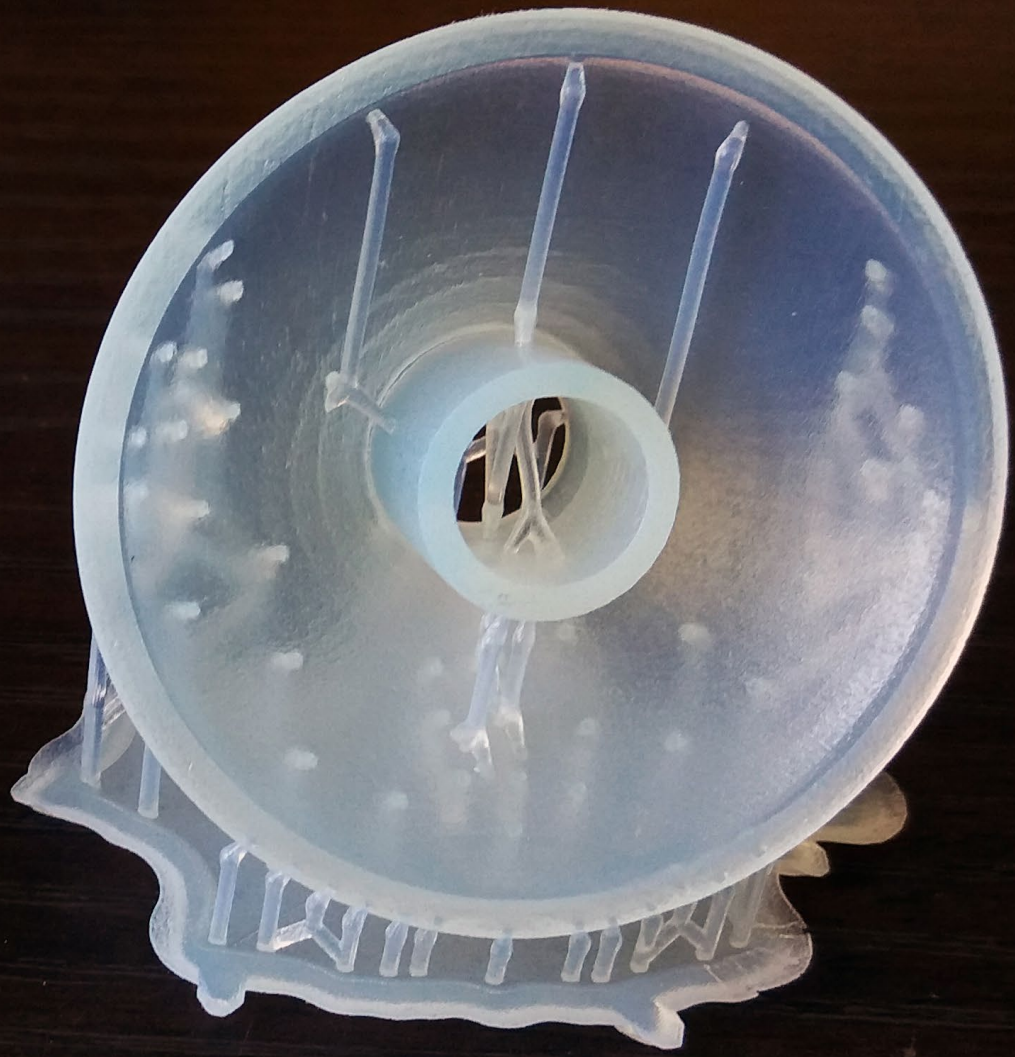
- *The Capillar is the concept to continue with*
- *A standard micro tube should be used within the device*
- *A test tube should be included within the blood sampling kit that already carries the patient's bar code.*

These modifications will be applied within the next phase of the project: The embodiment phase.

4. Embodiment

The conceptualization phase ended in a final concept. However, a concept is still not something that works. The embodiment phase gives body to the concept which will finally result in a finished product that could actually be used by the targetgroup. This phase focusses on aspects as: material, production, costs, aestethics, information providence and implementation. The embodiment phase ends with a working prototype that is tested with users within the targetgroup. The steps within this phase are visualized in the embodiment framework (figure 66).

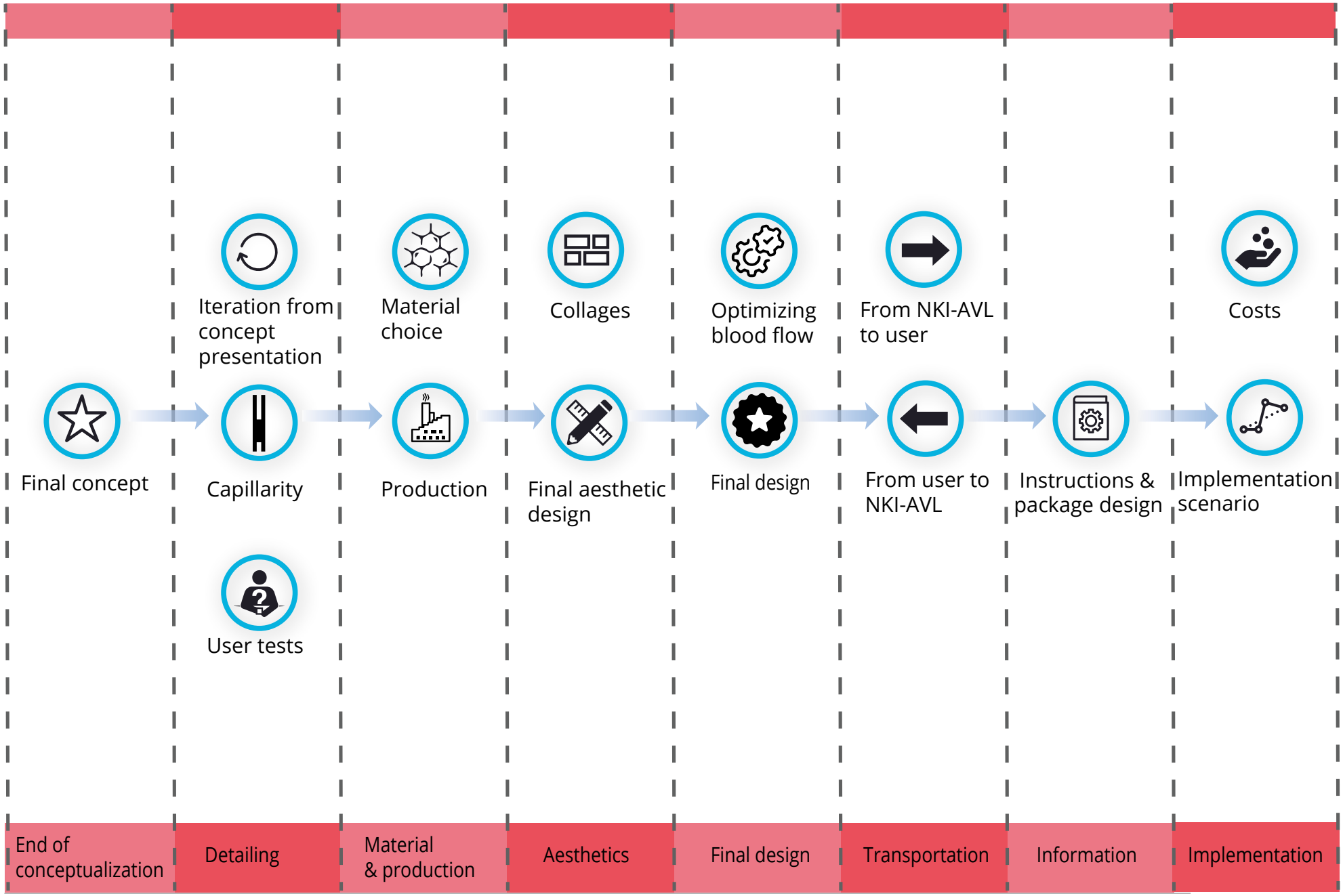




Two SLA printed prototypes have been born ▲

Framework embodiment phase

figure 66 - Framework embodiment phase



4.1 Iteration & user tests

Adjustments of The Capillar have been discussed during the concept presentation. This chapter describes the adjustments and integrates these adjustments in a new design that is validated in a user test.

Iterations

The Capillar consist of three main parts (bottom, container and top). it would be the most convenient for NKI-AVL to use a standardized container instead of a manual designed container. Strict regulations apply to these type of medical products, so the use of existing validated parts is the easiest way to go. It is decided to continue with the Microvette 200 (Kalium-EDTA) (figure 67). This microcontainer has a clear indication mark which the user can read. The microcontainer can be placed in the chemical analyzer without errors, this is tested in the same way as is described in Appendix C.

Figure 67 - Microvette 200 (PolyMed, 2017) ►

The choice for the micro container has a few drawbacks: The container is too small to place the patients bar code and the container does not fit inside the dimensions of the chemical analyzers rack. This problem will be solved by adding a test tube to The Capillar (figure 68).

Figure 68 - Test tube that will be used as part of The Capillar. (Universal Medical, 2015) ◄

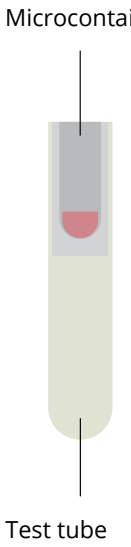
The micro container is placed in the test tube and will be integrated in the design of The Capillar. The user tests shows model E1 and consequently model E2. Both models are an adjusted version of The Capillar that integrates the micro container and the test tube.

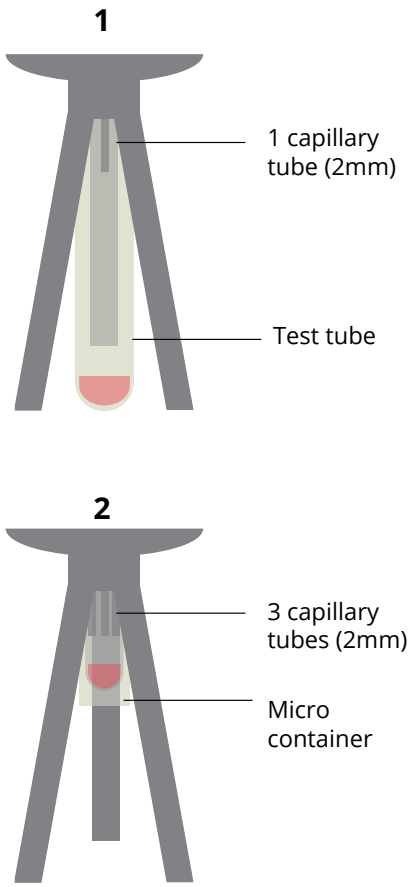
User tests

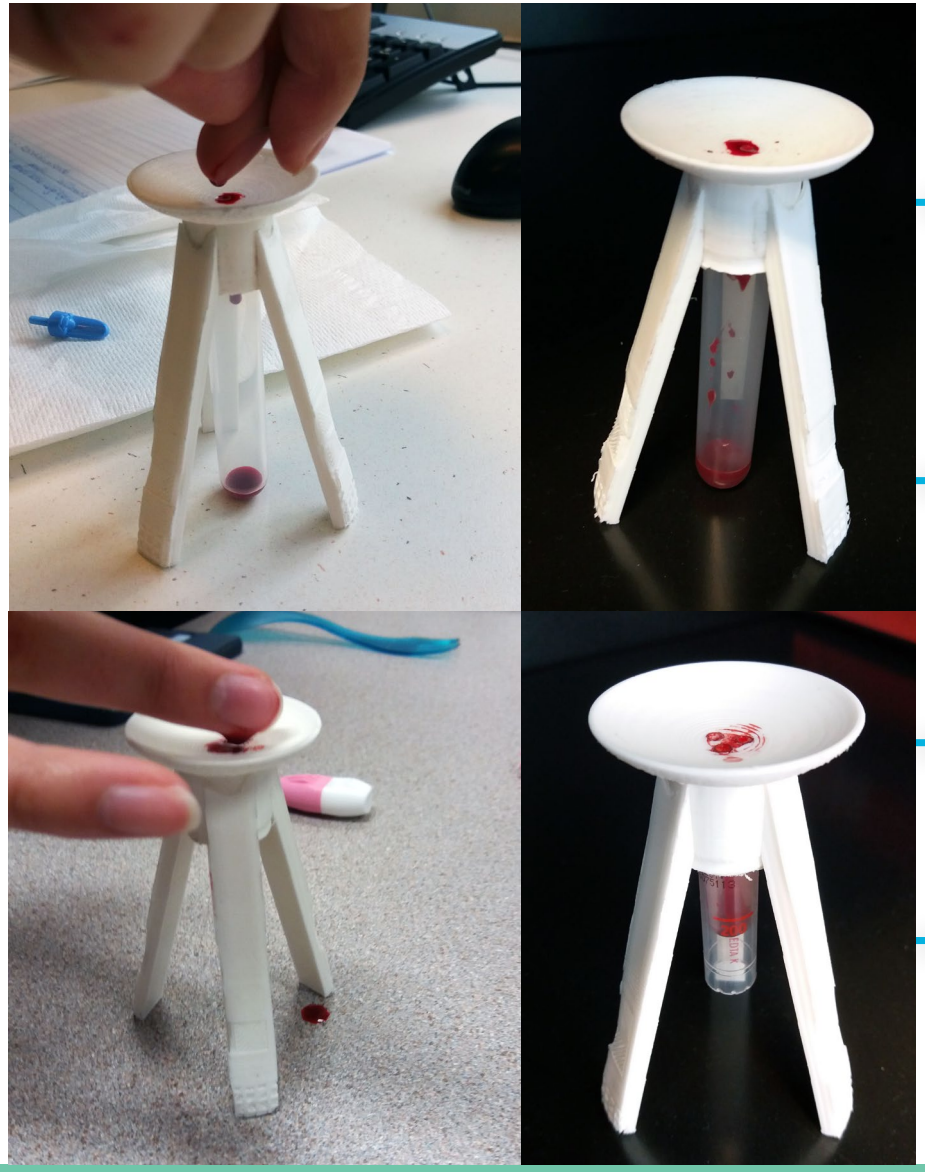
The tests are meant to find out whether the implemented iterations work in the right way. Also the principle of capillary action is again tested by using real blood from a finger puncture.

Final concept - working principle - model E1

Combining
The microcontainer and test tube are combined like in the drawing below. In this test they have been split up for the ease of testing.







User samples 200 microliter blood in the prototype

1 capillary tube resulted in less stagnated blood than the model with 3 tubes

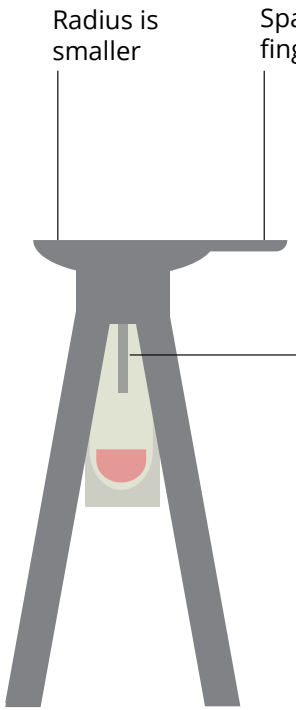
User samples 200 microliter blood in the prototype

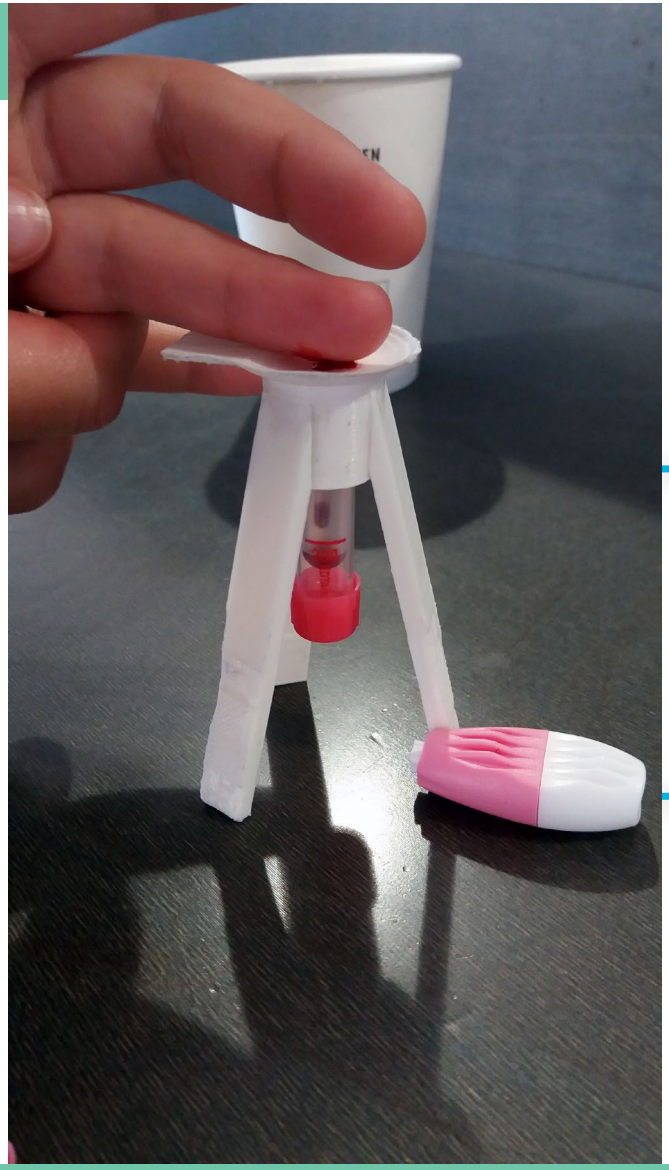
Note that blood is spilled during collection

Insights:

- Users tend to use only one hand during pushing the finger for blood flow.
- for model 1: tube did not coagulate due to EDTA inside.
- For model 2: punture was made on the side of the finger. The models dimensions interfered with the pushing motion of the finger which resulted in blood spilling, Dimensions should be adjusted for side punctures on the finger.
- 2 mm capillary tubes do work OK
- 3 capillars tend to confuse the user where to place the droplet of blood.
- puncture on the side of the finger is desired as it contains less nerves than the center.

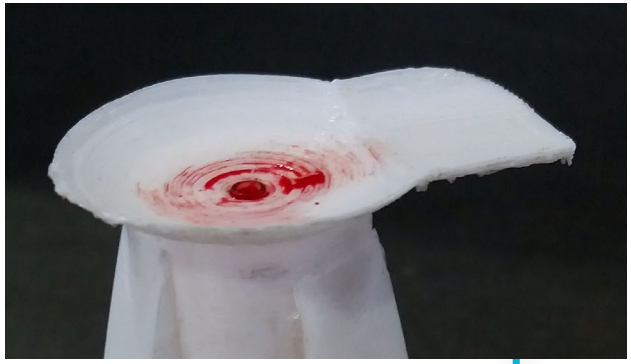
Final concept - working principle - model E2





User collects blood after a puncture is made at the side of the finger.

A middle flow lancet was used to make the puncture because high flow lancets were out of stock during testing.



Blood is spread out on the upper part of the model.

Insights:

- The puncture was made with a middle flow lancet, which is not big enough to sample 200 microliter blood. Use the high flow lancet.
- The space to place the finger sideways was considered usefull by the user.
- The user added a lot of small drops of blood in the tube which resulted in a lot of air trapped in the tube that resulted in stagnated blood .
- The pushing was more painfull than the puncture, user thinks that a bigger lancet would be less painfull as less pushing would be needed.

- *The Capillar intergrates a standard micro container and test tube that have been described in this chapter.*
- *The Capilar uses one single capilllar tube instead of three. This is proven to work better.*
- *2 mm capillary tubes are proven to work, hence they will be used in The Capillars design.*
- *The Capillars collection “funnel” at the top is extended to make blood sampling by side puncture easier.*

4.2 Material choice

This chapter compares different type of materials that could be suitable for the blood collection device. Material requirements within the medical industry are very strict due to safety regulations concerning the patient's health. Various material requirements are evaluated and a final material proposal is made.

What type of material?

The first question that should be asked is what general type of material fits the capillary blood sampler best. Transparency, sealability and price are important points of attention for the disposable blood sampler, which makes "plastics" the right material group to search further (figure 69). Looking at comparable medical products on the market confirm this assumption, as all disposables related to blood sampling are made from plastics.

Table 3.3 Property Comparison of Plastics vs. Metals, Ceramics, and Glass

Property	Plastics	Metal	Ceramics	Glass
Flexibility	Excellent	Poor	Poor	Poor
Clarity	Good	Poor	Poor	Excellent
Design versatility	Excellent	Poor	Poor	Poor
Barrier properties	Good	Excellent	Poor	Excellent
Toughness	Excellent	Good	Good	Poor
Strength	Poor	Excellent	Good	Good
Chemical resistance	Good	Poor	Excellent	Excellent
Sealability	Excellent	Good	Poor	Poor
Performance	Excellent	Poor	Good	Poor
Weight/volume ratio	Excellent	Poor	Poor	Poor
Performance/weight ratio	Excellent	Poor	Poor	Good
Performance ratio/cost	Excellent	Poor	Poor	Poor

Figure 69 - General material selection (Sastri, 2010)

Sterilization

It is important that the lancet that makes the puncture in the user's finger is sterilized as this prevents infections. Sterilization of the entire blood collection device however is not necessary as long as the blood collection devices are send to the patient in a secure way. Sterilization would be useful when the devices would be reused, however, the design is meant to be a disposable which make sterilization obsolete.

Chemical resistance

When medical devices come in contact with fluids or chemicals, it could happen that additives within the plastics are leached/extracted within the material. The capillary sampler is coated with EDTA, an anticoagulant that should prevent the blood sample to coagulate. The plastic should not extract/leach additives to the EDTA as this could potentially lead to contamination of the blood sample.

Hemocompatibility

This criteria evaluates whether the plastic is compatible with blood. Does the blood get damaged or contaminated in combination with a certain plastic? Damage due to hemolysis would not be a problem for this specific device as the chemical analysis on PSA will be executed with a hemolyzed sample anyway.

Surface

The contact surface of the plastic with the blood sample is a criterion to take into account. It is important that blood drops slide easily into the container with as little as possible blood loss due to adhesion to the plastics surface.

Other requirements that are derived from the list of requirements

Costs

As the blood collection device is a disposable it is important that the material is not too expensive as this would make the implementation of the system difficult.

Production

This criterion will be discussed in more detail in next chapter. It is important that the material that is chosen matches the desired production technique. Some materials do fit certain production techniques better than others.

Fracture toughness

It could happen that the collection device turns over and hits the ground. It is not desired that the device breaks or plastically deforms due to such forces. The material should therefore handle such situations without failure.

Regulations

All medical products that include human contact need to meet up to regulations. Different type of regulations exist to test whether materials are biocompatible:

USP in vivo biological reactivity tests

These test give a classification of the situation in which the medical device will be used. Each classification contains matching tests that should be executed with the concerned material in order to prove its applicability. USP tests are 5 day mouse or rabbit intramuscular implantation tests. The blood collection device would fit in USP class IV

ISO-10993

ISO-10993 is a newer more extensive test standard for the biocompatible classification of materials. The blood collection device can be classified as:
ISO-10883-external communicating device -blood path indirect - A

Five test that should be done in this classification in order to meet the ISO standard are:

Cytotoxicity test
Sensitization test
Irritation of intracutaneous reactions test
Systemic toxicity test
Hemocompatibility test

It is decided to hold on to the ISO standard as it is the worldwide golden standard for these type of classifications. For the material selection it is important that it has been tested according to this standard.

Conclusion

A bio engineering database (CES Edupack) is used to determine what would be the most suitable material for the purpose of blood collection. All material parameters that are described in this chapter are used as boundary conditions to find out what the best plastic would be. Figure 70 - shows the plastics that are suitable for the blood collection device.

" ISO-10993 is the golden standard for medical devices"

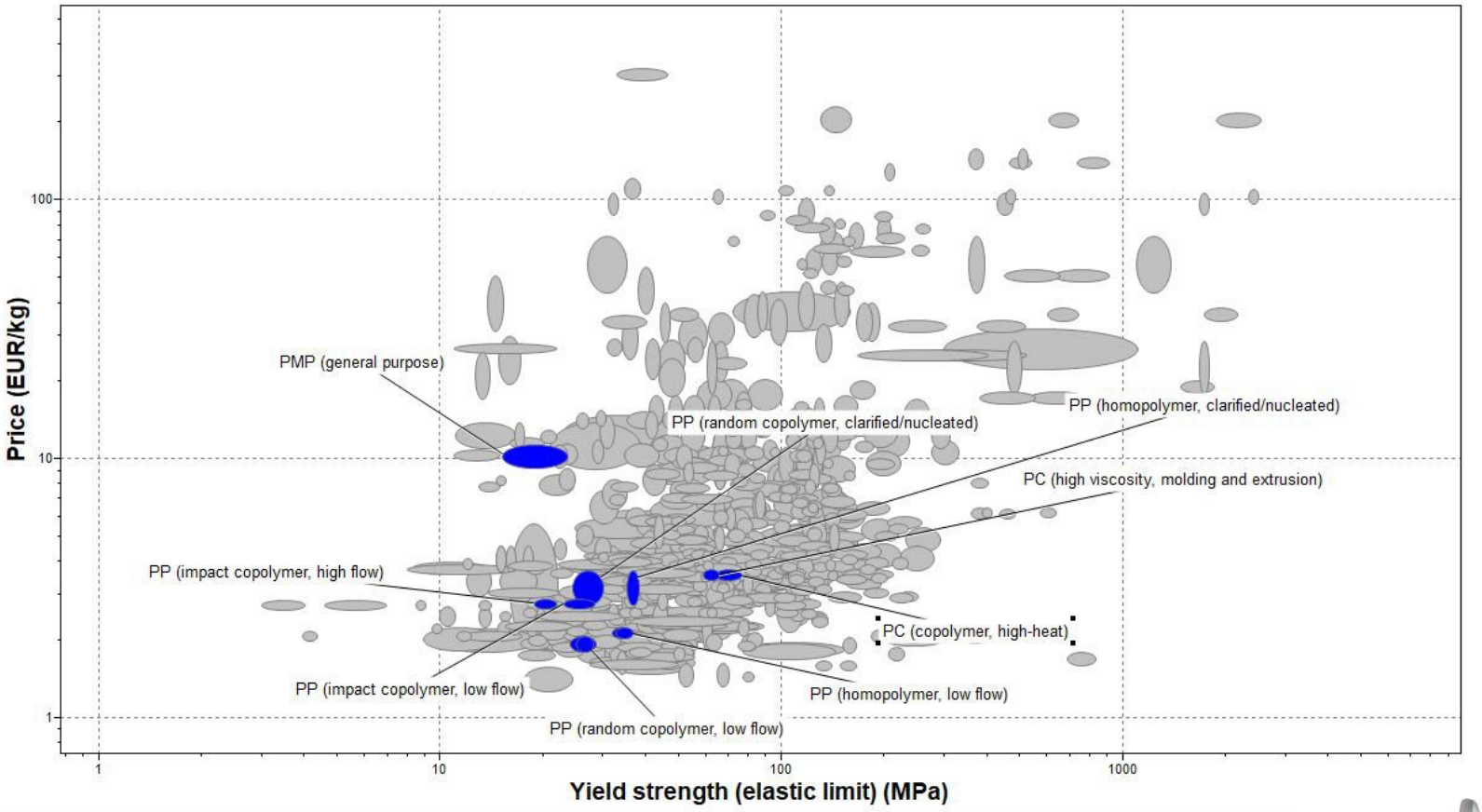


Figure 70 - Plastics that are suitable for the blood collection device as function of price and yield strength.

The two most promising polymers that can be observed as a result from the database search are Polypropylene (PP) and Polycarbonate (PC) as they are the cheapest. PP is slightly cheaper and PC has a higher yield strength. PP however, has a better chemical resistance against various solvents which might be desirable when the blood collection device will potentially be used in combination with other chemicals for other type of tests. The lower price and better chemical resistance are reason to choose PP above PC as material for the blood collection device. It is observed that a lot of medical equipment within the chemical laboratory are made from PP which confirms the suitable choice for PP in its context (figure 71). The material will be evaluated in next chapter whether it could be combined with a desired production method.

Figure 71 - Eppendorf cup made from PP (Biocompare, 2017)

4.3 Production

This chapter compares different production techniques for the production of the blood collection device. At the end of the chapter, two production scenarios are presented that could be used to fabricate the blood collection device.

Production techniques

In latter chapter it is decided that the material for the blood collection device should be a plastic. The most desirable plastic would be "Polypropylene". This chapter describes different techniques that could be used to produce the blood collection device. Four major production techniques for polymers are compared to find out what would be the most desirable technique to continue with. The production technique could also influence the material choice.
Figure 72 compares the four techniques on form freedom, batch size, production rate and costs (CES Edupack, 2017).

	3D printing	Injection moulding	Blow moulding	Thermoforming
Form freedom	Excellent	Excellent	Limited	Limited
Economic batchsize (min-max)	1 to 10	10000 to 100000	10000 to 1000000	10 to 10000
Production rate	1 - 5 pieces/h	60-3000 pieces/h	10 - 250 pieces/h	6 - 1000 pieces/h
Costs	No tooling or mold costs	Mold costs can increase price	Mold costs can increase price	Tooling and mold costs are low
Side notes		Limited mechanical properties Rough finish	finishing not suitable for smaller and detailed forms	Stress effects on corners

◀ *Figure 72 - Comparison of major production techniques for polymers*

3D printing

This technique is ideal for prototyping purposes as the form freedom is excellent. However, a batch sizes of 1000 that is needed for the blood collection device would become relative expensive. 3D print filament with medical grades that meet up to the ISO 10993 standard do exist (figure 73) but the material choice is limited within this technique.

Figure 73 - 3d prints from medical grade PA filament (3DFilaPrint, 2017) ▲

Injection moulding

This is a widespread method for creating plastic products. The design should be withdraw-able in order to injection mold the product, this is something that has design implications concerning the design of the blood collection device. However, the design freedom is still high due to high pressure that is used to push liquid plastic in even the tiniest cavities. This method is only profitable when the batchsize is high. 1000 pieces would be too low as the mold fabrication costs are rather high.

Blow moulding

Blow moulding is a technique in which plastic is pushed in a mold with air pressure. This technique is suitable for middle to large products. Smaller detailed parts are difficult to manufacture which makes this technique not ideal for the blood collection device.

Thermoforming

This technique is used a lot in the packaging industry. The costs are relatively low, but so is the form freedom. This technique deforms a plastic plate in the desired shape which has implications on the design of the product. The form freedom within this technique is too limited in order to fabricate the blood collection device.

Conclusion

Option 1: Use 3D printing as technique to develop the blood collection device. However, some concessions need to be made. Polypropylene is no longer an option as the material is not 3D printable due to warpage of the material. Other medical grades that meet up to the ISO norm should be found that also meet the other requirements of the blood collection device. This option is probably the cheapest option for a batchsize of 1000 pieces.

Option 2: Use Injection moulding as technique to develop the blood collection device. The challenge would be to find a manufacturer that can make a cheap mold for the batch size of 1000 pieces. However, a bigger batchsize would make this technique significantly more feasible. This is something to take into account in the implementation scenario of the blood collection device.

Packaging

The maximum dimension for a package to fit the mailbox is: 38 x 26,5 x 3,2 cm (Postnl, 2017)
It is important that the blood collection device can be transported within these dimensions. The height of the package of 3,2 cm is critical for the design of the device. Current models that are made are too broad to fit in these dimensions which means that the design needs to be changed. A stable basis is however needed in order to create a stable product that ensures trustworthy blood sampling.
Figure 74 shows a possible new design that fits within the dimensions of a mailbox package.

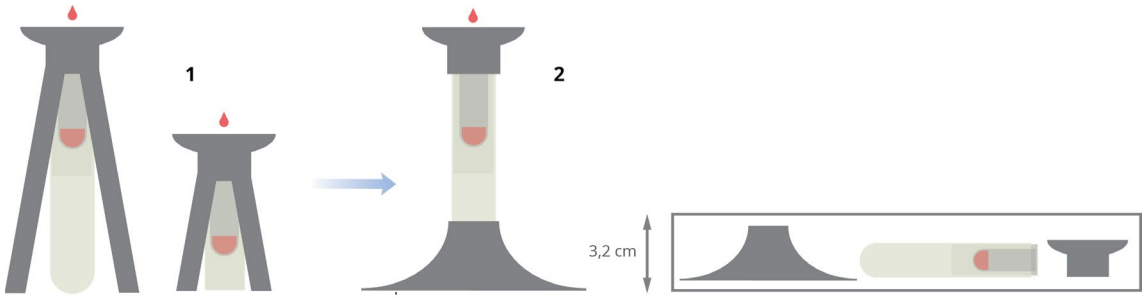


Figure 74 - (1) current design, (2) new design that fits in mailbox

Material in combination with production technique (iteration)

Latter text described that PP would be the most suitable material for the development of the blood collection device. However, chapter "production" described that injection moulding is not feasible due to the batchsize of 1000 pieces. 3D printing would be the most feasible concerning the batchsize. PP is not 3D printable which means that another plastic should be found that is compatible with this technique while living up to the ISO 10993 standard.

Type of 3D printing techniques
Various 3D print techniques are out there that can be used for the production of the blood collection device. The techniques differ from each other in detail precision, surface finish, material properties and production price. The three most commonly used techniques are described and compared for a well considered choice (Appendix I) (3Dhubs, 2017). Selective laser sintering (SLS) seems the best 3D print technique due to its high precision, relative low price and good surface finish.

Expert
Contact is made with 3D print expert: Oceanz (appendix D). This company is specialized in all type of 3D prints including medical 3D printing with the SLS 3D print technique. This company advises to use PA2200 as material for the print. It meets up to the ISO standardization. PA2200 products can be sterilized within the hospital by hot steam autoclavation when that would be desired.

Standards
ISO 13485
The company acts according to the quality managements system for the design and manufacture of medical devices under the name of ISO 13485. This is something that is desired for the production of the medical components that come in contact with the human body.

ISO 10993-1 and USP/level VI
3D printable PA2200 does meet up to the desired biocompatible regulations.

Surface possibilities
There are various finishing possibilities for the surface of the blood collection device. It is desired to treat the surface in a way it is as smooth as possible to guide the blood sample as efficient as possible towards the capillary tube.

- *First 1000 pieces within the batch size will be SLS 3D printed by using PA2200 plastic.*
- *Injection moulding with PP plastic is recommended to NKI-AVL when the batch size rises over 10000 pieces in a future scenario.*
- *The design of The Capillar is adjusted which makes it fit inside the users mailbox.*

4.4 Aesthetics

Until now, the focus on the design of the blood collection device was merely functional. Aesthetics are important in order to convey meaning during product user interaction. This chapter describes the aesthetics of the blood collection device. What should the product convey to the user when it is used? How could this be realised in the design of the device?

Six key points have been formulated that cover the desired form language that should be conveyed to the user by the blood collection device. For each key point, a collage is made as inspiration for the aesthetic design of the blood collection device (figure 75).
The key points embody *"trust and confidence"* which are part of the original design vision

Transparent
Transparency in the design has both a practical and cognitive advantage as the user can observe what is going on during the sampling procedure of his own blood. This is important as the user should receive feedback about the amount of blood that is sampled. It also makes the user feel more in control than within a more closed, less transparent design.

Minimalistic
A minimalistic design eliminates distraction, which is exactly what is desired in a product like this. It should be clear what the procedure steps are and what each part of the device is for.

Intuitive
This key point is closely related to minimalistic. The user should understand what steps to follow right away. This could be accomplished by choosing the right color, shape, texture, dimensions and material.

Hygienic
This keypoint is both practical and cognitive. From the practical point of view is it important to be sure that the device stays clean and hygienic. This can be accomplished by choosing the right surface texture, shapes and material. It is also important that the user gets the impression that the device is actually clean and hygienic, which can be accomplished by choosing the right color and texture.

Trustworthy
The user is dependent on the blood collection device as it collects and carries his own blood. The device should convey trust to the user which can be accomplished by stability during use, robustness, transparency and clear feedback from the device towards the user.

Friendly
Blood sampling might be a scary unpleasant thing to do as it requires a finger puncture and actual blood flowing from the finger inside the blood collection device. A friendly appearance compensates for this unpleasant experience. This can be accomplished by using calming, friendly colours and round shapes instead of hard edgy lines and shapes.

Figure 76 shows what the design of the working prototype looks like of The Capillar. This design will be the starting point for the aesthetic redesign.

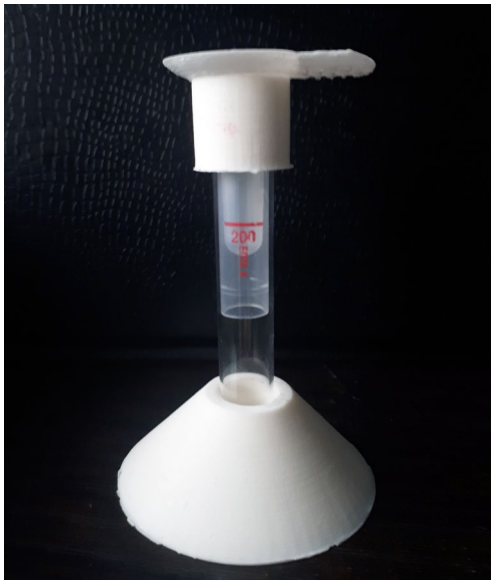


Figure 76 - Appearance of The Capillars working protoype.

Figure 75 - Overview of collages for desired aesthetics

Friendly

Transparent

Trustworthy

Intuitive

Minimalistic

Hygienic

New design

The general shapes of the blood collection device have already been defined by its functions. In the new design, the general shape is more organic and less edgy to make it appear friendlier. The seperate components flow into each other more naturally to make the design look more minimalistic and clean. The new design can be seen in figure 77 and 78.

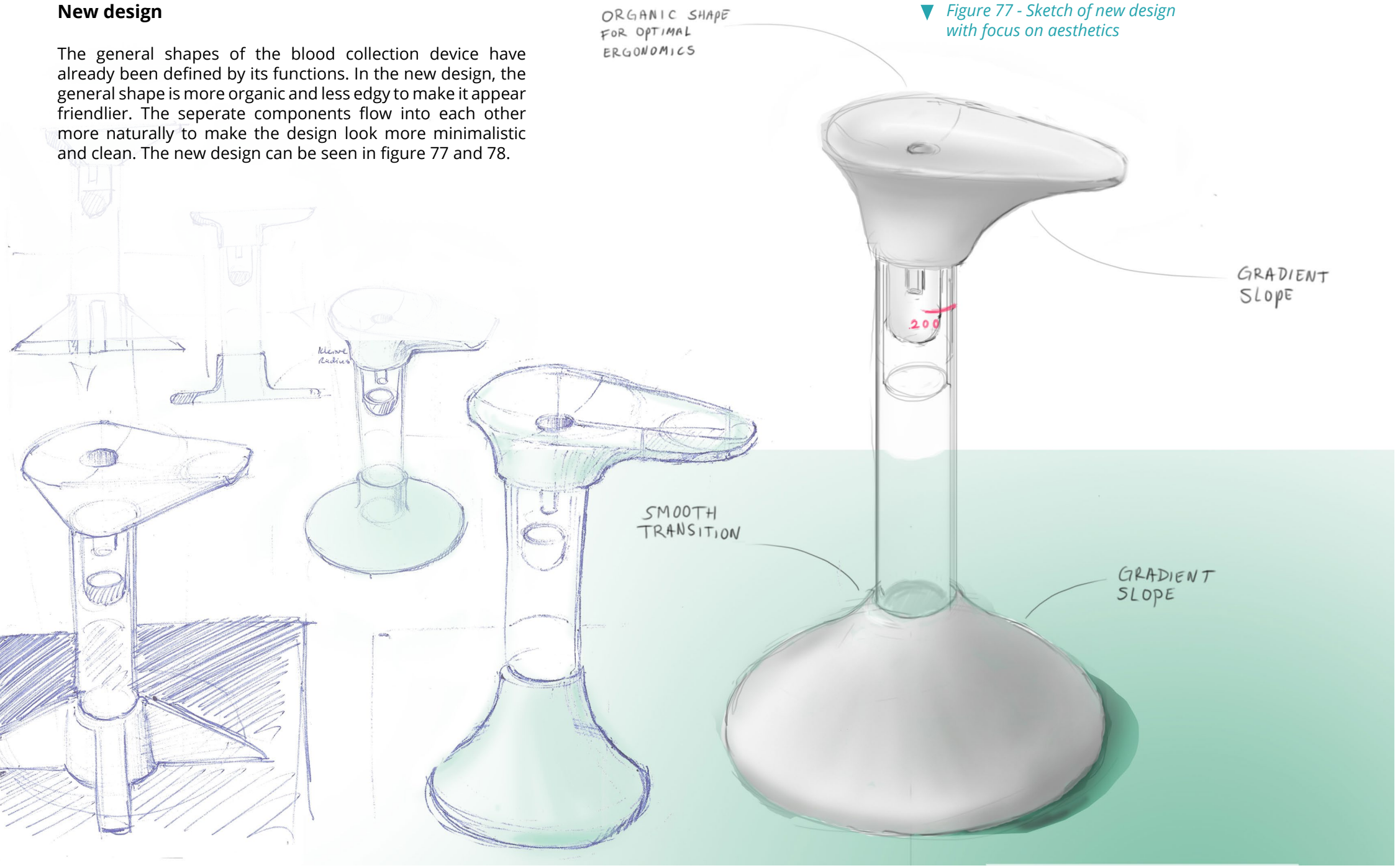


Figure 77 - Sketch of new design with focus on aesthetics

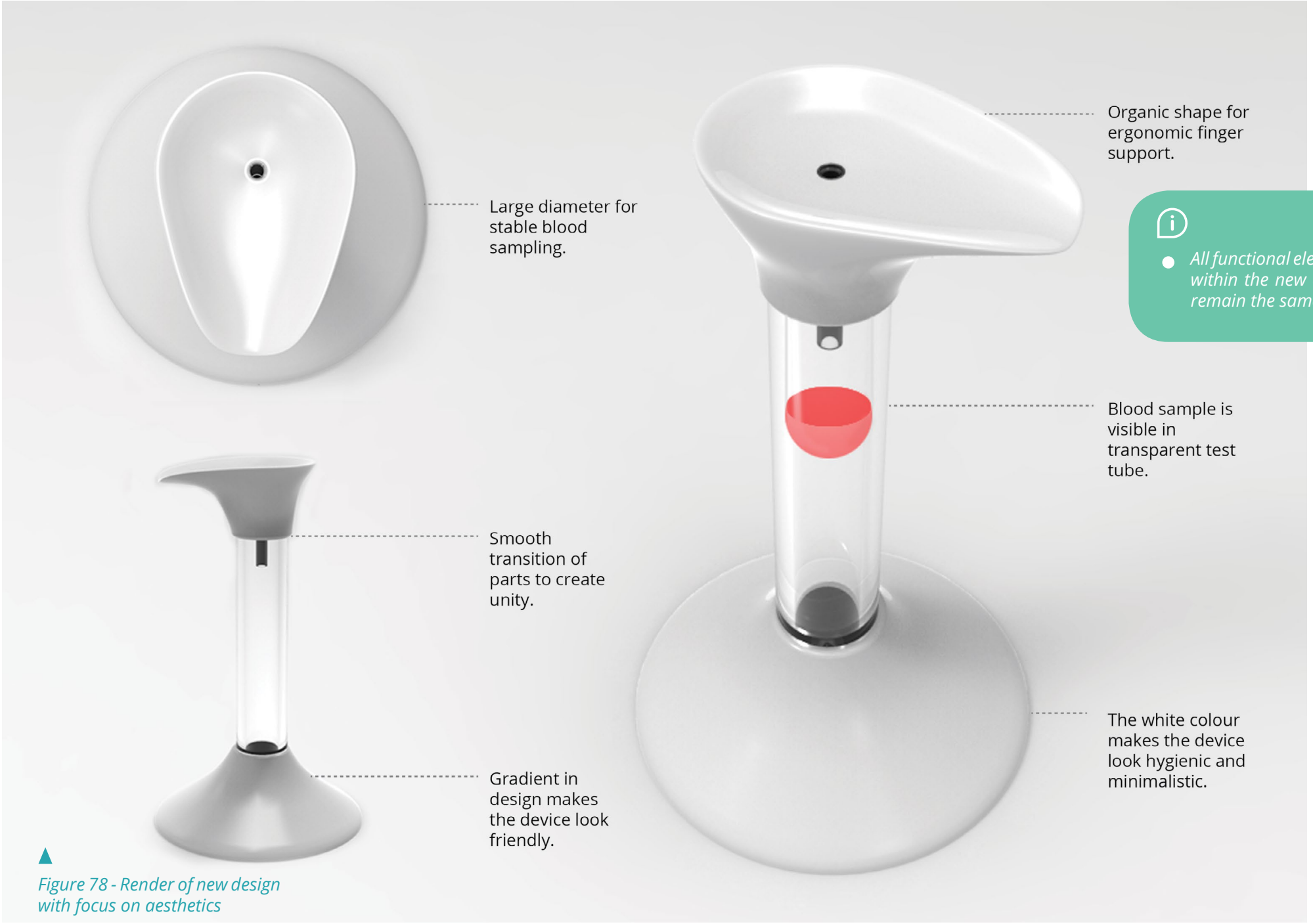


Figure 78 - Render of new design with focus on aesthetics

4.5 Optimizing blood flow

This chapter tests the aesthetic prototype to make it ready for the final user test. Findings from this test are used in an iterative way to come up with a design that functions and looks in the desired way.

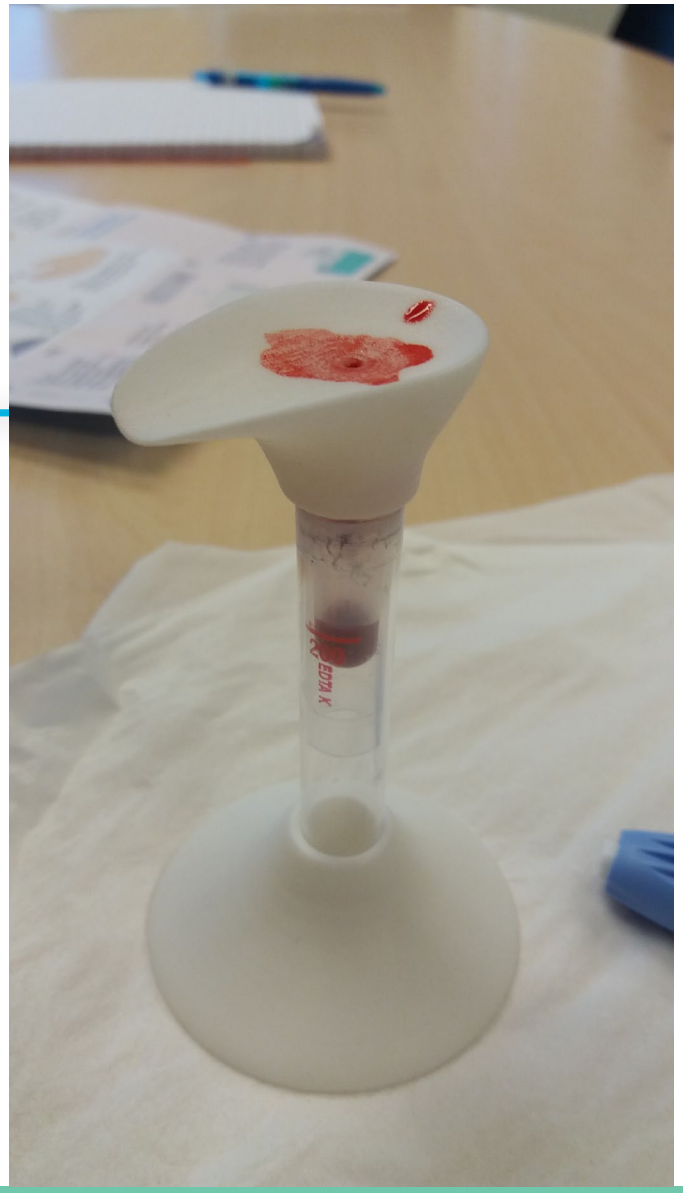
Testing the aesthetic prototype

The last time that the design of the Capillar was tested was before the creation of the aesthetic prototype. Although the working principle of the aesthetic prototype remains the same as the working prototype, it is important to also test this new design as the material, dimensions and tolerances of the new model have been adjusted. It would be shortsighted to just assume that the aesthetic prototype behaves in the same way. Next page shows the user test and insights that were derived during the test with the aesthetic prototype.

Test - Aesthetic prototype

Participant tests aesthetic prototype

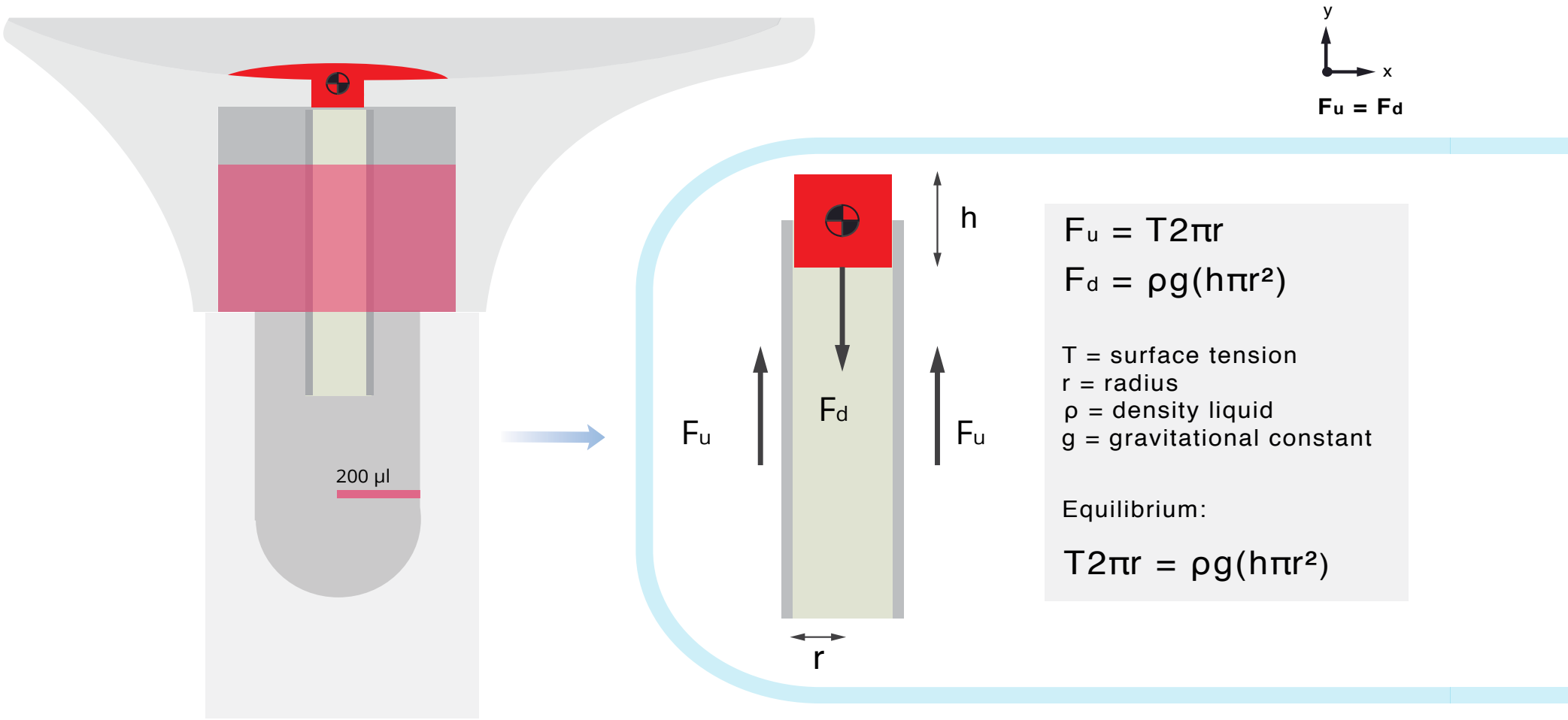
Results after blood sampling procedure



Insights:

- Ergonomics of the protoype are perceived as good
- The closing mechanism works good and participant is able to assemble and disassemble the device
- The blood does not enter the inlet of the device right away. After a while of stagnation, the blood starts to flow in the capillary tube and microcontainer. This is however perceived as confusing and untrustworthy.
- The user is able to collect the required amount of blood, but due the fact that the bloodflow stagnates at first, it is recommented to take a closer look at the blood flow of the system.

Figure 79 - Abstraction of the model's blood flow



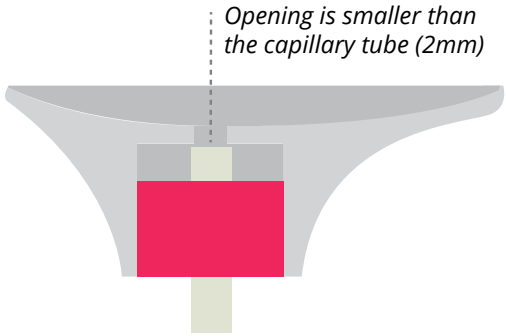
Stagnation of blood flow

The left side of figure 79 visualizes the situation of the blood flow within the aesthetic prototype, it shows the cross-section of the models side view. The situation is abstracted on the right side of the figure by applying Jurin's law, which describes the rise and fall of a liquid within a capillary tube. This abstraction has been derived from a study on capillary action that can be seen in appendix R. From observing the abstraction it can be concluded that the stagnation in blood flow is related to the total volume **(hπr^2)** within (or above) the capillary tube and the width of the opening above the capillary tube **(r)**

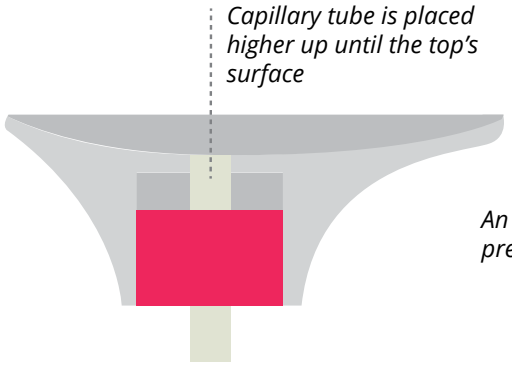
Pressure

Another possible reason that is not shown in the figure is possible under pressure that is created when blood enters the capillary tube. In the old working prototype model, the tolerances where quite loose which possibly resulted in leakages in which the air could 'escape' the model. This new model has tight tolerances with possibly less air leakage. Next page shows models (B,C,D,E and A2) with variations to the aesthetic prototype (A). These models are then tested to find out how to optimize the blood flow during sampling.

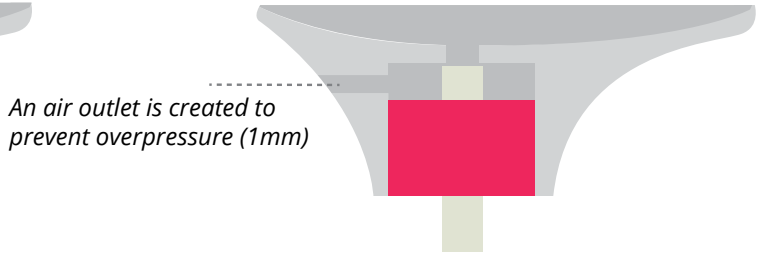
Fine tuning blood flow



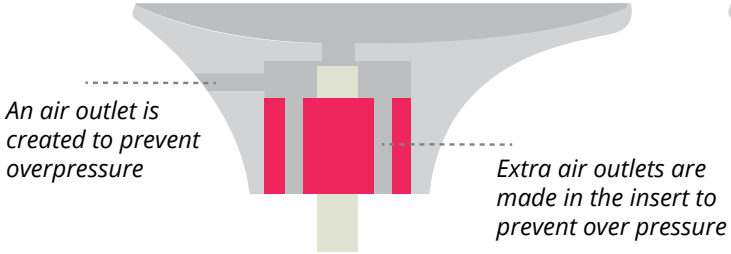
A This model is the 0 test. Last aesthetic prototype test showed that the capillary tube and opening had difficulties in transporting the sample towards the container.



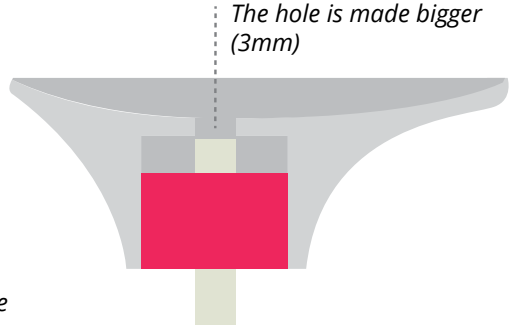
B The hole in the model is made bigger which enables the capillary tube to be placed directly on the surface.



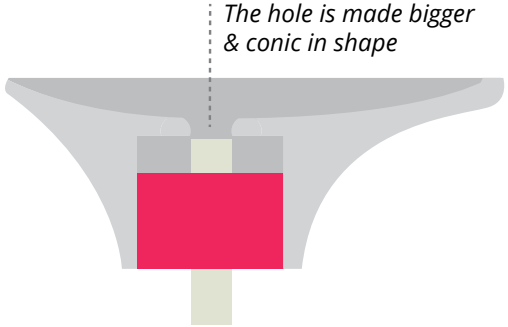
C An air outlet is made at the side of the model that should prevent overpressure within the device.



D This model is the same as model C except the fact that extra air outlets are made in the insert to prevent over pressure.



E This hole in the model is made bigger, but just small enough to make sure that the capillar can not go through.

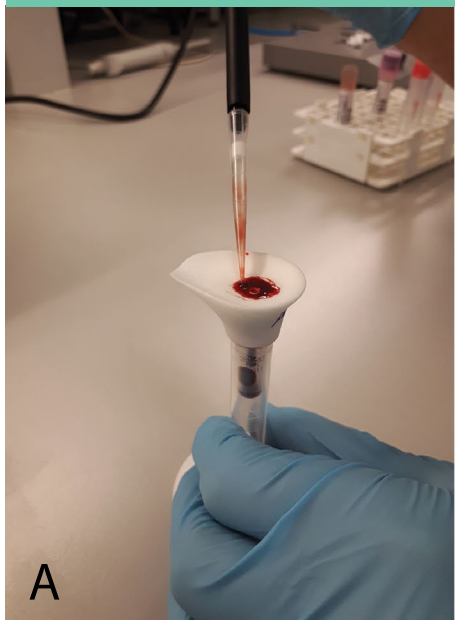


A2 This model is an iteration on model E. The hole is made conic to make sure that more blood volume can built up.

Variables that could influence test results

- **Inlet diameter:** An opening that is too small might result in too much capillary action, which prevents the blood from dripping in the microcontainer.
- **Overpressure:** When blood enters the capillary tube, air is compressed within the microcontainer as air cannot leave the device which results in overpressure. Air outlets could be a solution.
- **Inlet shape:**The inlet shape determines how much blood can be 'built up' upon the capillary tube. This volume can influence the blood flow.

Fine tuning blood flow



Setup
Whole blood from the laboratory is used for these tests as the number of tests required a significant amount of blood. Small droplets of blood (40 µl) are placed close the the models inlet hole by using a pipette. A finger is used to spread the blood out over the inlet. This is the best representation of the real situation.

A
Initially, the blood sample gets stuck at the surface of the inlet. After some time the blood starts to enter the capillary tube. When the blood start to flow, it is transported quite smoothly.

B
The blood does noy enter the capillary tube.

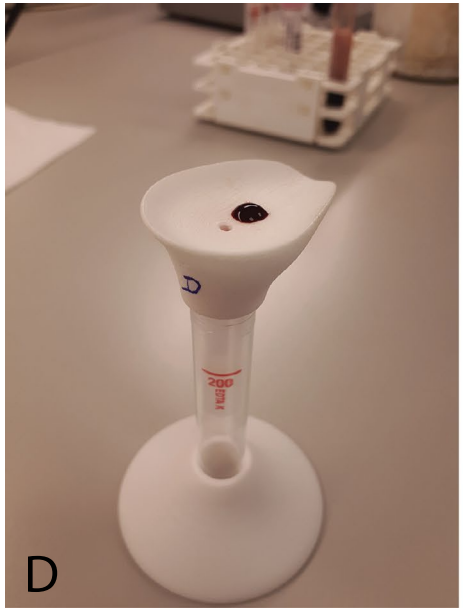
C
The blood does not enter the capillary tube at first. The results are quite similar to model A. After a while the blood starts to flow inside the microcontainer.

Insights

- Overpressure seems to be part of the problem. Model A and C eventually worked after initual stagnation. it seems that air can escape through small openings between the capillary tube and the model's surface.

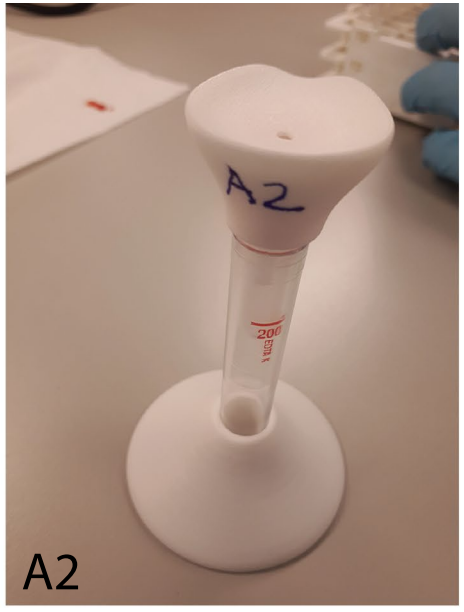
Air cannot escape model B due to a capillary tube that is placed though the models surface which seals of the air flow.

- Overpressure is not the only factor in smooth blood flow. Model C, with an additional air outlet, proves to work similar to model A. It can be concluded that the model needs tiny leaks for air. Aditional air outlets however have no effect on the blood flow.

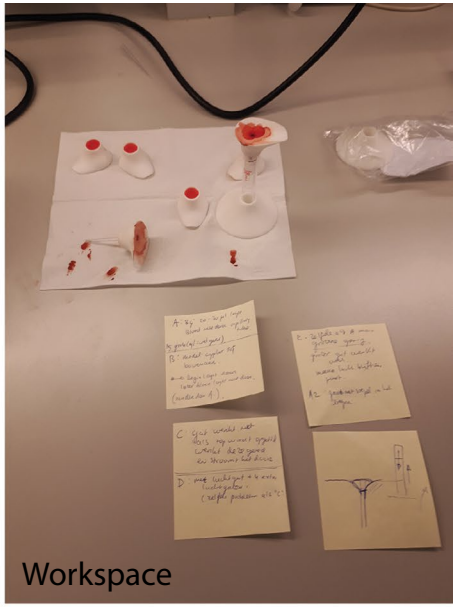


D
The results of this test is the same as within model C and A. At first a stagnation of the blood flow takes place. After a while when more blood is placed on the model, it starts to flow towards the microcontainer.

E
The bloodflow starts with a stagnation. The stagnation however, lasts clearly shorter than in model A. After that the blood starts to flow efficiently towards the microcontainer.



A2
The stagnation lasts very short after which the blood flows efficiently towards the microcontainer.



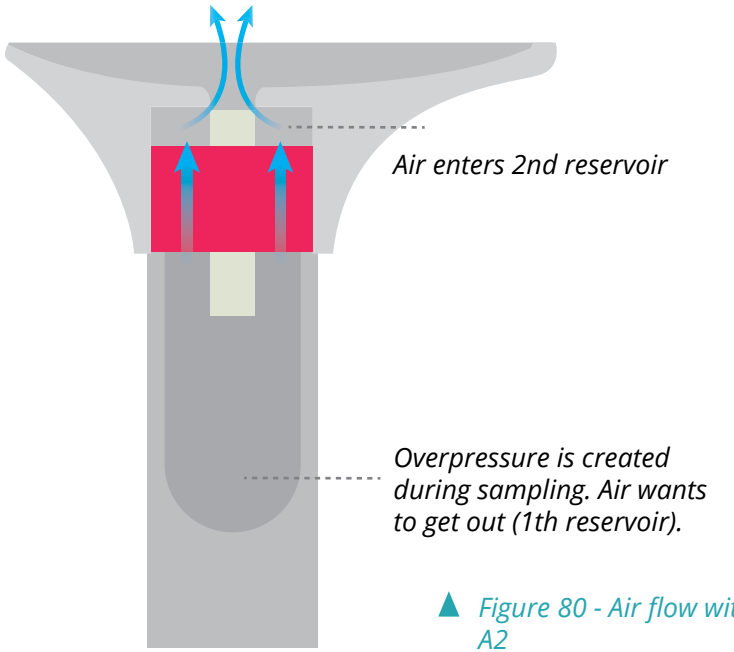
Insights

- Model D confirms that additional air outlets do not affect the blood flow of the model
- Model E shows that an increased diameter of the opening makes the blood flow better. This has to do with increased initial volume of the sample before it is transported towards the microcontainer. The principle is explained in appendix R.
- Model A2 shows that an increase in the openings volume results in better blood flow.
- It can be concluded that small air leaks and large(r) openings volume- result in a smoother blood flow.

Validation of model A2

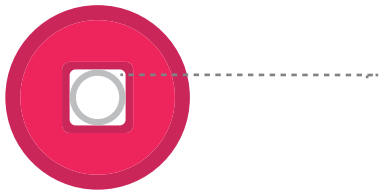
Latter test concluded that small air leaks and a larger opening volume resulted in better blood flow, which makes model A2 the best performing design. The model seems to work, but it is still unclear how the air in the system leaks out of the device. It would be shortsighted to trust on coincidence, which is the reason that 10 models of A2 have been made to test whether the design is trustworthy and can therefore be used during the final user test.

Results
7 out of 10 models resulted in smooth blood flow. 2 models did not work at all. The blood just lay on top of the device without any blood flow. 1 of the models resulted in slow blood flow. It is expected that these irregularities have to do with overpressure that is not able to leave the device. Figure 80 takes a closer look to the airflow of model A2



▲ *Figure 80 - Air flow within model A2*

Inlet
Figure 81 shows the inlet that is used inside the top. The air can leave the 1th reservoir due to the shape of the capillary tube inlet. When the air is through the inlet, it is arrives in a second reservoir.

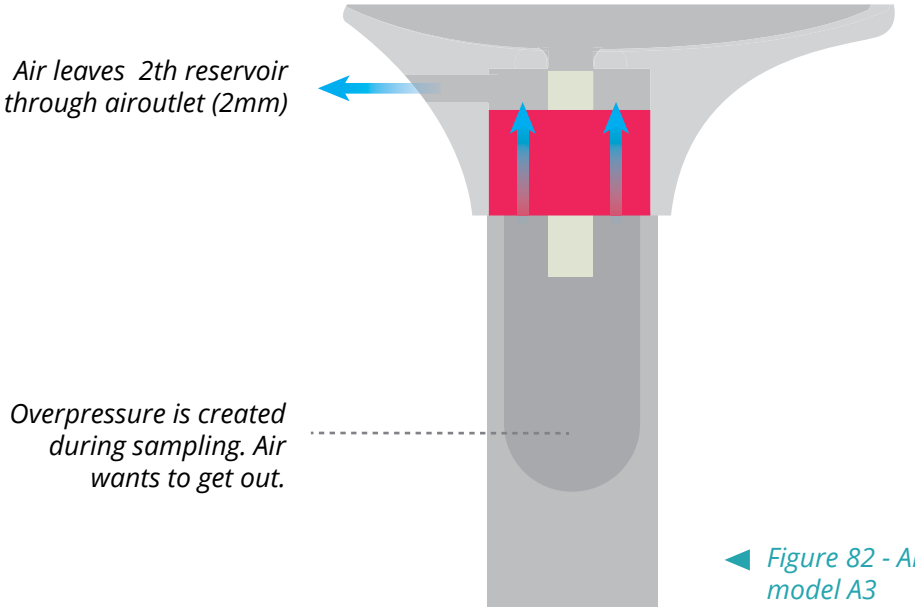


Shape of inlet capillary tube within the insert is squarelike. The space between the diameter of the capillary tube and the square inlet leaves room for air to escape the 1th reservoir.

◀ *Figure 81 - top view of insert*

Model A3

It is desired to have a design that is not so sensitive to slight production or assembly irregularities. A new model is made that has an air outlet just like model C (figure 82). However, this outlets diameter is 2mm instead of 1 mm. It is a possibility that the air outlets of model C and D failed because they were too small. The rest of the model is the same as model A2.



◀ *Figure 82 - Air flow of model A3*

Validation of model A3

This model is again tested 10 times for validation. It is expected that the blood flow will be constant due to the integration of an intended air outlet, that is not dependent on tolerances (figure 83)

Results
All the models had smooth blood flow without any flaws. There was also no initial stagnation observed in the beginning of the blood flow in any of the models. It can be said that model A3 has the desired blood flow that is constant and trustworthy. It will therefore be used as final model during the final user test.

Figure 83 - Model A3

Conclusion

It would have been better when the air outlets in model C en D were bigger as that would have resulted in quicker insights. Wrong assumption were made based on these models. It would also have been better to test each model multiple times in order to eliminate coincidences.

- *Model A3 will be used for the final usertest as the model facilitates the desired blood flow.*
- *Model needs a bigger conic shaped opening*
- *Model needs an air outlet to prevent over pressure.*

4.6 Final design

This chapter presents the final design of The Capillar. Each component within the total assembly is shown to get a clear understanding of the device. Additional information per component can be found in the bill of materials (Appendix D) and technical drawings (Appendix S).

Assembly

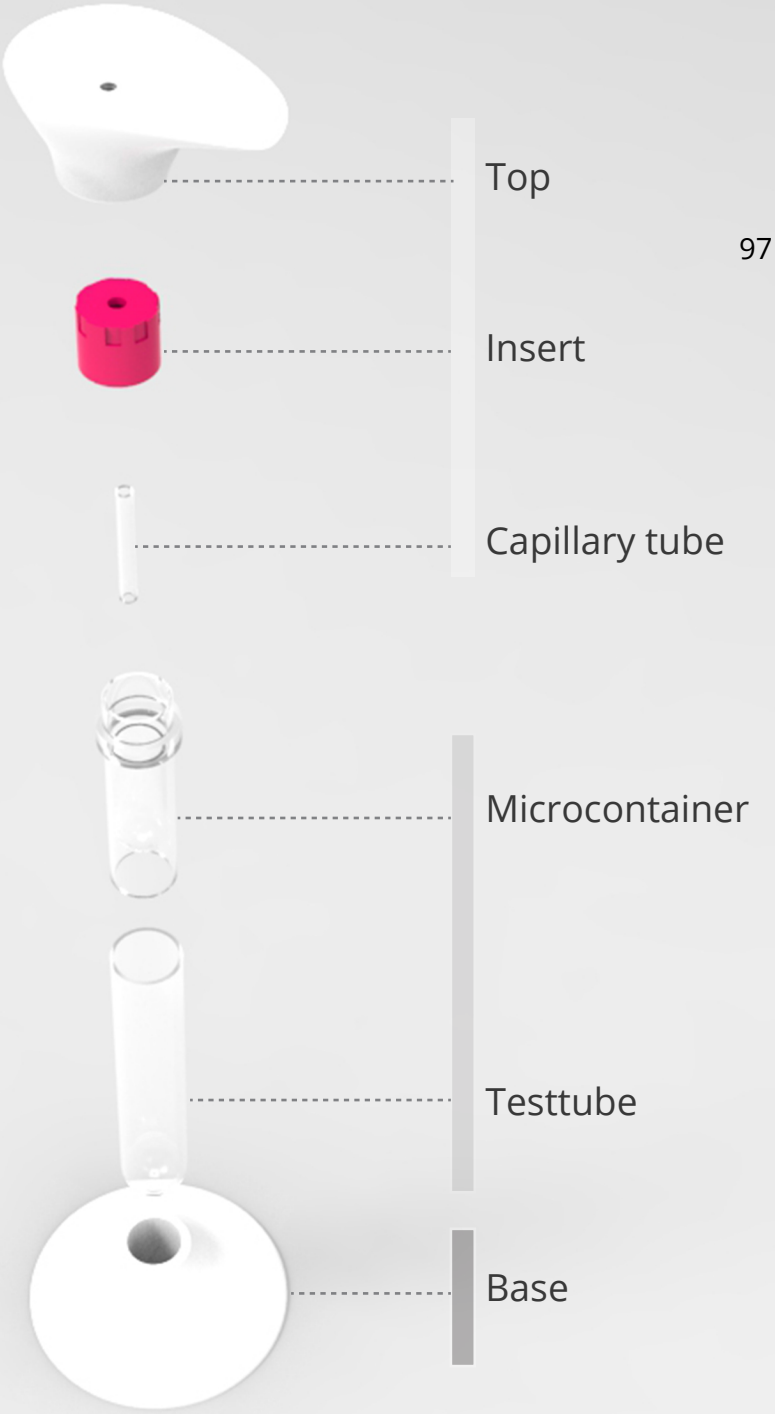


Figure 84 - Assembly and exploded view of The Capillar

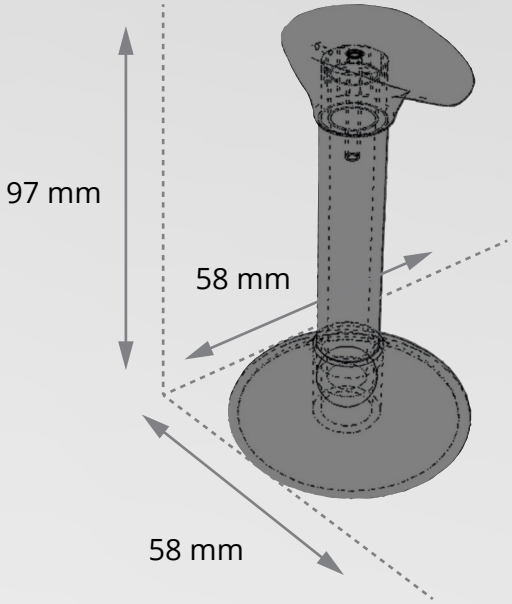
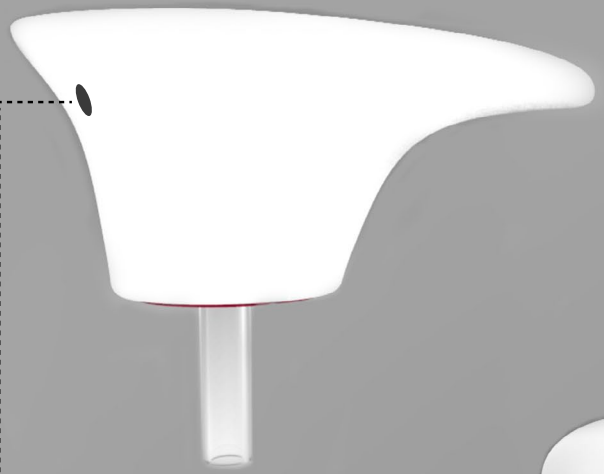


Figure 85 - Outer dimensions of The Capillar

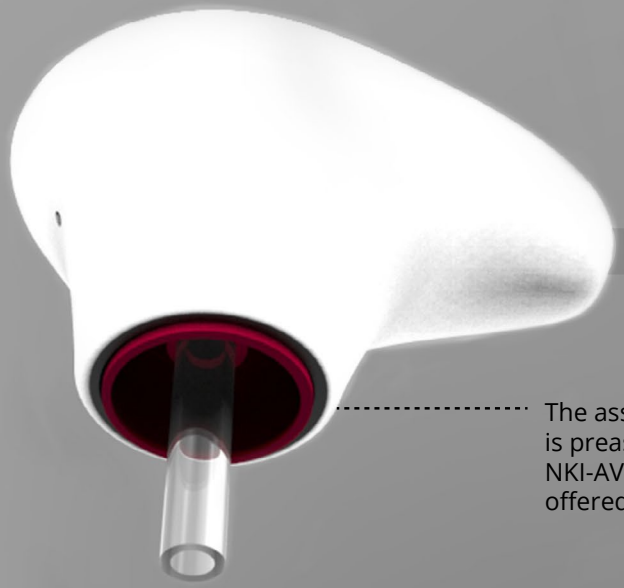
Assembly

Figure 84 shows the assembly and exploded view of The Capillar. The top, insert and capillary tube form a subassembly that will be shown on next page. The microcontainer and test tube also form a subassembly. The base is a standalone part. Figure 85 shows the outer dimensions of The capillar.



Air outlet makes sure that air can leave the device to prevent over pressure.

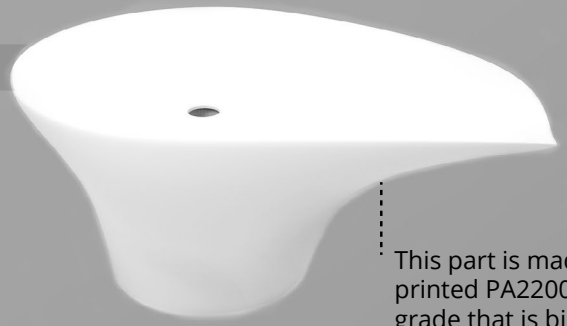
The top and capillary tube can both be assembled by force fit. No additional adhesives are needed.



Subassembly

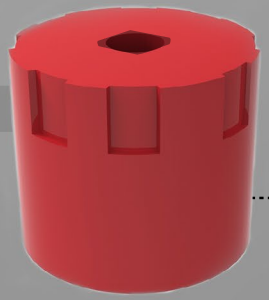
The assembled top part is preassebled within NKI-AVL before it is offered to the user.

Top



This part is made from (SLS) 3D printed PA2200 plastic, which is a grade that is biocompatible. A surface finish makes sure that the blood will flow easiliy towards the hole. The elongation is meant for the finger to rest upon. The bill of materials in appendix D show additional details such as the manufacturer and costs.

Insert



This part is a purchase part. It is the upper part from the Microvette 200 (appendix D). The part can be assembled to the top by force fit by pressing the ribs within the ribs of the top part.

Capillary tube

This part is a purchase part. It is a tube with an inner diameter of 2 mm. It is coated with EDTA to make the component anticoagulant. The purpose of the component is to attract and transport blood from the finger towards the microcontainer.

Subassembly

The microcontainer is placed within the testtube. The parts are assembled by adding a tiny bit of polymer glue between the two parts. The adhesive is transparent and invisible to the eye.

Microcontainer

This part is a purchase part, The purpose of the component is to preserve the blood sample. The dead volume within the container is kept low due to the round shape. The pink line indicates the amount of blood that needs to be sanmpled. The container is coated with EDTA.

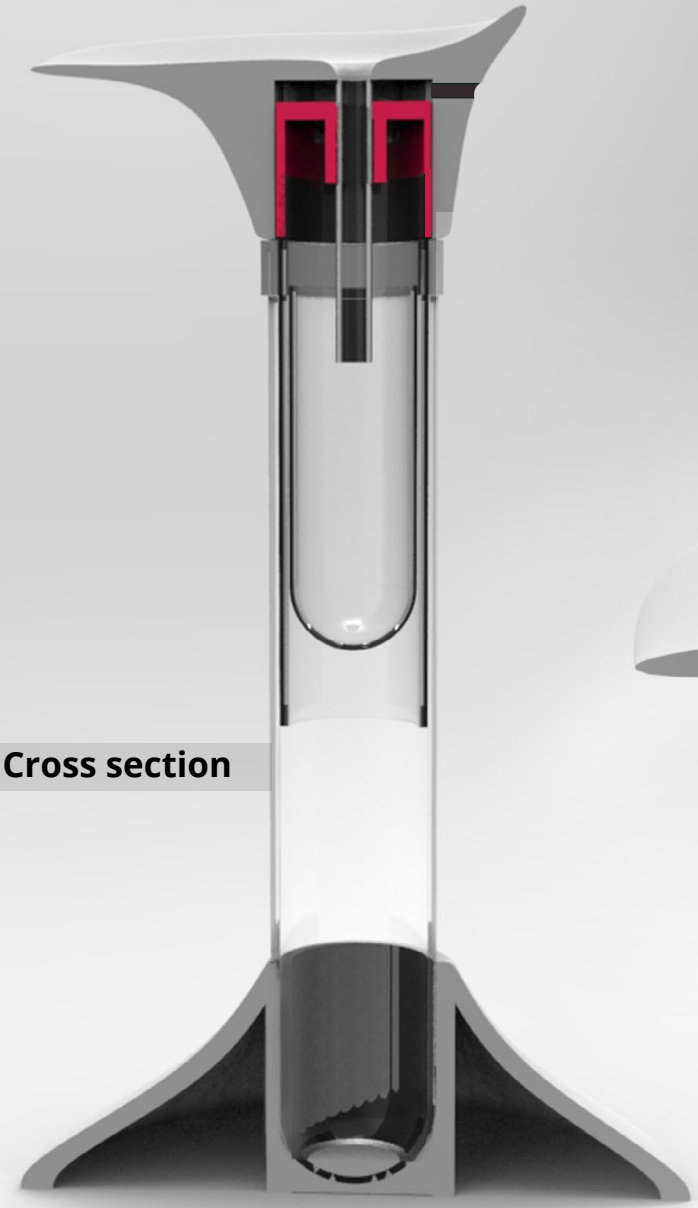
Testtube

This part is a purchase part. It is a standard PS testtube that will make sure that the blood sample can be directly offered to the chemical analyser due to its standardized dimensions. Appendix D shows details about this part.

"The use of an adhesive does not have implications on the safety of the system as only the outer part of the microcontainer comes in contact with the adhesive."

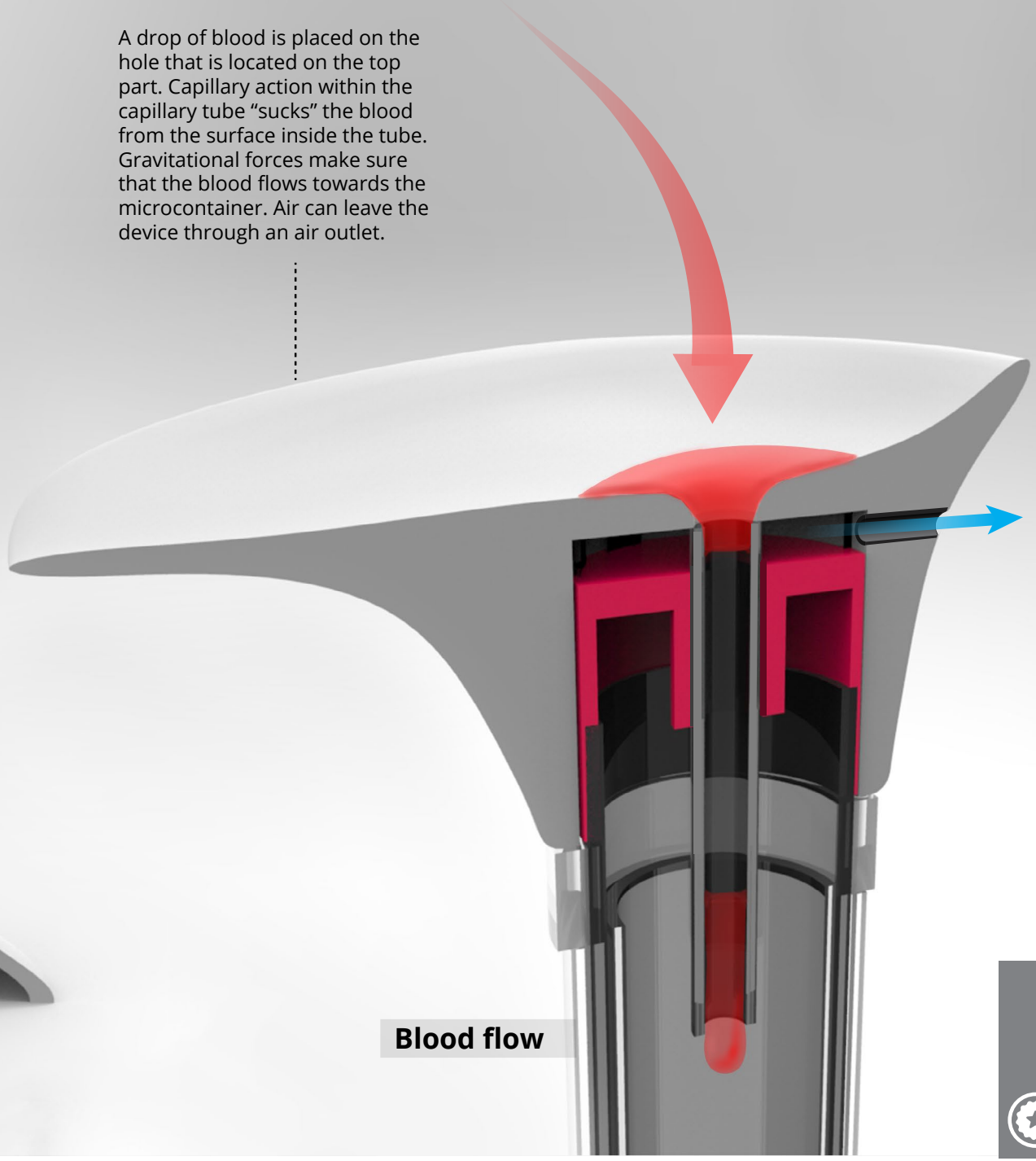
Base

This part is made from (SLS) 3D printed PA2200 plastic, which is a grade that is biocompatible. The broad diameter makes sure that the device is stabilised when being in use. See appendix D for additional details.



Cross section

A drop of blood is placed on the hole that is located on the top part. Capillary action within the capillary tube “sucks” the blood from the surface inside the tube. Gravitational forces make sure that the blood flows towards the microcontainer. Air can leave the device through an air outlet.



Blood flow

User samples blood with The Capillar ▲

This chapter described the final stage of the design of The Capillar. The next chapters describe packaging, transportation and implementation.

4.7 Transportation

This chapter describes the transportation of the blood collection device. How should the components of The Capillar be packaged, what regulations should be taken into account and how is the package send?

The transportation of The Capillar can be divided in two separate actions. The delivery of the package from NKI-AVL towards the user and the delivery of the blood sample towards NKI-AVL (figure 86). Both actions have their own challenges.

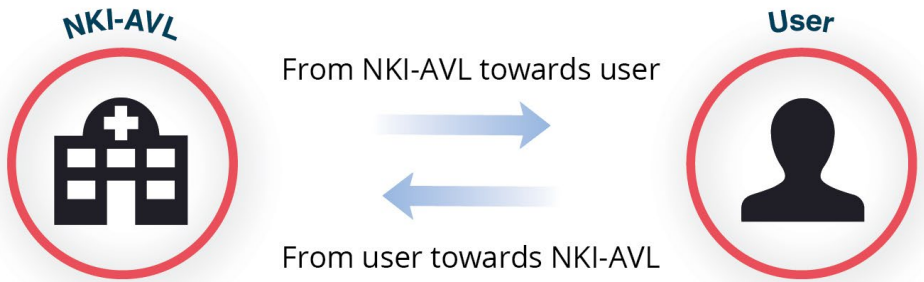


Figure 86 - Transportation of The Capillar and blood sample divided in two actions

From NKI-AVL towards user

Packaging

NKI-AVL sends The Capillar by regular mail to the user. It is important that the package fits within the mailbox of the user as earlier is mentioned.

So the package should fit within the mailbox of the user. It is also important how the user opens the collection kit as this conveys how the kit should be used. A box in which the upper lid can be opened is desired as it creates a clear overview of components that are inside the blood collection kit. A folding box is a box that meets up to this wish (figure 87). Boxes are often sold in paper size dimensions. A folding mailbox with A5 dimension would be a good option as it is big enough for all the components, small enough to fit in the mailbox and contains a clear and easy opening for the user.

Figure 87 - Folding box

From user to NKI-AVL

This action is more complex as the user sends biological material towards NKI-AVL. Regulations make sure that no contamination takes place which might otherwise be damaging to mail deliverers and other people involved.

Packaging regulation

The transportation of biological specimen should be done according to the UN3373 category B regulation. IATA Packaging instruction 650 (IATA, 2017) describes how such a package should look like. The most important elements that should be present in the packaging of the blood sampling are the following:

Packaging must consist of three components:

1. *A primary container/vial in which the blood sample is stored.*
2. *A secondary packaging of the container that is leak proof and contains absorbing material.*
3. *An outer packaging that protects the components inside. The packaging should be sealable.*

1. Primary container

Figure 88 shows the primary container in which the blood sample will be stored. The microcontainer is embedded in a test tube which is closed by push cap.

◀ *Figure 88 - Primary container of blood sample*

2. Secondary packaging

The secondary packaging should stabilize the blood sample and prevent it from leaking. An absorbing material should prevent the blood from spreading out the package when it somehow started to leak. Figure 89 shows a transport blister that is specially designed for blood sample transport. The blood sample can be placed inside and closed. The inner part is covered with absorbing material. A wholesaler for this component can be found in the bill of materials (Appendix D).

◀ *Figure 89 - Transport blister for blood sample*

3. Outer packaging that should be sealed

The outer packaging of the blood sample should make sure that no liquid can leave the package as it should be sealed. This is an extra safety measure as the secondary packaging also seals the blood sample from its environment. Figure 90 shows the outer packaging that will be used. It is a padded envelope that can be sealed. The packing also communicates that it contains biological material according to UN3373 regulations. The wholesaler for this component is described in the bill of materials (Appendix D).

◀ *Figure 90 - Safety bag as outer packaging for blood sample*

- *An A5 folding box is chosen as packaging of the kit.*
- *The kit contains components that comply to UN3373 regulations to enable the user to send back the blood sample to NKI-AVL.*

4.8 Instructions & package design

This chapter describes how information of the use of the blood collection device is conveyed towards the user. In what way is the use best communicated? User tests have been done to validate what would be the best approach and whether elements in the instructions should be changed.

User- information touch points

The user scenario has been analyzed in the beginning of the project. For the manual/instructions it is interesting to map where the information providence of The Capillar towards the user takes place (figure 91). The following paragraphs will elaborate on points 2,3 and 4. How to make these touch points in information providence to the user as effective as possible.

Manual

The Capillar consists of several components that the user should both assemble and disassemble during usage. The question is what sequence in the assembling and disassembling is considered the best. Points of attention are the number of actions that it takes to perform the blood collection, the clearness of actions during the blood collection and the chance of failure during sampling.

Packaging / manual proposals have been made and tested during user tests to find out whether information is conveyed in the desired way and in what way The Capillar should be offered to the user. Iteration steps and user test can be seen in appendix P. Figure 92 shows the manual's final design. Figure 93 will be placed inside the packaging to make the introduction of parts easy.

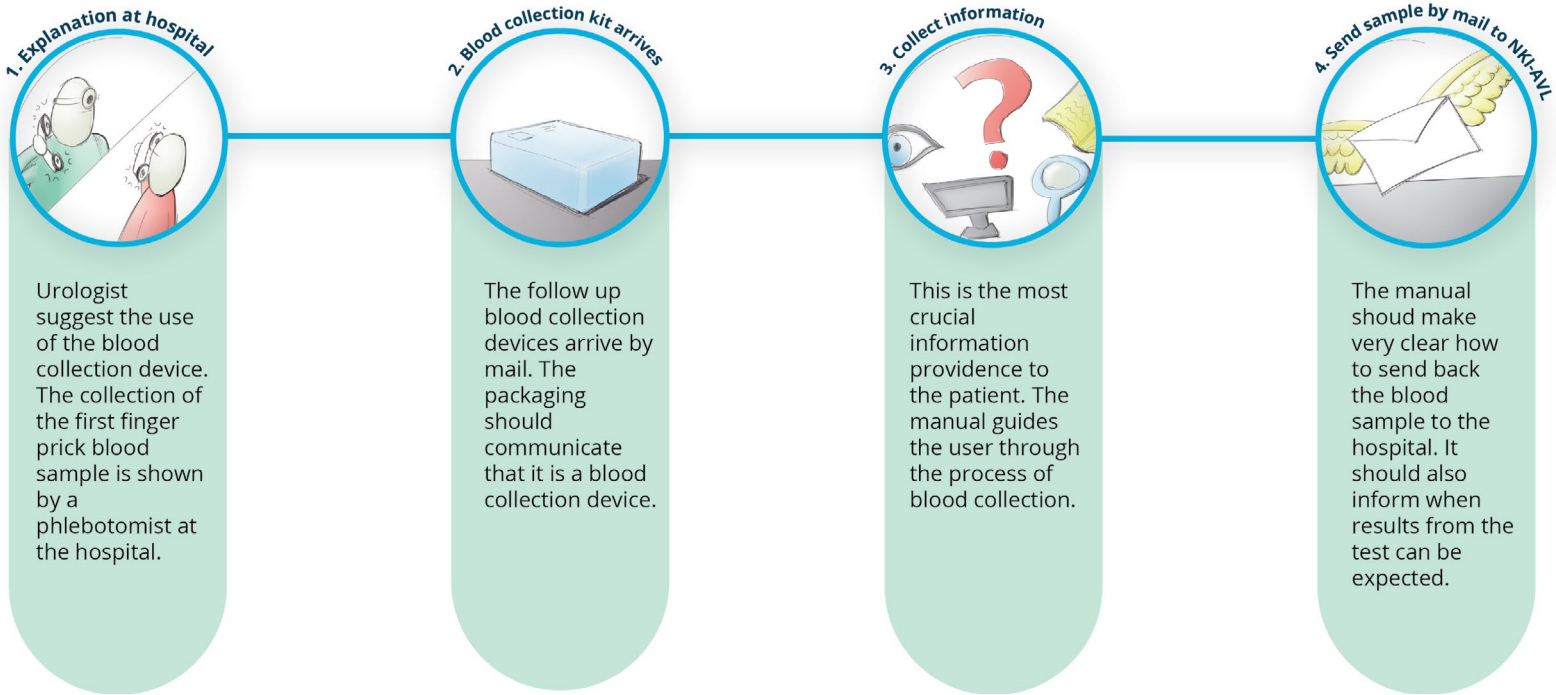


Figure 91 - User-information touchpoints

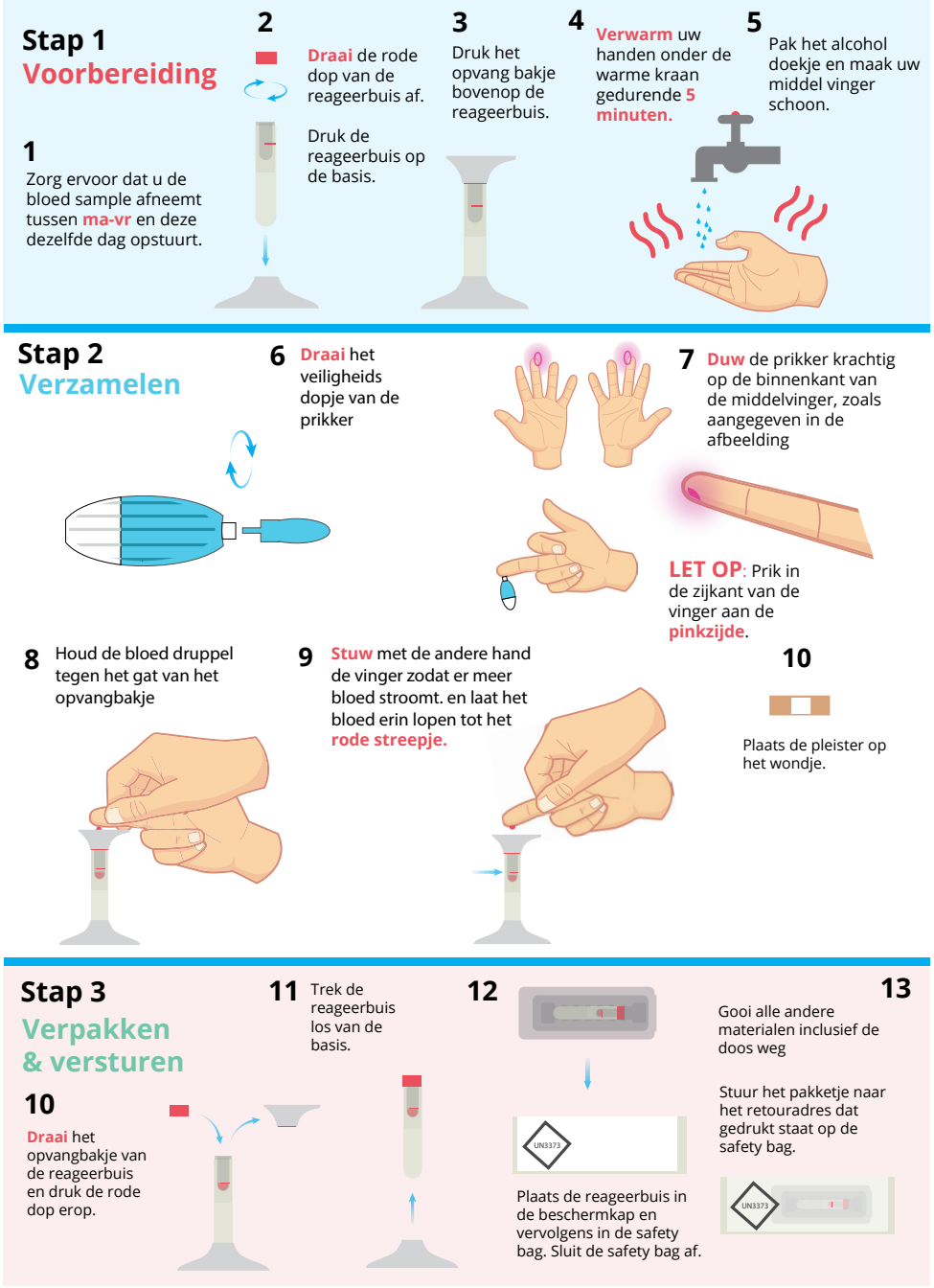


Figure 92 - User manual

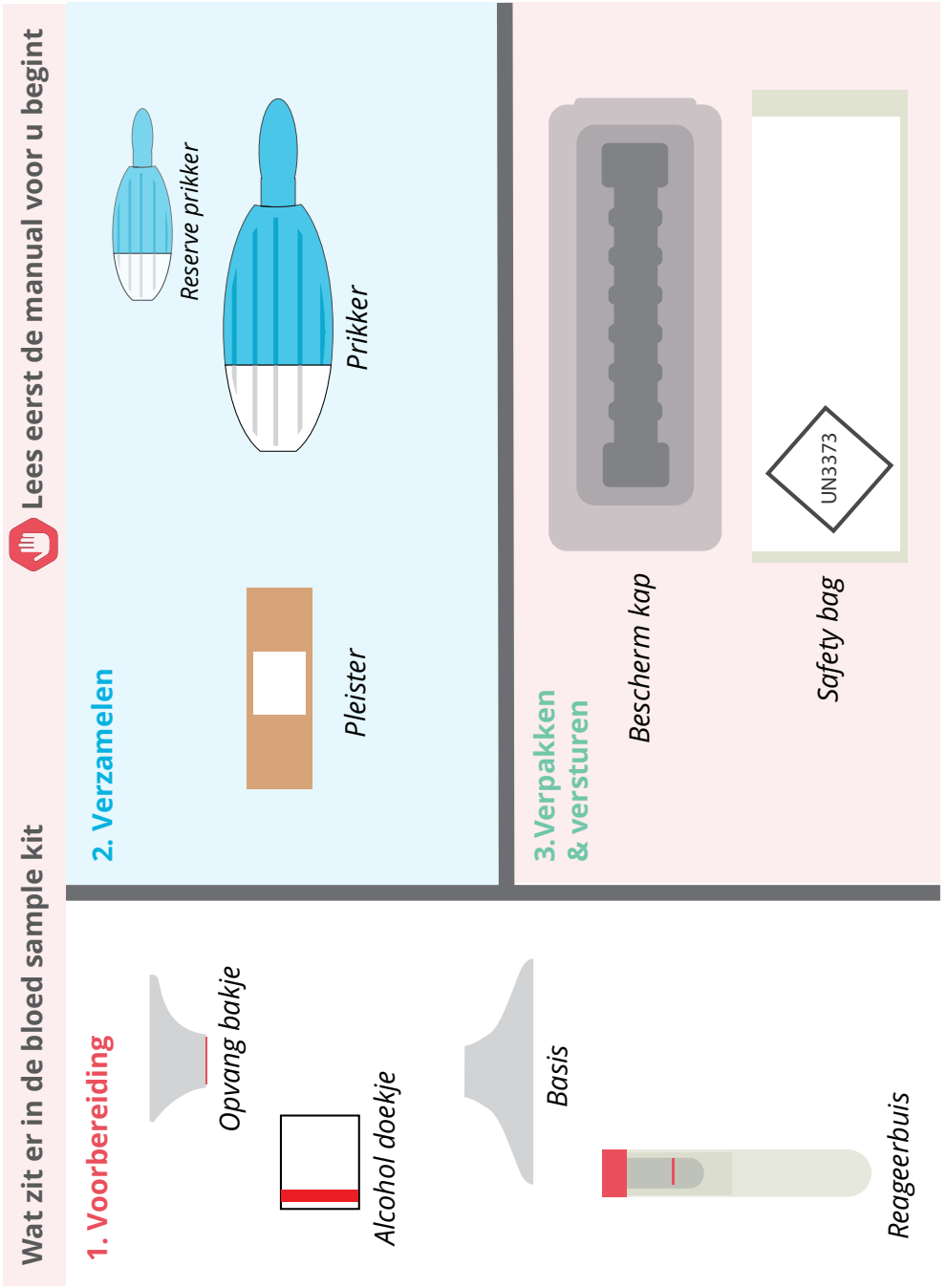


Figure 93 - inventory of parts

Figure 94 - Design of the upper part/lid of the box

Figure 95 - Outer design of user manual

Print

A text, logo and/or colours can be applied to the box in order to give the package a character, to communicate to the user what the device is about and to give a professional medical touch to the package which might convey trust to the user when it is opened (figure 94). The bill of materials (Appendix D) describes a manufacturer that is able to print custom made designs on A5 folding mailbox boxes. The outer part of the manual contains the same graphic design to maintain unity within the overall appearance (figure 95).

Inner design of package

The components that are inside the package need to be kept in place. This is important to prevent the components from damaging during transportation and important for the communication of the blood collection procedure The fixation of components will be done by cardboard dividers, which will be introduced in next paragraph.

Integration of package design and instructions

Figure 96 and 97 show the integration of transportation elements described in latter chapter and instruction / package design. Combining the two results in intuitive communication of its content.

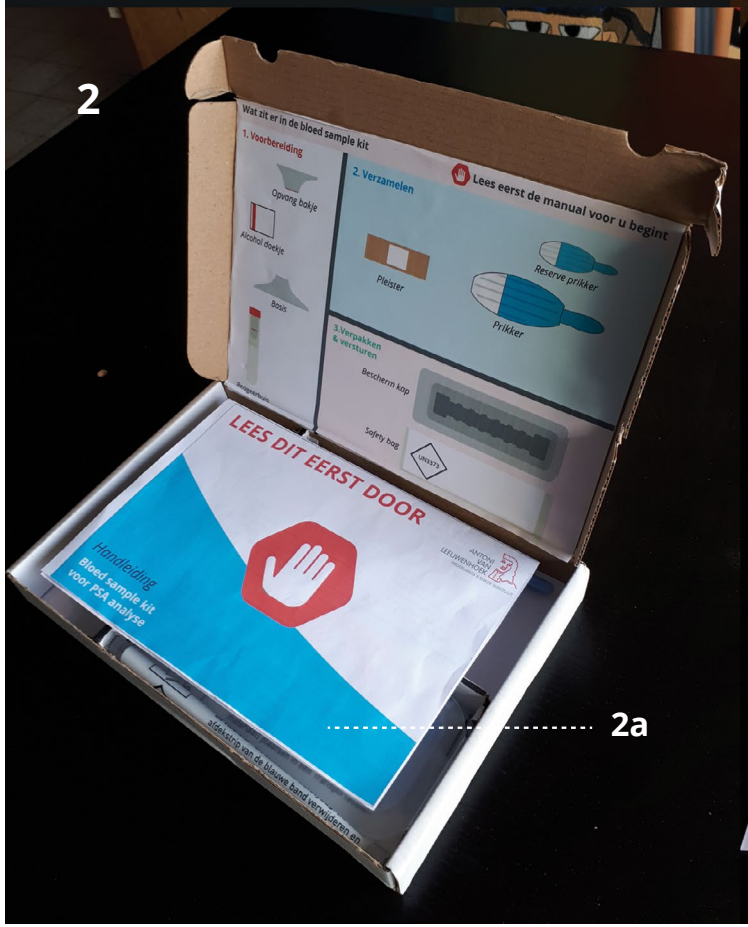
Figure 96 - Opening of the blood sample kit

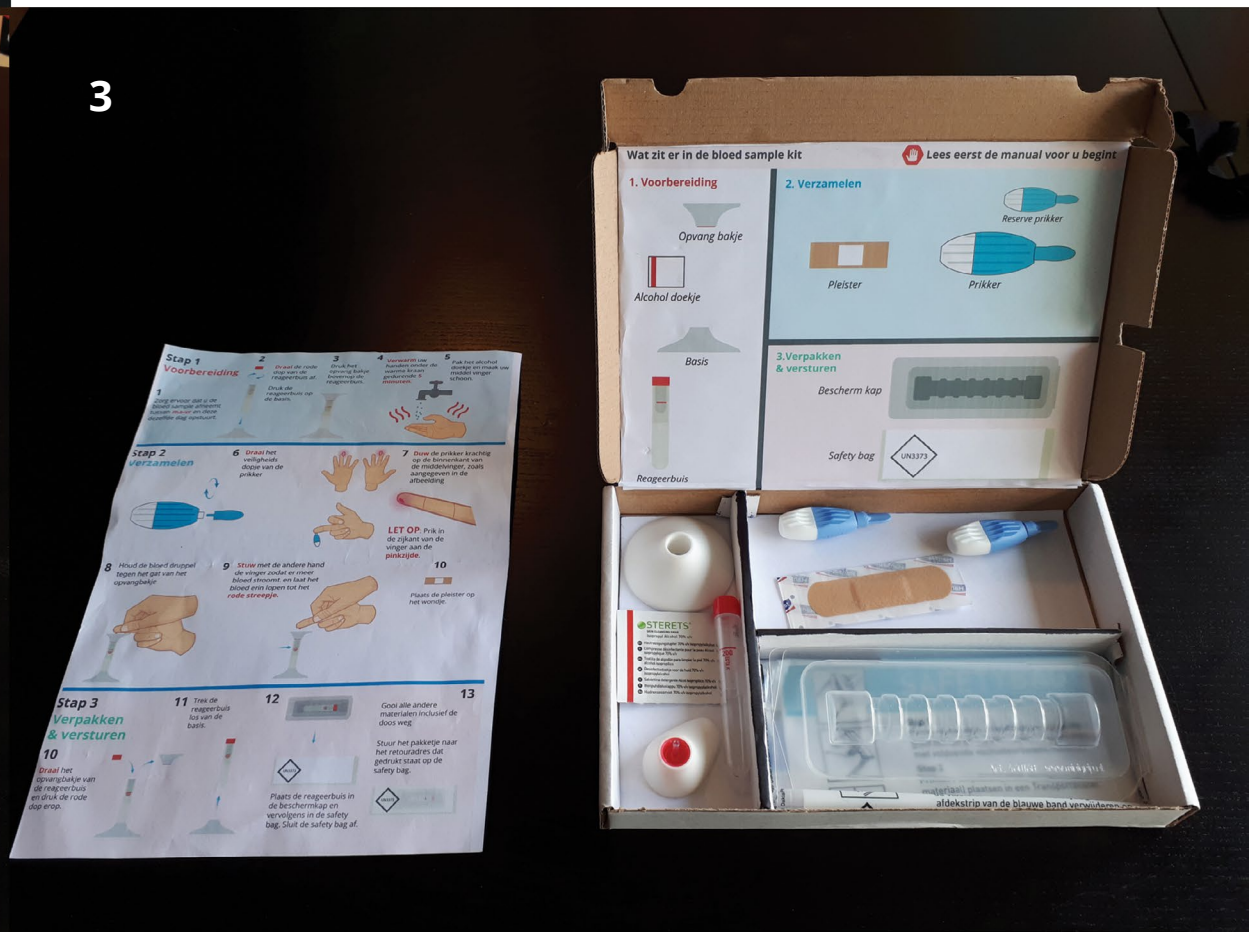
1
This is the package as it arrives in the mailbox of the user.

2
The user opens the package in this way. The inside of the lid reveals the first part of information, which is the kit's inventory of parts.

2a
The lower part of the kit is covered with the manual that is folded and communicates to the user that it needs to be read before starting the blood sample procedure.

3
The user takes away the manual and the different parts within the kit are revealed.





Packaging design

Colours and parts correspond with the manual and actual parts located at the lower part of the kit

This model integrates the manual and the packaging to make the instructions more intuative. The introduction of parts is now located at the inside of the package.

Deviders create 3 compartment for different parts and actions within the blood sampling process.

- *This chapter showed what the final packaging design and information providence towards the user looks like.*
- *The blood sample actions have been split op in categories in both manual and packaging design to enhance clarity.*
- *Colors, unity in graphic design and positioning of information should make communication more intuitive .*
- *This chapter showed the last iteration of the packaging design, instructions and parts that will be used within the final user test.*

4.9 Implementation & costs

This chapter describes how NKI-AVL should implement the blood collection device in its context considering cooperation with partners, production, use, distribution and overall communication. The overview on next page visualises the actions of implementation (figure 98). The end of the chapter shows an overview of the costs involved.

The kit is personalised with patient information during the second assembling step

Production

Purchase
The blood collection kit consists of several components that need to be purchased. NKI-AVL should collaborate with the wholesalers that are described in appendix D for the purchase of such components. The parts will be send to the address of NKI-AVL.

Production of parts
The blood collection kit consist of 2 parts that need to be custom made. NKI-AVL should collaborate with the production partners described in appendix D for the production of these parts. The parts will be send to the address of AKL within NKI-AVL.

Assembling (1)
The blood collection kit consists of 5 components that need to be assembled and should be placed together in a kit before they are operational. NKI-AVL should find someone that is able to assemble the component when they arrive at NKI-AVL.

Storage
NKI-AVL should find a place in which the blood collection kits can be stored after assembling.

Assembling (2)
When a request for PSA monitoring pops up, an analyst takes a blood collection kit from the storage and adds the last component to the kit: the test tube with barcode and name of the patient. The kit is now sealed, the patient's address is added and placed in the mailbox, ready for distribution.

Distribution

Distribution of parts
The parts that have been ordered by the wholesaler and production partner need to be transported towards NKI-AVL. The transportation of these parts will be covered by the partners. NKI-AVL doesn't need to take action for this distribution.

Distribution of blood collection kit
When all parts have been assembled(2) it can be send towards the patient that needs it. These kits can be send by regular mail. A mailbox casing is used that makes sure that the package fits within the dimensions of a regular mailbox. NKI-AVL should find someone that is responsible for the distribution of the blood sample kit to the concerned user.

Distribution of blood sample
The user needs to send back the blood sample in a special biospecimen bag. The return address is already written down on the envelope and the package has been franked. The bio envelopes will arrive at the logistic point within AKL.

Use

Opening the package
The blood samples arrive within a bio envelope, which are opened by analysts working within the department. The package can be thrown away.

Hemolysation
Analyst place the test tubes in a refrigerator that causes the samples to hemolysate. After the hemolysation, the samples need to be thawed by placing the samples outside the refrigerator.

Centrifugation
Analyst place the tubes in a centrifuge rack and centrifuge the samples in order to separate cellular debris from the hemolysed fraction.

Analysis
The samples are now ready for analysis. Analysts place the samples in a Hitatchi rack and place them in the chemical analyser.

Communication

Introduction of blood sample kit
NKI-AVL should introduce the novel blood collection kit to the user. The introduction is done by the urologist that is treating the concerned user. The urologist asks whether the patient is interested in using the kit and informs the user about the advantages of using the home sampling kit.

Instruction of blood sample kit
When the user is interested in the use of the blood collection device, he goes to the polyclinic within NKI-AVL. Phlebotomists will give an instruction of the use of the blood collection device.

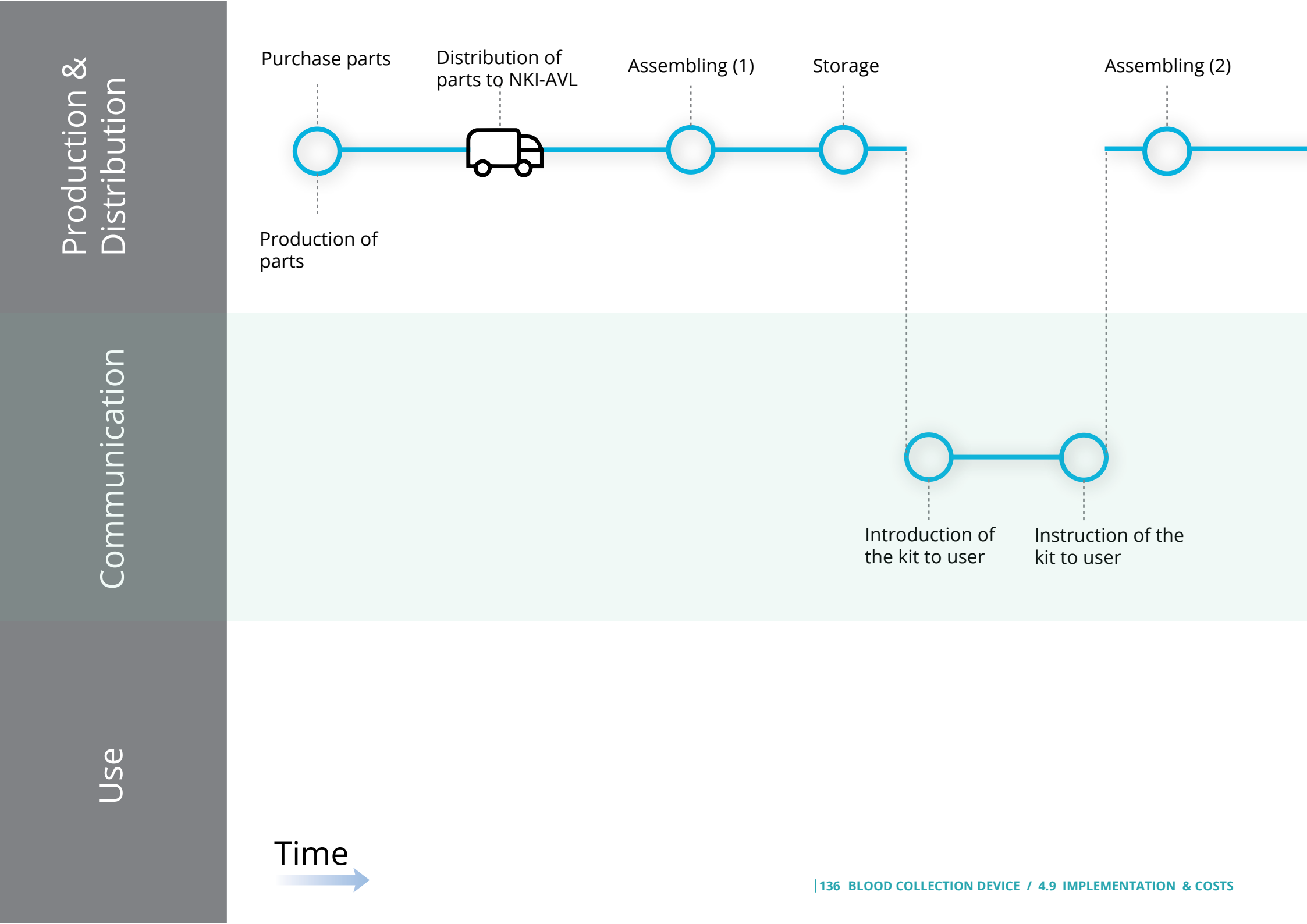
PSA results
The results of the PSA analysis by the chemical analyser are automatically send to the urologist that is treating the user. It is the responsibility of the urologist to inform the user about his PSA level.

Keypartners & people involved

It is necessary to work together with partners and people involved in order to successfully produce and implement the blood collection device. The following list gives an overview:

Production partners
Distribution partners
Wholesalers
Assembly employee
Analysts
Urologists
Phlebotomist (at polyclinic)
Users

Figure 98 on the next page shows the timeline of actions that should be taken by NKI-AVL in order to successfully implement the blood collection device in its context.


Production & Distribution
Communication
Use
Purchase parts
Distribution of parts to NKI-AVL
Assembling (1)
Storage
Assembling (2)
Production of parts
Introduction of the kit to user
Instruction of the kit to user
Time

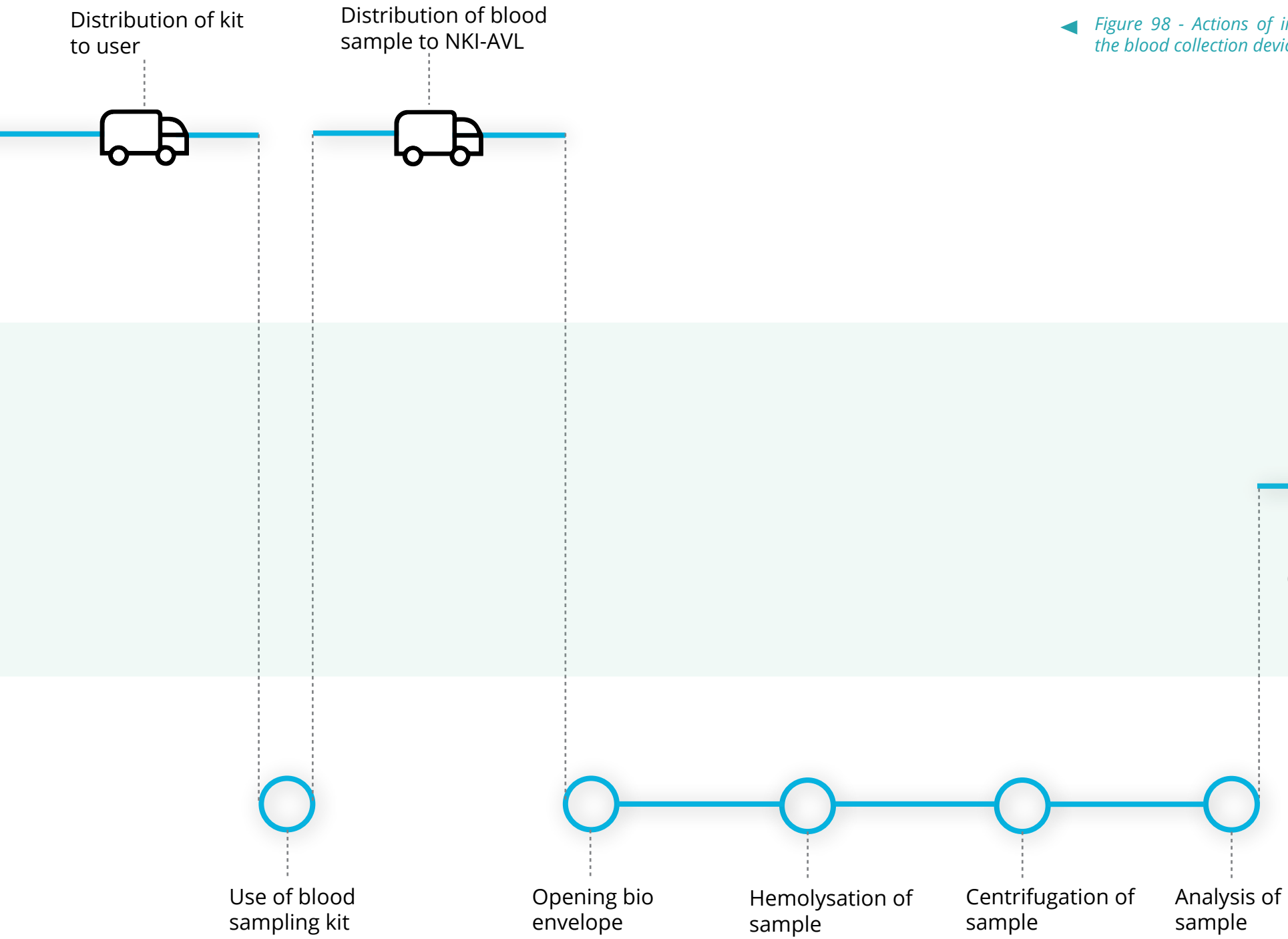


Figure 98 - Actions of implementation of the blood collection device by NKI-AVL

Costs

The actions of implementation on latter page showed all actions involved. Some of the actions cost NKI-AVL a certain amount of money whereas others require effort from the user. Some of the actions are easily translatable to money, for others its more a speculation than hard numbers. This paragraph tries to give an indication of the costs that are involved when The Capillar will be implemented. The paragraph ends with a comparison between this novel system and currents system.

Production and distribution

Production and purchase of parts
The complete blood sampling kit will cost **16.56 euro.** For the parts that need to be produced an invoice is requested in order to determine the costs, For the purchase parts, the retail price is taken into the calculation. The total sum can be seen in the bill of materials (Appendix D)

Assembling
An employee needs to assemble the kit for each specific user. It is estimated that this will take 5 minutes for each kit. This translates to **1 euro.**

Distribution
NKI-AVL will need to pay for the distribution of the kit towards the user and retour. PostNL is the distribution partner of NKI-AVL. They charge **3.50 euro** for a post-paid mailbox package (PostNL, 2017)

Communication

Introduction of kit
A Phlebotomist will give a brief introduction how to use The Capillar. This is a one time event, For the follow up blood samples, the patient uses the manual of the kit to acquire information.

Communication of results
The urologist calls the patient to communicate the results of the PSA analysis back.

Use

Processing sample
Analysts working at AKL need to process the samples that arrive at the department by mail. The samples need to be hemolysed and centrifuged, this requires some actions from these employees.

Performing PSA analysis
The chemical analyzer analyses the PSA of the samples, which has influence on depreciation costs of the device.

Comparison

Figure 99 shows a table that compares costs and advantages for both current venipuncture ans novel blood sample system (The Capillar).
The initial costs of The Capillar (20 euro) are larger than the initial costs of the venipuncture (1.50 euro). However, phlebotomists need to perform the blood sampling for the patient which requires time and money as well. The advantages that come along with the new system outbalance the costs that it brings along. The production price can be reduce significantly when it is decided to produce the device in bigger quantities in a future scenario. The evaluation at the end of the report discusses whether, and for who, value is added by the implementation of this new system.

Costs - advantages comparison

Variable	Venipuncture	The Capillar
Production and purchase of parts	**1.50 euro**	**16,56 euro**
Assembling	**-**	**1 euro**
Distribution	**-**	**3.50 euro**
Communication	**- Communication of results to user**	**- Instruction to user** **- Communication of results to user**
Use	**- Policlinic performs blood sampling** **- Analyst processes the sample**	**- Analyst processes the sample**
Advantages	**- The system does not require capital investment**	**- patient saves time, effort & money**
Advantages	**- Samping is performed within hospital, which makes things easier for patients**	**- PSA measurements are uniform according to NKI-AVL standards**

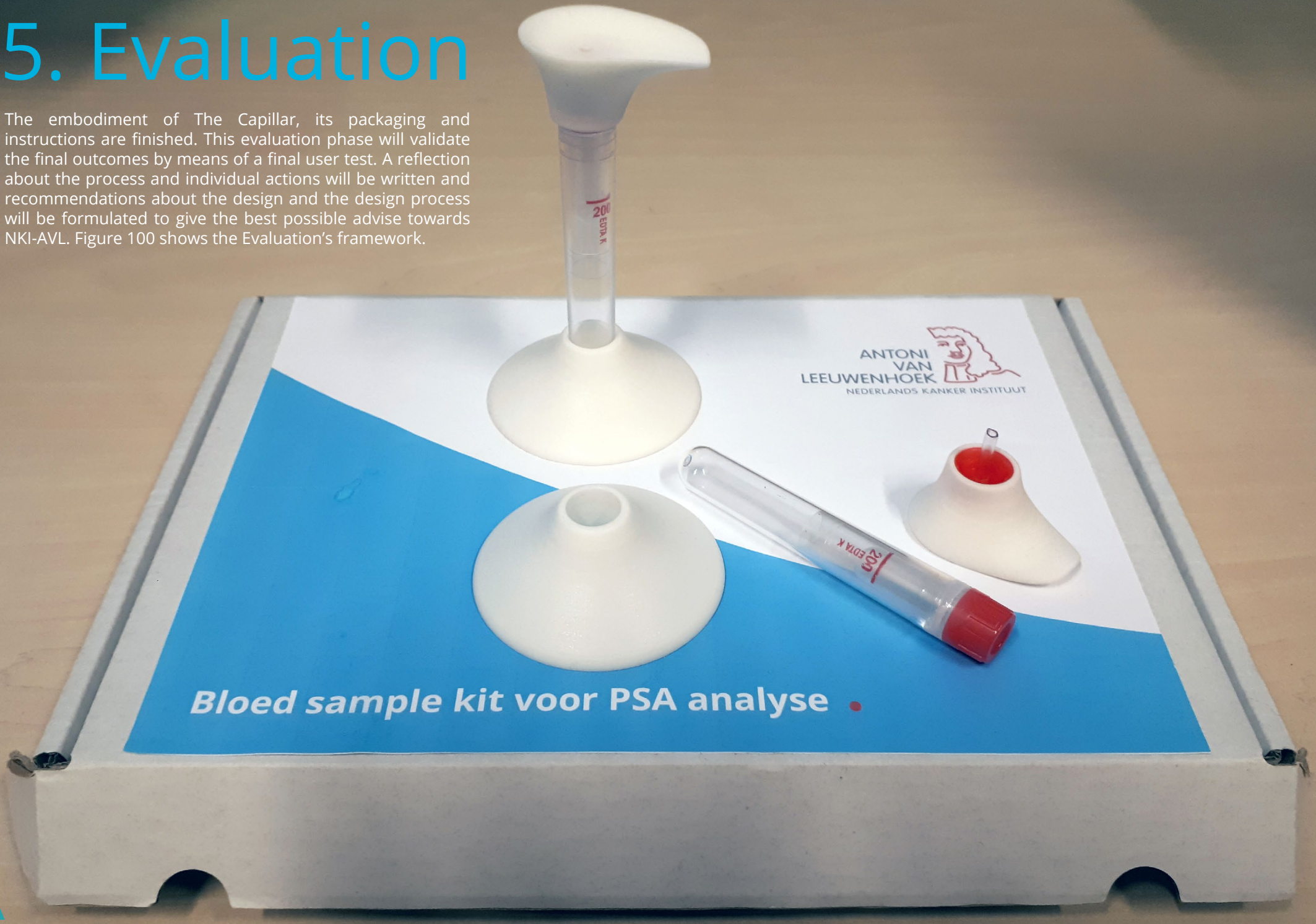
◀ *Figure 99 - Costs - advantages comparison*

"It is difficult to compare the two systems in absolute numbers as it is uncertain how much the advantages contribute in terms of cost reduction."

NKI-AVL should make an employee responsible for the production, assembly and distribution of The Capillar

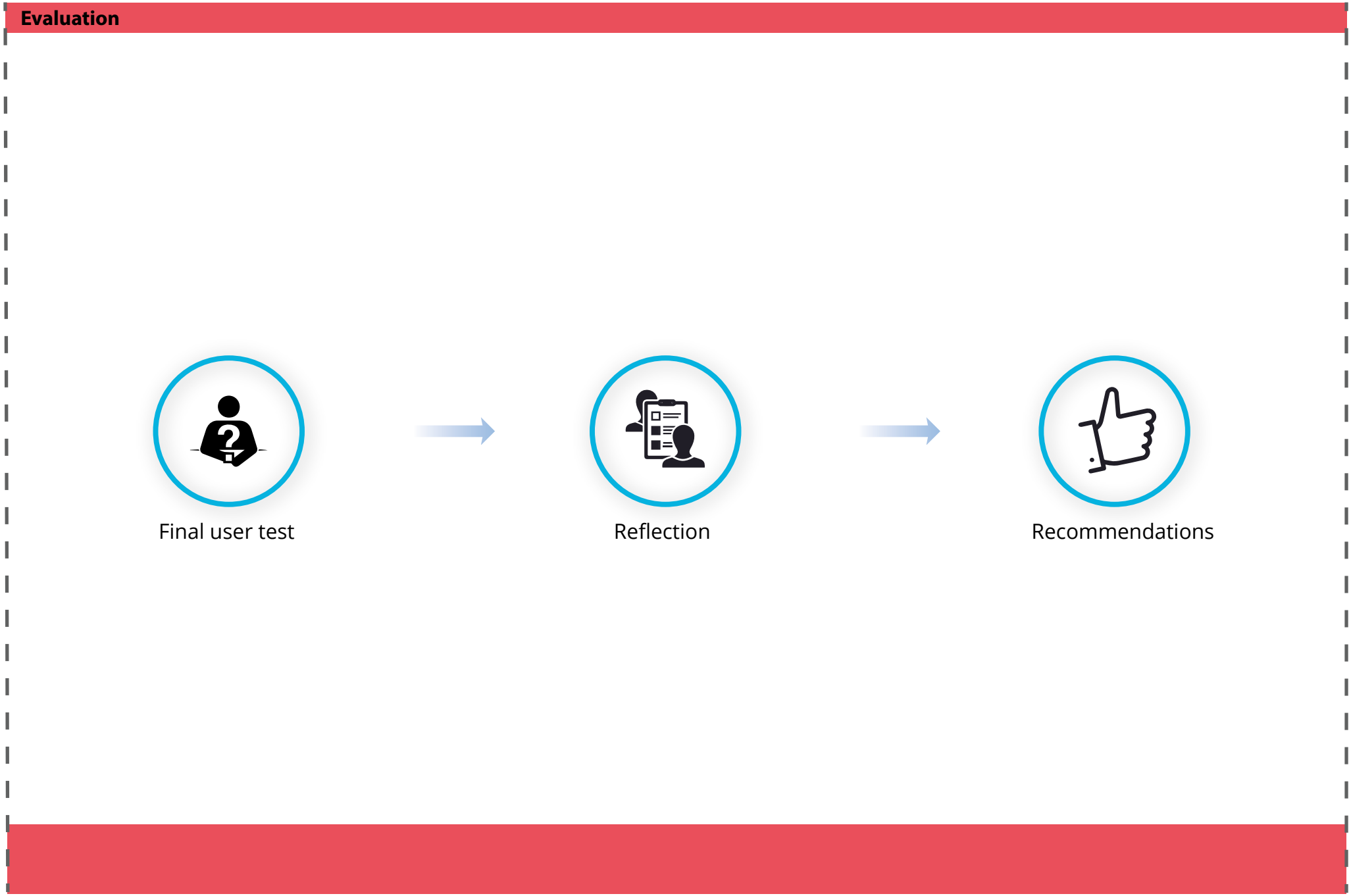
5. Evaluation

The embodiment of The Capillar, its packaging and instructions are finished. This evaluation phase will validate the final outcomes by means of a final user test. A reflection about the process and individual actions will be written and recommendations about the design and the design process will be formulated to give the best possible advise towards NKI-AVL. Figure 100 shows the Evaluation's framework.



The Capillar and its packaging that has been used during the final user test.

▼ *Figure 100 - Framework of evaluation*



5.1 Final user test

A final user test will be done now that the embodiment phase is over and The Capillar, its packaging and instructions have been designed. A lot of different aspects have already been tested. However, in this final holistic user test all elements that have been designed and discussed throughout this report come together for final validation. This chapter shows the final user test and insights that were derived during the test. For elaborate user test results see appendix T.

Setup

The kit that has been shown at the end of chapter *"4.8 Instructions & package design"* has been used during this final user test. This package includes The Capillar. A situation is simulated in which the package arrives in the mailbox of the participant. The participant is asked to speak out loud while he performs the blood sampling procedure as is described in the manual. Participants were selected that had no affinity with blood sampling. Preferably, the participants had no medical knowledge whatsoever.

Some differences with the real situations were noticed during the user test. The fact that the participant was observed during the test resulted in pressure and rushed actions. In the real situation, the patient has all time to concentrate himself on the task.
Another point of attention is the commitment to the test. In the real situation, the blood sampling kit is part of the treatment and diagnostics of the patient's cancer, which probably results in improved motivation during blood collection. The test person's health is not at stake, which probably makes the test person more indifferent when it comes down to reading the manual and understanding the blood sampling procedure.

Tests

The user tests have been split up in two different parts. The insights from first user test have been used to optimize the package / instructions. The second user test uses the optimized packaging / instructions. Final chapter "Recommendations" elaborates on recommendations that have been derived from these tests.

Materials

The following materials have been used during the user test:

2x Lancet
1x Test tube
1x Base
1x Top
1x Lid
1x Alcohol swipe
1x Transport blister
1x Safety bag
1x Manual
1x Parts inventory
1x Plaster
1x Packaging

User test insights

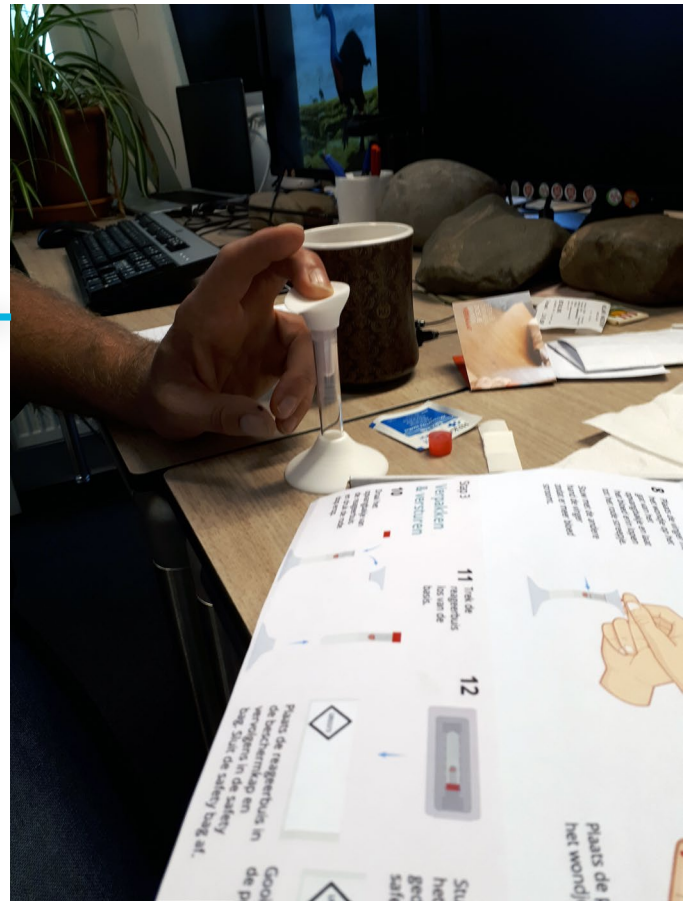
- **1**: The Capllar itself worked flawless. When the participants understood how to sample their blood, the test tube was filled quick and clean.
- **2.** Manual was not read
- **3.** Participant doesn't understand that the lid needs to be removed from the test tube.
- **4.** Participant is hesitant in puncturing the finger, which results in a bad puncture
- **5.** Participant did not understand that the test tube needed to be filled until the red line
- **6.** Participant did not understand how to pressure the finger. It was often skipped.

Final user test (1)

User punctures his finger during the user test

The first user test is done with 4 participants (53-64 years old)

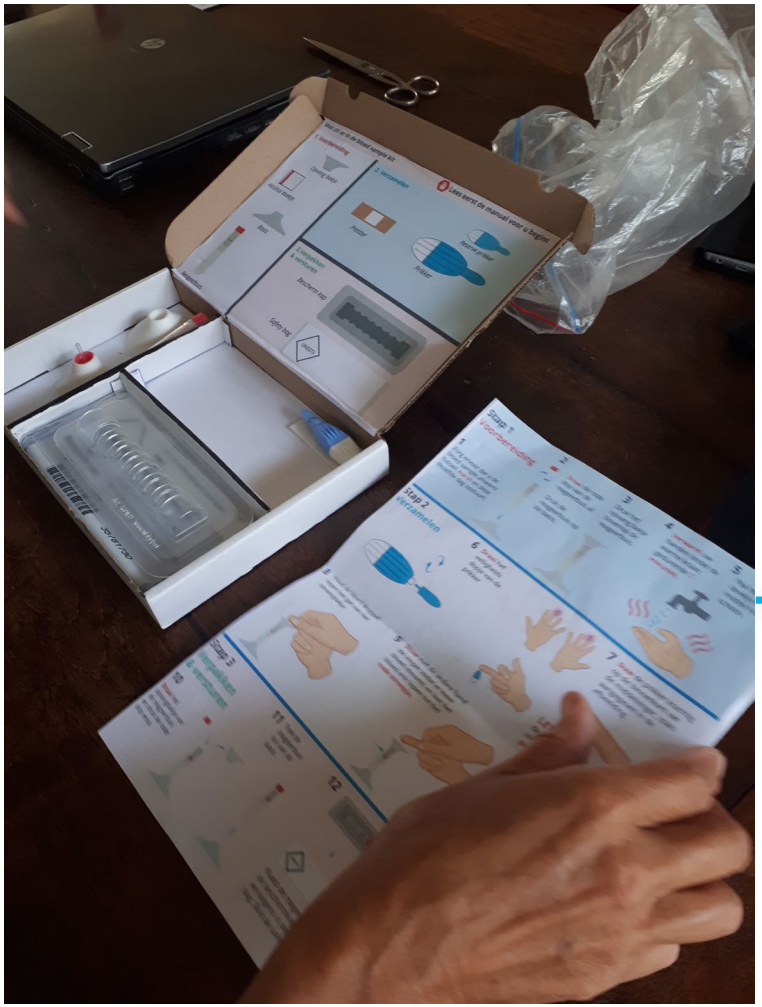
User holds his finger on top of The Capillar during sampling. Pushing and collection by capillary action is not understood.



- **7.** Participant is confused which side of the middle finger needs to be punctured (thumb side or pink side)
- **8.** Participant thought that the test tube (including the blood sample) needed to be put back in the packaging.
- **9.** Participant doesn't understand the importance of warming the hands in warm water.
- **10.** The participants didn't have problems with step 10,11,12 within "verpakken en versturen"

Solutions (appendix T) will be implemented in the design of the instructions and new tests with participants will be executed in usertest 2.

Final user test (2)



The second usertest is done with 3 participants (60-68 years)

User pushes the finger for impoved blood flow.

User test insights

- **1**: The communication towards the user is improved compared to user test 1
- **2:** It is still not clear how the user should push the finger.
- **3.** It is unclear that the user should place the drop of blood gently against the hole of the device. Participant places finger firmly against the hole and starts pushing

- *Insights from the final user tests have been used to formulate recommendations that can be seen in the last chapter of this report.*

5.2 Reflection

This chapter will give a reflection on the project's process and the final design. It will highlight decision moments that have been made during the project. A personal reflection will elaborate on personal learning goals and achievements that I had in mind at the beginning and during the project. At the end of the chapter, recommendations about the implementation and process are given.

Reflection on design process

Design brief

The design brief as it was given by NKI-AVL at the start of the project was as follows:

"To allow finger puncture blood collection by patients themselves at home, a blood collection device has to be developed that allows collection of a suitable blood sample for PSA analysis. Furthermore the blood collection device has to be user friendly, safe and be compatible with the available automated PSA work-up and PSA analysis machinery used in the Netherlands Cancer Institute. The finger prick blood collection device will be developed in close collaboration with the general clinical laboratory staff".

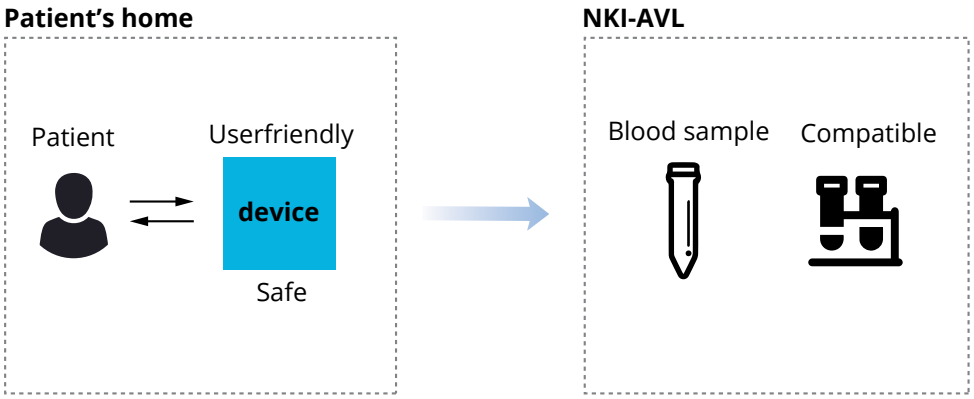


Figure 101 - information in design brief

Figure 101 shows all things that where known during the design brief. A user friendly, safe device should be developed that could be used at the patients home to somehow sample an unknown amount of blood from an unknown place. The sample should be transported to NKI-AVL in which the device/sample should be compatible to the machines at AKL. The design brief initially stated that the sample should be taken from the finger, this was however an assumption that was not based on argumentation. The design goal was in a way very clear in its formulation, but left also a lot of space for the designer as a lot of elements where unknown and needed study.

This design project is split up in three phases; The analysis, conceptualization and embodiment phase. Each chapter in this report ends with design implications to give the reader a clear understanding what contribution the concerned chapter made to the development of The Capillar. Next paragraph reflects on these phases and their design implications. Figure 102 shows a *design implications time line* that maps all important insights and decisions over time that led to the development of the final product. The reflection in next paragraph will refer to this time line by the use of numbers.

Process

Analysis phase

At the start of the project it was important to know who was going to be involved in the project and which parties could benefit from the development of a blood collection device. By doing an internal and external analysis it became clear that NKI-AVL had a lot of stakeholders. The most direct and important stakeholders were selected and their benefits have been mapped (1). The patients were clearly an important stakeholder as this was going to be the group of persons for which the blood collection device was going to be designed. By doing literature studies, talking with urologists, analysts and users, the target group of man between 50-80 years old was selected (2). It appeared to be quite difficult to come in contact with actual patients, which resulted in fewer interviews with

the target group than initially was intended.
A state of the art finger prick PSA kit was bought from the internet to test its functionality during the first user test with a user within the target group. The test appeared to lack user-friendliness which resulted in ergonomic requirements for the blood collection device (3)

The next step in the analysis phase was a context analysis in which all actions / attributes/ persons that contributed to blood collection were mapped (4). It was difficult to understand what was going on in the chemical analyzer as there were no technical people around that could help with that. The determination of container dimensions was done by trial and error. Technical information from an expert would have been better. Now that the context of blood collection was clear, it was time to focus on how to actually sample the blood from the patient inside some sort of container. This analysis started out by doing market research, this led to an overview of possible blood collection techniques that could be used for the development of the blood collection device (5). It appeared that a lot of blood collection techniques were out there, also quite some novel ones. It was difficult to estimate what technique would be feasible and what would not work, this is something that needed to be validated before application. A clear overview of context, user, and collection techniques was now created and it was time to combine this knowledge in the creation of a user scenario that mapped all user actions within its context. This led to a lot of general insights and design requirements (6). At this point, the end of the analysis phase was almost reached. It was time to prepare for the conceptualization phase, which was in this case done by formulating 6 design challenges and one design vision (7).

Conceptualization phase

This phase started off with ideation. This is the fuzzy part of the project in which solutions need to be found for the design challenges. Different creative tools have been used to come with solutions (8). I found it difficult to translate these outcomes directly to solutions as a lot of them seemed far-fetched. I also noticed that it was easy to hold on to a preferred idea, which made an open view towards other solutions difficult. Next time I will engage more people with different (relevant) expertise within the ideation phase, as I believe that more input will result in better, more feasible solutions to the challenges. The ideas that were created made use of different ways of transporting blood. However, there was still no proof that these ideas actually worked, which meant that I could still not rely on these ideas. This uncertainty made me want to validate those principles that were used within different ideas (9). This was a very important step as I found out that some ideas that I preferred did not work at all. The principles that appeared to be feasible where applied within 3 concepts that were created (10). I wanted to create three really different concepts to make the concept directions as broad as possible to make sure that no directions and possible solutions where overlooked. This appeared to be difficult as the ideas I created, had a lot of similarities. This might have been the case due to the fact that the assignment is focused in one specific direction with little room for varying ideas, but maybe I needed more time in the ideation phase to come up with a wider range of ideas. It could also be a combination of the two. This conceptualization phase ended with a selection of one concept to continue with. I wanted to rate the concepts based on a list of criteria but also by discussion to make the choice on both objective and subjective argumentation (11). The TU Delft board, NKI-AVL and I agreed to continue with the concept called “The Capillar” (12).

Design implications timeline

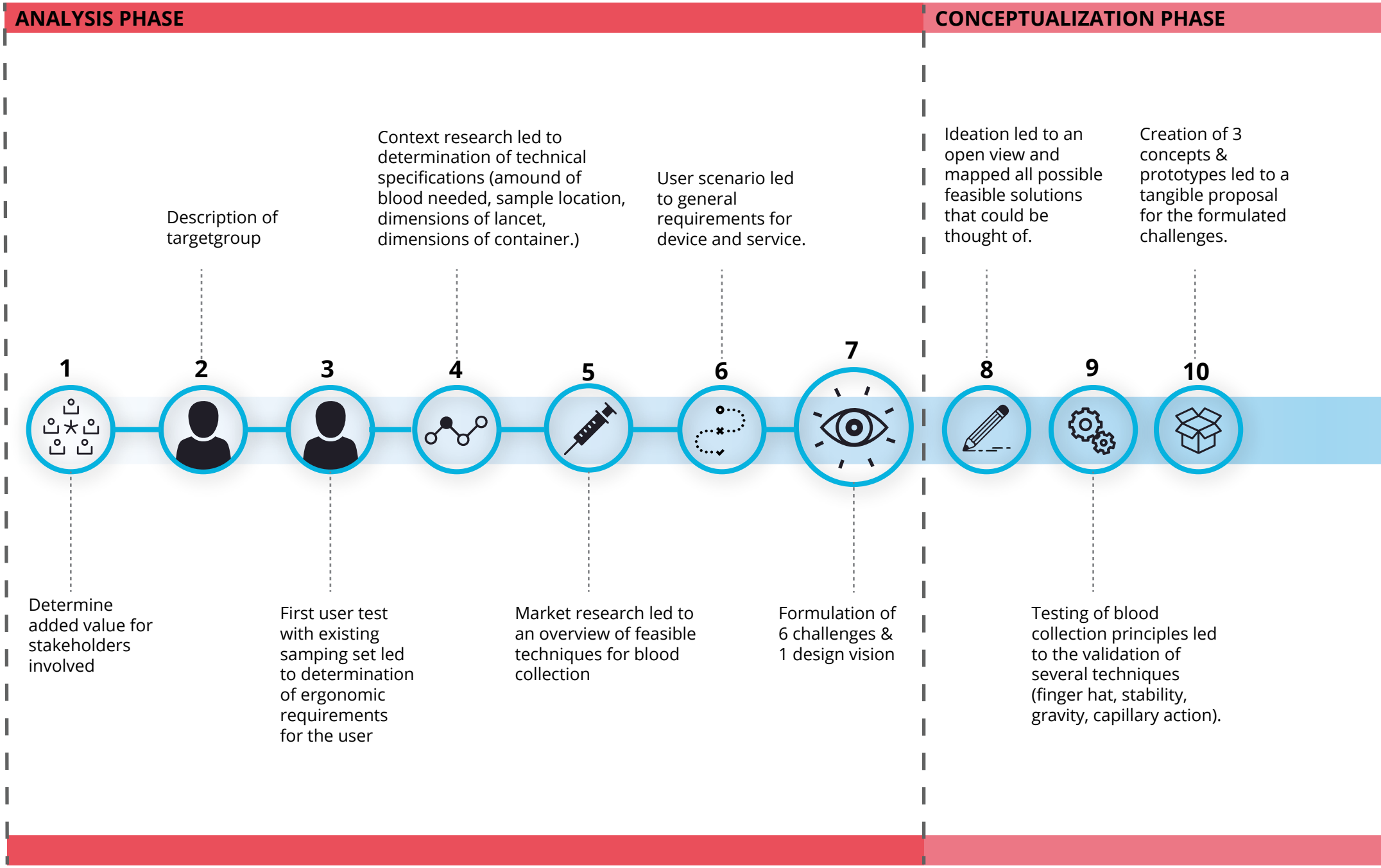


Figure 102 - Design implications time line

EMBODIMENT PHASE

11 — 7 criteria are set up to rate the 3 concepts. TU Delft board & NKI-AVL are part of the decision making.

12 — Decision making led to the choice of "The Capillar". The discussion led to 2 adjustments of the concept (use of standard microcontainer + use of standard test tube).

13 — Iteration on final concept by user test led to integration of microcontainer and test tube. The device now uses 1 instead of 3 capillary tubes. The top part is extended to make sampling easier.

14 — by using a database, a material & production technique have been chosen. (PA2200 polymer) (SLS 3D printing)

The production/packaging choice affected the device's design. It is devided in 2 parts to make it fin in a mailbox.

15 — Aesthetics have been integrated in the design of The Capillar to convey meaning during product-user interaction.

16 — Experiments have been executed to optimize The Capillar's blood flow.

17 — The Capillar is finished, all parts and their specifications can be found in the bill of materials.

18 — A manual is written through an iterative process.

19 — The packaging is designed according to UN3373 regulations, as well as the graphic layout on the cover and the inner design of the package/components.

20 — A protocol for NKI-AVL is written on how to implement the system in their context. One employee should be responsible.

21 — Final usertest. Validation of final design with user.

Embodiment phase

The concept did originally use parts that where custom designed for NKI-AVL. During the discussion it was recommended to use existing parts in the design in order to make the embodiment easier and the costs lower (13). A user test that integrated these purchase parts was conducted and it was found that the participant had difficulties in sampling blood due to the shape of the top part. It was decided to extend the top part in order to support the finger. It was also decided during the user test to only use 1 instead of 3 capillary tubes in the design as this appeared to work better (13). The design of The Capillar was a bit bulky at this point and when thinking about a material / production choice. I found out that it would be very difficult to produce such a design. It also did not fit in the mailbox. This was something I should have known beforehand as a design requirement was: "Device should fit in user's mailbox". The list of requirements was pretty long and unclear and therefore not always as useful as it should be during the design process. This design glitch could however be solved by separating the device in two separate parts that could be placed in a mailbox. The shape was now also more suitable for the production. I chose to first select an optimal material for The Capillar after I focused on the production process. However, it would have been better to switch the order as the production technique seemed to be the limiting factor rather than the material choice, which meant that an iteration step was needed in order to balance the right production/material choice (14). Now that a working prototype was made and the device had been materialized, you could argue that the design met all requirements. However, no attention had been paid to the product's aesthetics. NKI-AVL and TU Delft deemed that not too much effort should be put in the aesthetics as it is a rather functional device without commercial ambitions. I agreed in a way, but I thought that a lot of product-user interaction is dependent on how the product looks, so I tried to implement desired product-user interaction in the aesthetic design of The Capillar (15). The functions already determined major parts of the design, but small improvements could be made regarding the looks. A working / aesthetic prototype was made to once again test the device. It appeared that the blood flow of the device was not optimal. It was questionable why this was not noticed earlier on during the validation of the technical prototype. It could be that the new aesthetic design somehow influenced the blood flow of the device. It could also be that the working principle tests were not elaborate enough as conclusions were drawn on the outcomes of just two test results. This insight led to the creation of multiple models that should eliminate this blood flow flaw. Small adjustments in The Capillar's design were made according to the test result to improve the blood flow (16). After this technical problem was solved, The Capillar was finished (17).
Now that the design of the device is finished, the user should be informed in an easy, effective way on how to use the device when it arrives by mail. I first started to develop a manual by doing small user tests. I noticed that I used way too much information. It was not easy to fit all this information on a piece of paper. When I started to think about a packaging option, it came in mind to combine the manual and packaging to make the information providence easier and more effective (18,19). I wrote an implementation scenario for NKI-AVL on how to implement this new system in their context. This is a recommendation towards them, because some elements in this scenario were speculative and could possibly be handled in an alternative way (20).
At last as evaluation, a final user test was done with 7 people to find out how the whole design worked together. Insights were translated to design recommendations (21).

Conclusion

These phases were meant to create structure in the overall process, In reality they had a lot of overlap, which meant that sketches for example were already made during the analysis phase and that in the conceptualization and embodiment phase things were still being analyzed.

Prototypes

The development of The Capillar was accompanied with a lot of prototypes. Integrating prototypes early on in the process helped

making validated decisions that were important for the continuation of the project. Elements that were not validated during the process could later on have led to unforeseen design flaws.
To put it into a quote: *"Prototypes are important to eliminate unforeseen design mistakes and validate the correct ones, they are tangible mediators between the desired end result and your personal design input."* Prototypes are also effective communication tools towards external parties.

Meetings with TU Delft chair and mentor

The graduation project was a project in which I had all freedom to do whatever I wanted. I was basically the project leader of my own project in which the chair and mentor fulfilled an advisory role. Whenever I had a question or needed guidance, we would arrange a meeting and discuss the concerned points of attention.

Work at NKI-AVL

NKI-AVL provided me a workspace within AKL in which I worked 2 to 3 times a week. It was important to spend enough time at the location to get acquainted with the field of knowledge. Interpersonal contact also helped a lot in both terms of motivation and insights. One time a week I would discuss developments with Huub, my mentor at NKI-AVL.

Reflection on final design

Proposed added value

Figure 103 shows a benefits overview for the most important stakeholders that was proposed in the analysis phase. Let's find out whether the end result meets up to these claims in terms of added value to the concerned stakeholders.

<u>NKI-AVL</u>
The Capillar replaces the service of phlebotomist, however the claim that this leads to diminished costs is false as the development of the

"Prototypes are important to eliminate unforeseen design mistakes and validate the correct ones, they are tangible mediators between the desired end result and your personal design input."

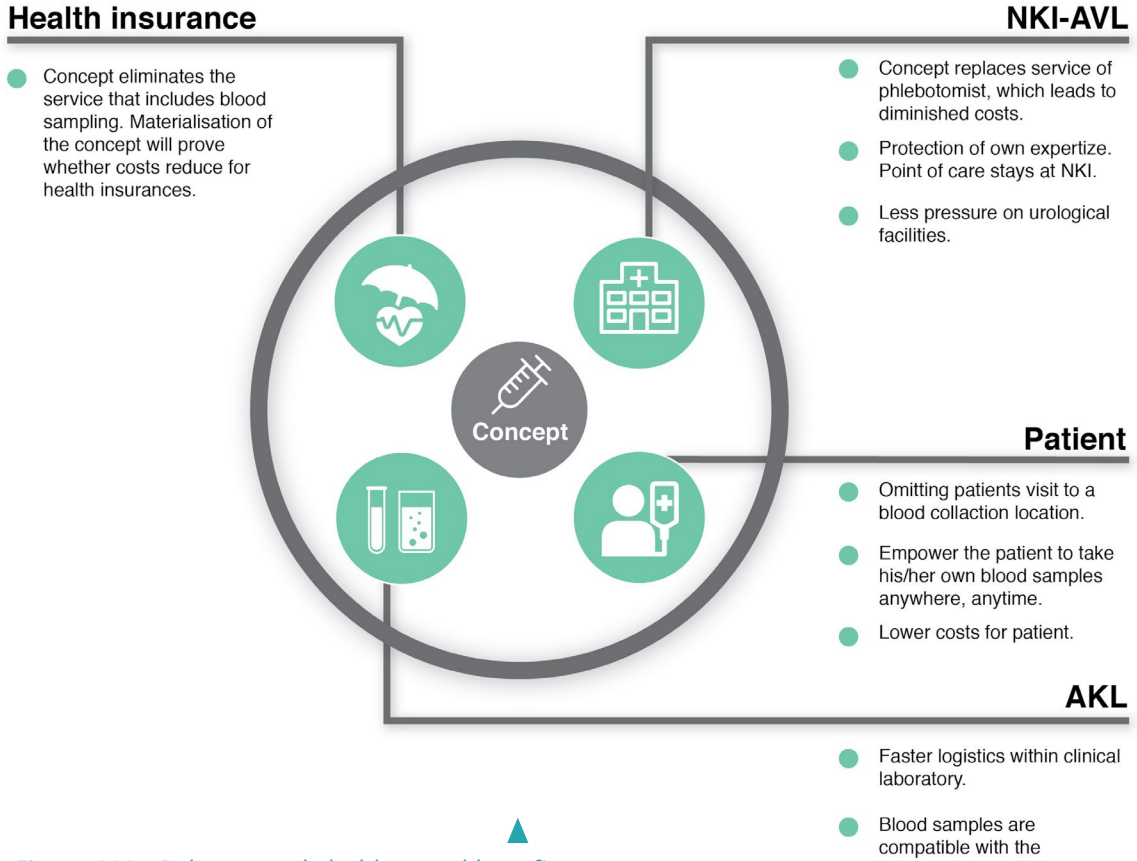


Figure 103 - Relevant stakeholders and benefits

device brings costs of its own.
The Capillar protects the expertize within NKI-AVL as the point of care stays within the institute. It can also be said that urological facilities are less pressurized because PSA monitoring is moved from the hospital towards the patients home.

Patient
The statements have been embodied in the design of The Capillar. The device makes sure that the patient can omit a visit to a blood sample location. It also empowers the patient to take his blood anywhere, anytime. Patients save money in travel expenses towards sample facilities as well as lunch costs by the implementation of the new system.

AKL
The Capillar leads to faster logistics within the clinical laboratory as the container is compatible with the machinery of AKL. The old system required an extra pipetting action.

Health insurances
It is claimed that The Capillar will eliminate the service of blood sampling in the health insurances package which results in diminished costs for insurance companies. This scenario is not yet met. However, in a future scenario in which The Capillar is produced in bigger batch sizes and the production price goes down, The Capillar might be a cheaper solution for health insurances in which value is created for this stakeholder.

Comparison with venipuncture
In chapter "Implementation and costs" a cost-advantages comparison is made. The new system has advantages over current system that have been described in latter paragraphs. The initial costs for the new system will clearly be higher than within current system. However, further development of the system will most likely result in diminished production costs.

Conclusion
Some claims in added value have not been met (yet) in the design of The Capillar, others do. Is it possible to add a value judgment to the final product? It depends which value is prioritized the most by the stakeholders, as a lot of values rely on subjective interpretation. However apart from the costs, it can be said that both NKI-AVL and patient experience advantages with the implementation of the new system in comparison with the old system.

Reflection on list of requirements

The framework of the The Capillar is built upon the list of requirements that can be seen in appendix M. It can be seen that all requirements are met. For this reflection we look back at the workable list of requirements that was set up at the end of the analysis phase:

1. *Feedback to user on how much blood is sampled (200 µl) is good*
2. *The amount of blood loss during sampling is low*
3. *The use of the device is intuitive (easy to understand)*
4. *The design is feasible (easy to develop and implement)*
5. *The device is easy to use*
6. *The 200 microliter blood is quickly sampled (speed of action)*
7. *The chance on contamination of blood sample is low*

Most of these requiremenets are met and validated during the final user test. However, during the final user test it became clear that point 3 and 5 need improvement. The device is easy to use when you know how to use it. The use of the device is not really easy to understand due to specific actions within the blood sampling

procedure which the user is not familiar with. This observation led to recommendations which can be seen in next chapter.

Personal reflection

What have I learned

A lot of different things happened during the project when I look back at it. There are certainly a lot of things I learned during the past 6 months. I will name the most important ones:

Solely responsible for such a big project forced me to take responsibility for the complete project as no one else would do that. I think that I have never in a project planned so much in advance in order to be able to finish everything on time.

In depth knowledge about 3D printing
I gained a lot of understanding in 3D printing due to extended use of 3D printing techniques for the creation of prototypes. In total three 3D techniques have been used (SLS, FDM and SLA printing).

Clinical chemistry
At the beginning I did not know anything about clinical chemistry, but due to the fact that I was emerged in the topic for the past 6 months, I created a basic understanding in PSA analysis in blood samples, which I think is valuable as it enlarges my understanding in medical design.

Medical design
This is the most "hard core" medical design project I have done. During the project I came across a lot of regulations, restrictions, patient protection and material certification that had the sole responsibility to protect the patients health. This half year experience contributed to my understanding in medical design.

What should I have done differently

Some of my actions within the project could have been done differently in order to bring the process to a better or faster end result. The major points are listed:

Use of participants was limited in number. A more varying user group would have led to a more accurate framework for the design of the blood collection device.

More co-creation with stakeholders. Patients, phlebotomists and urologist could have had more input in the design of the device in for example creative sessions. The participants of he creative session that was held during the project included solely students from the faculty of industrial design engineering, what might have led to unidirectional ideas.

Timewise, the planning of the project was divided in three equal parts (analysis, conceptualization, embodiment). However, the embodiment phase required more time than the analysis phase which resulted in more work in the end of the project. I am not sure whether it is possible to estimate the time division of activities correctly in such projects, but the separation in three equal parts should not be taken for granted.

5.3 Recommendations

This chapter focuses on future scenarios concerning the further development and application of The Capillar. Recommendations about the device´s design and further development will be given .

One step further

Now that the product is finished, the question arises whether to implement the device internally at NKI-AVL or should the company pursue the commercial pathway?

Contact with Technology Transfer Office (TTO)

TTO protects and manages the intellectual property created within NKI-AVL. In a conversation with Koen Verhoef of TTO, it was discussed whether it was possible to patent The Capillar. Koen Verhoef told us that the design is quite difficult to patent as the technologies that it contains are not new. It would be possible to apply for general design protection. However, slights changes in design would abolish this protection. NKI-AVL could pursuit the following two scenarios:

1: Apply for a patent and start by introducing The Capillar intern at NKI-AVL. When other parties become interested, the device is protected and an outside manufacturer could be found to make the device commercially attractive.

Advantage
When The Capillar becomes a success, NKI-AVL will be the only party that benefits as it is owner of patent(s) that protect the device against counterfeits.
When NKI-AVL only wants to use The Capillar intern, this would be the easiest way to go.

Disadvantage
A patent application is expensive. It is also not clear yet whether the patent will be viable.
NKI-AVL does not have internal R&D which makes it hard to bring the device to the market

2: Introduce The Capillar to a prominent biomedical company such as Sarstedt, BD or Greiner who can adopt the design and become co-owner of the idea. Costs such as patent applications could be funded by these companies. They also have better resources in terms of production and sales market.

Advantage
These companies are able to fund patent applications. Risks will be split by both the biomedical company and NKI-AVL.
These companies have their own R&D department and will be able to place The Capillar on the market.

Disadvantage
Future profit is shared. It is uncertain how much of the intellectual property remains property of NKI-AVL.

Conclusion
Option 2 seems to be the most promising direction to pursue as NKI-AVL lacks an R&D department, has no experience in introducing new products and has questionable patent viability. A big biomedical company willing to cooperate will probably accelerate the commercial introduction and implementation of The Capillar.

Contact is made with Sarstedt at the moment of writing. Two representatives from the bio medical company visited NKI-AVL to discuss possibilities in cooperation. No NDA's were signed yet, which meant that not that much about the project could be shared. However, their attention has been drawn and further conversations have been put on the agenda.

Incorporation of other analysis

The Capillar is specially designed for PSA analysis, The design is adjusted to hemolysed blood samples. The Capillar makes use of purchase parts from a biocontainer manufacturer which makes the design directly compatible with other micro containers from this manufacturers assortment (figure 104), which means that The

Figure 104 - Different micro containers from Sarstedt that are compatible with The Capillar

Capillar could be used to monitor other diseases as well. New clinical validation studies are needed to prove their viability.
The incorporation of new analysis methods would increase the commercial viability of the device. It could potentially become the new standard method in monitoring blood. These blood collection methods and clinical validation go hand in hand.

Recommendations in design

During the final user test, it became clear that the amount of blood that leaves the finger after the finger has been punctured varies a lot. People with blood thinners obviously provide the largest blood sample, which is for the design of The Capillar ideal. The blood of people with a high hematocrit value is more viscous and therefore less ideal for The Capillar. This hemocrit value has influence on the speed of coagulation. It can be said that The Capillars performance goes hand in hand with this variety in bleeding behavior. It would be interesting to do follow-up research in patients bleeding behavior, which insights could optimize The Capillars performance to a constant and adequate level.

During the final user test it was observed that when a user did not do the action within the sampling process in the proposed way, the process took to long. This resulted sometimes in coagulation of the blood on top of The Capillar, as this part of the device is not impregnated with EDTA. It could happen that coagulated blood enters the capillary tube which eventually constipates the device. A possible solution would be to also impregnate the top part with EDTA to eliminate the chances on coagulation by slower use of the device.

It became also clear during the final user test that the type of lancet that was used was not desirable as the patients were hesitant to push the lancet onto their finger. This resulted sometimes in bad punctures and limited blood flow. It is recommended to use the *"Sarstedt Super purple lancet".* This lancet has a button that leaves no room for the user to withdraw his hand during hesitation, which most likely leads to better punctures.

It was also found during the final user test that it was very difficult to communicate to the user how to get the blood inside the microcontainer. Most of the participants did not completely read the text that was provided within the manual. It is recommended to add an additional communication method that clarifies this specific action. This could be done by instruction at the hospital. The communication can also be done by instruction video online. The combination of the manual, the instruction at the hospital and an instruction video that can be watched online (Youtube) would communicate the proposed use of The Capillar the best. An online instruction video is an effective communication method as the user can clearly see all actions of blood sampling . The user can consult the instruction whenever he wants. Ongoing research should proof whether the combination of these communications methods suffice.

Recommendations in design approach

Various prototypes have been made during the development of The Capillar that required test punctures in the finger to validate certain principles and concept updates. It was important to do these test on short term, as this would be beneficial for the work flow. However, the use of test participant was biased, as only 4 to 5 persons where used that appeared to have almost the same bleeding behavior that resulted in large blood samples.

During a few test, stored rest blood from within NKI-AVL was used. However, it was assumed that this blood was similar to actual “fresh” blood during blood sampling. The anticoagulants that are deluded within these blood samples made the blood less viscous and thus not representative to the real situation.

Using multiple test persons would have given me the insight that some peoples blood is way more viscous. It takes more time to find these test persons. However, blood is such a varying liquid, that it seems essential in the design of a blood collection device to find the widest possible range of situations.

The age of the test person could have been more diversified. All test have been done with people ranging from 23 - 68 years while the target group of The Capillar ranges from 50-80 year olds.

Publication of design and clinical study

The development of the The Capillar continues after this graduation assignment. AKL will continue to validate hemolysed finger puncture samples for PSA analyses by using The Capillar as collection device. Upcoming months will be used to set up this study in which 250 patients from within the hospital will participate. The research ends by the creation and publication of a paper. The first title proposal of the paper is the following:

“Development of a fingerprick blood collection device and validation of a consecutive PSA test; designed for patient self-supportive sample collection and direct immunochemistry analyzer loading”

6. References

This chapter gives an overview of references that are used throughout the report. The references are listed in APA style.

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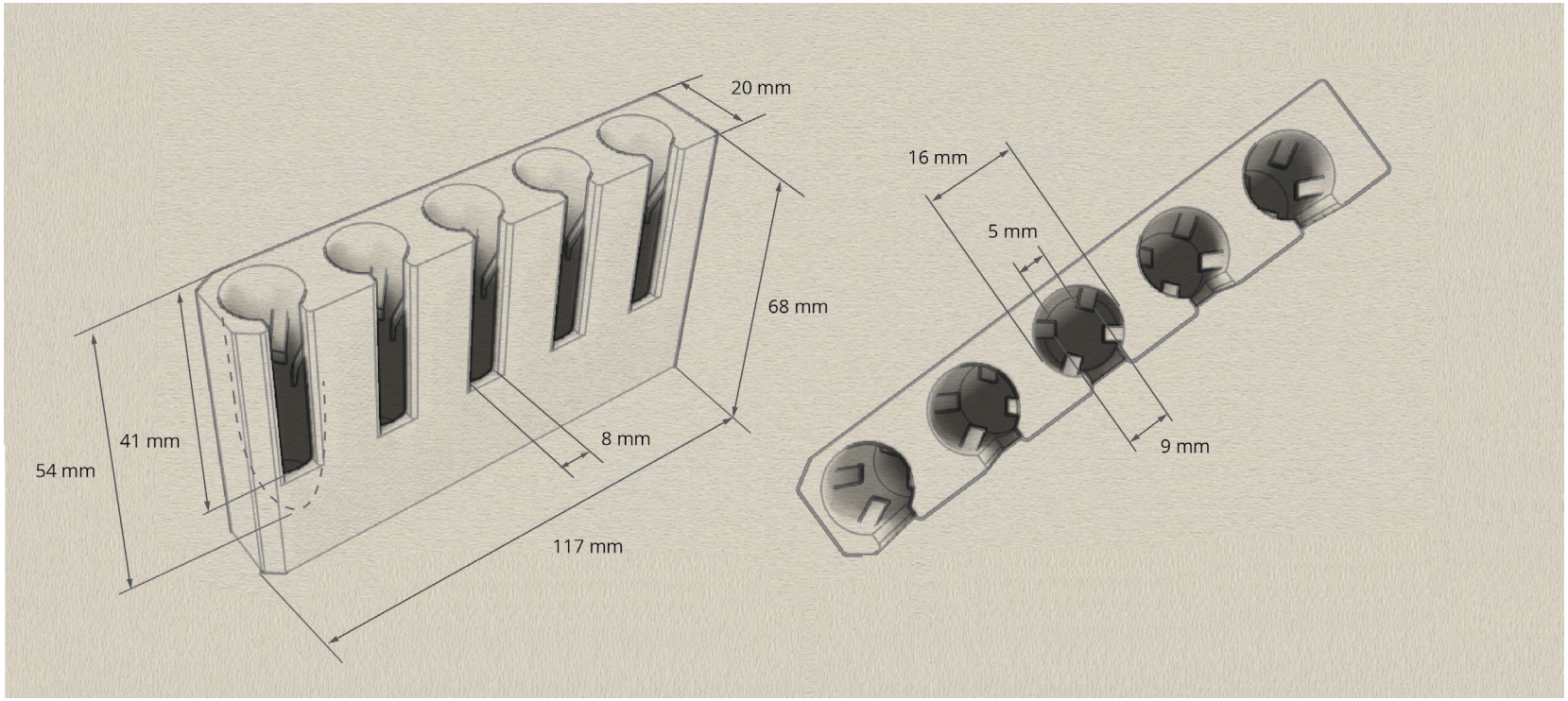
7. Appendices

This chapter contains appendices which is referred to throughout the project. The information given in the appendices is too profound for the regular text in the report and is therefore placed inside this chapter as reference material to back up statements that are made in the report.

INDEX

Appendix A - Dimensions of Hitachi calibration rack

The Hitachi calibration rack is the standardized rack that is used in chemical analysers to offer the tubes with samples to the machine. These dimensions are of importance for the design of the tube as it needs to fit the rack in order to be operational (list of requirements)



Appendix B - Physical location of blood collection

The human body has different type of blood transportation. Arteries transport oxygenated blood and veins transport deoxygenated blood within the human body. The smallest of a body's blood vessels is called "capillaries". Capillaries are useful vessels when small blood samples need to be collected as they are often located close the surface of the human skin, which means that a superficial puncture can be made in order to start the blood flowing. In order to find the best location on the human body for blood collection, it is useful to focus on the following points of attention:

- Sensitivity of location
- How superficial are the capillaries located?
- Is it easy for the patient to reach this location?
- Thickness of the skin.

Finger
The most common location to extract blood in small quantities is the finger as they contain a high density of capillaries close to the surface (figure 1). The outer sides of the middle and ring finger are preferred to peform the puncture. The index finger and the thumb have calluses which complicates blood flow. The little finger is to be avoided because the tissue is thin (WHO, 2010)

Heel
The heel is a location that is only used in pediatric and neonatal patients. Neonatal patients do not have developed callus which makes the heel a suitable location for blood sampling.

Earlobe
This body part contains a high concentration of capillaries. The sensitivity of the earlobe is less than sensitivity of the finger due to a lower density of nociceptors. However, the perceived discomfort is higher as the patient cannot see the ear being tested (BBC, 2000).

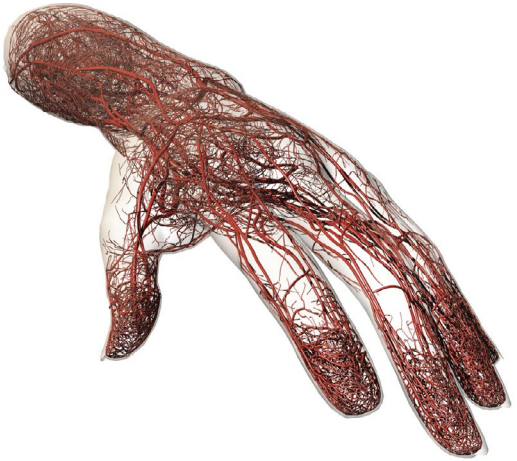


Figure 1- Vessels within the hand

Other
Other parts of the human body could be used as well. There are a few reasons not to sample blood from other parts. It requires the patient to remove clothing, which can be unpleasant in accompany of other people. In order to sample enough blood, it is needed to push the blood out of the puncture that is created. For the finger and earlobe, this is fairly easy. For other parts on the human body this is more difficult.

Conclusion
The finger seems the most logical place to take the blood sample as the hands are not covered by any cloths and are easily accessible. Exposure of the fingers is not considered controversial which means that samples could be taken in presence of other people. High density superficial capillaries in the skin make superficial low invasive sampling possible.

Appendix C - Exploring dimensions of test tubes.

Aim of the test & setup
This test is meant to find out what dimensions fit the Roche chemical analyser that is located at NKI-AVL. When the tube is too small or long it is known by the analysts working at NKI-AVL that the chemical analyser is not able to perform the PSA analysis. It is unknown what the working dimensions are of the machine. Four tubes are used in this test. The four tubes vary in dimensions which is to determine what shapes work and which do not.

The following parts can be seen in figure (2)

Tube 1
This is the Hitachi cup. It is designed for the Hitachi rack that is commonly used as standard equipment in chemical labs. The cup is broad on top (17mm), which enables the cup to fit tightly in the rack. This dimension should be a requirement for the design of the container (Appendix M). The broad top of the cup also stabilize the cup inside the rack which is desired as the chemical analyzer is a machine that is about precision. Tight tolerances are a must.

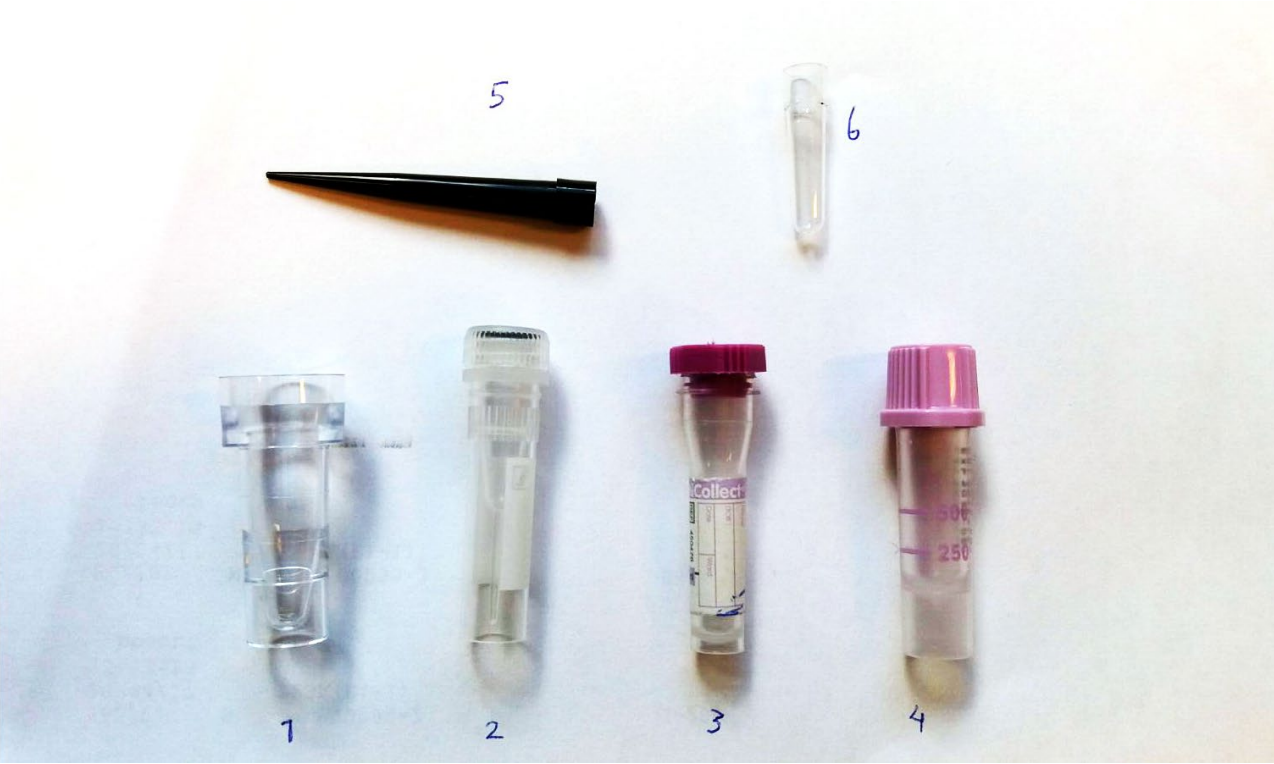


Figure 2- test tubes ▲

Tube 2
This is a tube manufactured by Sarstedt, a large medical equipment manufacturer. The sample container is placed high inside the tube and has a descending shape.

Tube 3
This is the Greiner Minicollect. The tube is small and long.

Tube 4
This is the BD Microtainer, a tube that has a straight, broad and wide shape

5
This is the pipette that is used by the chemical analyser to sample 20 µl blood from the tube.

6
This tube is used to store the 20 µl sample that is extracted by the pipette.

Three different sample volumes for each tube are analysed in the machine to find out whether small samples sizes are accepted in different tubes. All samples are taken from one single serum fraction to assure that the composition of the samples are equal.

Results
The Greiner Minicollect is the only tube that was refused by the chemical analyser (figure 3).
The analyser gives values between the 1.62 and 1.69 µg/l PSA for the rest of the samples (figure 4). The varying results in PSA value have to do with the analysers accuracy.

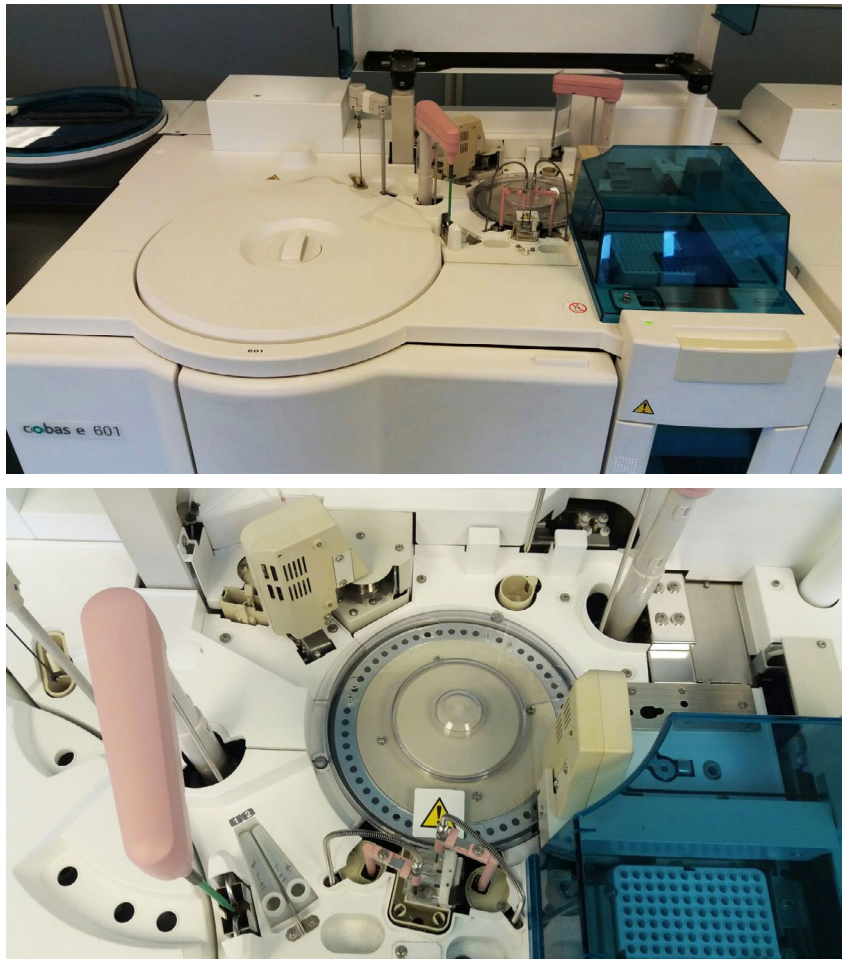


Figure 3 - Chemical analyser Cobas E-601

Type of tube	sample size (µl)	PSA (µg/l)
Tube 1	150	1.69
	200	1.63
	250	1.67
Tube 2	150	1.62
	200	1.64
	250	1.64
Tube 3	150	Error
	200	Error
	250	Error
Tube 4	150	1.68
	200	1.64
	250	1.66

Figure 4 - Results of tube PSA test

Conclusion & follow up

Tube 3 is probably rejected due to the fact that the shape of the container is long and thin. It was remarkable that tube 2 was not rejected as the shape was also rather small. The container however was not deep which enables the pipette to extract the 20 µl sample more superficially (figure 5). It is expected that the electromagnetic pulse to detect the liquid interferes with the tube when it is too small and deep.

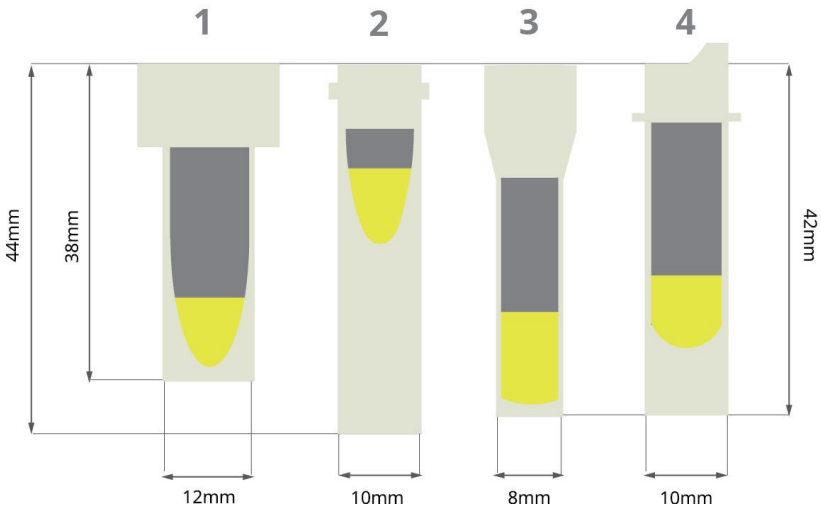


Figure 5 - dimensions of tubes with serum samples

For follow up research it is interesting to see what the minimum volume of the sample is without the analyser rejecting the sample. Tubes with different diameters will be prototyped to explore possible dimensions that can diminish sample volume while being operational.

Appendix D - Bill of materials

	Part	Amount	Material	Retailer	Production	Colour	Dimension	Price (each) (€)	Link
2									
3	Top	1	PA2200	Oceanz	3D printing (SLS)	White	various	5.00	http://oceanz.eu/?g
4	Capillary tube	1	PP EDTA coated	Sarstedt	Purchase	Transparent	3 mm outer diam	0.00	https://www.sarstedt
5	**Microcontainer**	1	PP	Sarstedt	Purchase	Transparent	n/a	0.20	https://www.sarstedt
6	**Insert**	1	PVC	Sarstedt	Purchase	Pink	n/a	0.00	https://www.sarstedt
7	**Base**	1	PA2200	Oceanz	3D printing	White	58 mm x 20 mm	9.00	http://shop.3dfilaprir
8	**Testtube**	1	PS	Greiner bio-one	Purchase	Transparent	11 mm inner diam	0.02	https://www.fishersc
9	**Packaging**	1	Cardboard	Envelopeland	Printing / purchase	White & colour prin	A5 mailbox case	0.49	https://www.envelop
10	**Inside of package**	1	Cardboard	Envelopeland	cutting	White	various	0.10	https://www.envelop
11	**Lancet**	2	Various	BD	Purchase	Blue	n/a	0.27	http://www.verloskur
12	**Band aid**	1	Fabric	Manutan	Purchase	n/a	n/a	0.12	http://www.manutan
13	**Sterilize wipe**	1	Paper	Fysiosupplies	Purchase	n/a	n/a	0.03	https://www.fysiosup
14	**Manual**	1	Paper	NKI-AVL	Printing	n/a	A4 format	0.03	n/a
15	**Transport blister UN 3375**	1	PS	Daklapack	Purchase	Transparent	n/a	1.00	http://www.un3373.c
16	**Sealed envelope**	1	Unknown polymer	Daklapack	Purchase	n/a	n/a	0.30	https://shop.transpo
17									
18									
19									
20									
21							total:	16.56	

For the full hyperlinks in the bill of materials, see the Excel file.

Appendix E - Patient interviews

Patienten interview 2-5-2017

Patient 1

Leeftijd: 81 jaar

Overig: Is aanwezig samen met vrouw.

Moet u vaak langs het ziekenhuis om bloed te laten afnemen voor een PSA check. Hoe vaak?
Nu een aantal keer bij de polikliniek geweest om een PSA test te doen.

Is dat altijd hier op NKI-AVL?
Ja, tot nu toe altijd op NKI-AVL geweest

Kost het u veel tijd en moeite om langs te komen en bloed te laten prikken?
Het prikken zelf is zo gedaan. Vandaag hoeven we maar 15 minuten te wachten voor we aan de beurt zijn. Ik heb ook wel eens meegemaakt dat ik 2 uur lang moest wachten voordat ik aan de beurt was.

Hoe ervaart u het langskomen en prikken in het ziekenhuis?
Het langskomen wordt gezien als aangenaam.

Introductie van PSA thuistest (Medichecks)

Wat is uw eerste indruk van deze set?
Ziet er begrijpelijk uit en is makkelijk te snappen. Klinkt als een idee dat reistijd bespaart.

Is het duidelijk hoe het gebruikt moet worden?
Het ziet er begrijpelijk uit.

Ziet u uzelf gebruik maken van deze set?
Ja, Dit lijkt mij een handig product. Het hangt er wel helemaal vanaf hoe vaak ik een follow up PSA test zou moeten ondergaan. Ik ben nog niet zo vaak getest. Als dit maar 2 keer per jaar is, vind ik het allemaal niet zo'n probleem.

Wat vindt u van het idee om thuis bloed af te nemen en te laten testen in het ziekenhuis?
Dit is prima

Wat vindt u van het idee om zelf in de eigen vinger te prikken?
Meneer vindt het geen probleem om bij zichzelf te prikken.

Wat vindt u ervan dat u zelf kunt bepalen wanneer en waar u kunt prikken?
Het zelf bepalen wanneer er geprikt kan worden heeft niet heel veel meerwaarde voor meneer.

Wat zouden voordelen kunnen zijn van het nieuwe product?
-
Wat zouden nadelen kunnen zijn van het nieuwe product?
-

Patient 2

Leeftijd: 65 jaar

Overig: Is aanwezig samen met vrouw. Meneer heeft in Januari een prostatectomie gehad en hoopt nu dat zijn PSA waarde "0" zal aangeven. Meneer en mevrouw komen uit Alkmaar.
Meneer is diabetes patient.

Moet u vaak langs het ziekenhuis om bloed te laten afnemen voor een PSA check. Hoe vaak?
Dit is de eerste keer dat de PSA waarde gemeten zal worden sinds de prostatectomie in Januari. Daarvoor is meneer 3 keer eerder langs geweest voor een PSA test.

Is dat altijd hier op NKI-AVL?
De eerste keer was in Alkmaar, daarna is meneer doorverwezen naar het NKI-AVL. De arts raadde meneer aan om ook voor deze PSA controle naar het NKI-AVL te komen. Meneer weet niet waarom hij hier heen moest komen ipv de test uit te laten voeren in Alkmaar.

Kost het u veel tijd en moeite om langs te komen en bloed te laten prikken?
Het kost 1 uur heen en 1 uur terug van en naar Alkmaar naar het ziekenhuis. Ook moet er tussen het prikken op de poly en het consult bij de uroloog nog 3 uur gewacht worden. Dit kost erg veel tijd.

Hoe ervaart u het langskomen en prikken in het ziekenhuis?
Dit kost veel tijd, maar wordt niet gezien als onaangenaam.

Introductie van PSA thuistest (Medichecks)

Wat is uw eerste indruk van deze set?
De eerste vraag die opkomt is de haalbaarheid van de 5 druppels bloed die geprikt moeten worden bij de patiënt. Het ziet er naar uit dat het product veel tijd bespaart.

Is het duidelijk hoe het gebruikt moet worden?
Het ziet er begrijpelijk uit.

Ziet u uzelf gebruik maken van deze set?
Ja

Wat vindt u van het idee om thuis bloed af te nemen en te laten testen in het ziekenhuis?
Dit is prima

Wat vindt u van het idee om zelf in de eigen vinger te prikken?
Meneer vindt het geen probleem om bij zichzelf te prikken en zou zichzelf willen prikken wanneer hij het product in gebruik zou nemen. Hij zou zijn vrouw of naasten hier niet mee lastig willen vallen. De onafhankelijkheid speelt hier een rol.

Wat vindt u ervan dat u zelf kunt bepalen wanneer en waar u kunt prikken?
DIt is fijn

Wat zouden voordelen kunnen zijn van het nieuwe product?
De twee uur reistijd en het besparen van 3 uur wachten in het ziekenhuis zijn de pluspunten.

Wat zouden nadelen kunnen zijn van het nieuwe product?
Bij tremor zal het niet goed werken wordt opgemerkt.

Overig: NKI-AVL is het beste ziekenhuis voor de behandeling, dus mensen komen speciaal hiervoor naar het ziekenhuis.

Patient 3

Leeftijd: 74 jaar

Overig: Is aanwezig samen met vrouw. Meneer heeft een prostatectomie gehad en is samen met zijn vrouw uit Almere overgekomen voor een PSA test. Mevrouw heeft diabetes.

Moet u vaak langs het ziekenhuis om bloed te laten afnemen voor een PSA check. Hoe vaak?
De eerste keer dat er getest werd op PSA was in Almere, daarna is naar het NKI-AVL doorverwezen. Dit is de eerste keer sinds de operatie dat er weer wordt gecontroleerd.

Is dat altijd hier op NKI-AVL?
Nee, de eerste keer was in Almere.

Kost het u veel tijd en moeite om langs te komen en bloed te laten prikken?
Dit kost best veel tijd. Wanneer de controle 1 keer per jaar is vindt meneer het geen probleem om langs te komen. Wanneer dit echter 4 a 5 keer per jaar zou zijn is het een ander verhaal en is het wel een gedoe.

Hoe ervaart u het langskomen en prikken in het ziekenhuis?
Het langskomen wordt gezien als aangenaam.

Introductie van PSA thuistest (Medichecks)

Wat is uw eerste indruk van deze set?
Het ziet er begrijpelijk uit. Mevrouw vraagt zich af in hoeverre oude mensen is staat zijn 5 druppels bloed te prikken. Door mevrouws diabetes is het soms moeilijk om bloed uit de vinger te krijgen. Ze probeert vingers af te wisselen zodat niet een vinger het meest wordt belast. Ze zegt dat dit een bekend probleem is bij diabetespatiënten.

Is het duidelijk hoe het gebruikt moet worden?
Ziet er begrijpelijk uit.

Ziet u uzelf gebruik maken van deze set?
Ja, dit klinkt als een handige vernieuwing.

Wat vindt u van het idee om thuis bloed af te nemen en te laten testen in het ziekenhuis?
Dit is prima. Meneer heeft er ook vertrouwen in dat de sample veilig bij het ziekenhuis zal aankomen.

Wat vindt u van het idee om zelf in de eigen vinger te prikken?
Meneer vindt het geen probleem om bij zichzelf te prikken. Meneer zegt dat hij dit graag zelf wilt doen en zou niet snel om zijn vrouw of familie om hulp vragen. Onafhankelijkheid speelt een rol.

Wat vindt u ervan dat u zelf kunt bepalen wanneer en waar u kunt prikken?
Dit is handig

Wat zouden voordelen kunnen zijn van het nieuwe product?
-
Wat zouden nadelen kunnen zijn van het nieuwe product?
-

Patient 4

Leeftijd: 71 jaar

Overig: Is aanwezig samen met vrouw. Meneer en mevrouw komen uit Spijkenisse. Meneer heeft diabetes.

Moet u vaak langs het ziekenhuis om bloed te laten afnemen voor een PSA check. Hoe vaak?
Ze zijn nu een paar keer naar het ziekenhuis geweest voor een PSA test.

Is dat altijd hier op NKI-AVL?
Ja, dit is tot nu toe altijd op NKI-AVL geweest, behalve de eerste keer toen prostaatkanker werd geconstateerd.

Kost het u veel tijd en moeite om langs te komen en bloed te laten prikken?
Het kost veel tijd om hier te komen. Op en neer van en naar Spijkenisse en hier in het ziekenhuis moet nog 3 uur op de uitslag worden gewacht.

Hoe ervaart u het langskomen en prikken in het ziekenhuis?
Dit is een soort uitje. Het kost natuurlijk veel tijd, maar zo gauw het om mijn gezondheid gaat heb ik dit er graag voor over. Het is hier erg ontspannen.

Introductie van PSA thuistest (Medichecks)

Wat is uw eerste indruk van deze set?
Het ziet er onpersoonlijk uit. Nu zie ik de arts niet meer in eigen persoon? Meneer vind het een op een gesprek meerwaarde hebben tegenover het feit dat er tijd bespaard wordt door het product. Meneer is geopereerd door dokter van der Poel en heeft dus graag persoonlijk contact.

Is het duidelijk hoe het gebruikt moet worden?
Het ziet er begrijpelijk uit.

Ziet u uzelf gebruik maken van deze set?
Meneer staat open voor innovaties. In eerste instantie staat hij sceptisch tegenover het product, maar hij zou het graag een kans geven en zou het uitproberen wanneer aangeboden tijdens een consult.

Wat vindt u van het idee om thuis bloed af te nemen en te laten testen in het ziekenhuis?
Wanneer je je PSA laat testen in het ziekenhuis weet je zeker dat het goed gaat, aangezien professionals aan het werk zijn. Wanneer de patiënt thuis zijn eigen bloed afname doet is het maar de vraag of het goed gaat. Is er niet te weinig bloed verzameld en gaat alles wel OK? Het neemt een bepaalde zekerheid weg.

Wat vindt u van het idee om zelf in de eigen vinger te prikken?
Meneer vindt het geen probleem om bij zichzelf te prikken. Hij is ervaren door de suikerziekte die hij heeft.

Wat vindt u ervan dat u zelf kunt bepalen wanneer en waar u kunt prikken?
Meneer geeft hier niet zoveel meerwaarde aan. Het reizen maakt hem niet heel veel uit.

Wat zouden voordelen kunnen zijn van het nieuwe product?
-
Wat zouden nadelen kunnen zijn van het nieuwe product?
-

Vragen aan medewerker Polikliniek

Wie: Petra van de bloedafname

Is er een verband tussen verhoogde PSA en diabetes?
Nee. De overeenkomsten zijn toevallig.

Waarom raden artsen aan om terug naar NKI-AVL te komen voor een PSA follow up test?
Artsen zeggen dat de resultaten kunnen verschillen wanneer afgenomen op een andere locatie.
Ze nemen het liever zelf af en willen behandeling op dezelfde locatie.

Appendix F - interview blood collection department

Tijdens het bezoek aan de bloedprik afdeling wordt er meegekeken hoe een venipuncture wordt uitgevoerd. Hierna worden een aantal vragen gesteld over zowel de venipuncture als de vinger prik.

Hoeveel bloed komt er gemiddeld uit een venipuncture prik?
Er wordt gebruik gemaakt van een 5 ml bloed sample voor een PSA test

Heb je wel een last van stolling reacties wanneer je een venipuncture uitvoert?
Hier heb je geen last van aangezien het bloed erg snel uit de arm wordt gezogen. In venipuncture buisjes bevindt zich een onderdruk, wanneer de naald hierin wordt geprikt, stroomt het bloed snel binnen. In theorie zou dit wel kunnen als de prik te langzaam zou gaan.

Is het mogelijk om 200 microliter bloed uit de vinger te halen van een persoon van 80 jaar met slechte doorbloeding d.m.v een vingerprik?
Dit is mogelijk, het hangt er vanaf hoe groot je de incisie maakt die nodig is voor de vinger prik. Ook kan de bloedcirculatie van de vingers bevorderd worden door de vingers te stimuleren of te verwarmen met warm water.

Is het gewenst dat de patiënt eerst een venipuncture test ondergaat alvorens een follow-up test wordt uitgevoerd m.b.v. een vingerprik?
Dit weet ik niet. In principe zou de patient dit ook thuis kunnen. Het voordeel is dat de patient snel resultaat heeft, wanneer hier geprikt wordt.

Gaat een venipuncture wel een verkeerd, treden er wel een complicaties op?
Dit gebeurt vrijwel nooit

Denk je dat een vingerprik veilig is wanneer een patient deze zelfstandig moet uitvoeren?
Als de patient goed wordt voorgelicht, lijkt mij dat de patient dit ook zelf zou moeten kunnen. Wel moet de uroloog dan goed inschatten of de patient hiertoe in staat is.

Kun je op korte termijn een afspraak maken om een venipuncture prik te hebben? Als bijvoorbeeld een uroloog de patiënt doorstuurt, wordt hij dan nog dezelfde dag geprikt?
De venipuncture wordt hier uitgevoerd in de polikliniek. Patiënten kunnen hier zonder afspraak langskomen als ze zijn doorverwezen door de uroloog. Wanneer het bloed is geprikt wordt de sample in een buis gestopt. Deze buis wordt vervolgens op buizenpost gestopt en gestuurd naar de verdieping hierboven waar het algemeen klinisch lab zich bevindt (dit systeem functioneert d.m.v. drukverschil). Dit duurt 10 minuten. Vervolgens wordt de sample geanalyseerd door het algemeen klinisch lab. Van prikken tot PSA resultaat duurt gemiddeld 3 uur.

Appendix G - Interview met Henk van der Poel - Uroloog - 21-4-2017

Hoe oud zijn patiënten? Zijn veel patiënten ouder dan 80 jaar?
De meeste patiënten zijn tussen de 50 - 75 jaar oud. Ook zijn er mensen ouder dan dat. Ook zijn er soms patiënten ouder dan 90. Ongeveer 5% van de groep is ouder dan 80 jaar.

Tot welke leeftijd wordt er geopereerd aan prostaatkanker?
Er wordt geopereerd aan prostaatkanker als de patiënt in goede conditie verkeerd. Meestal ligt de grens bij de 75 jaar. Wanneer de patiënt oud is, zal de ontwikkeling van de tumor minder snel zijn waardoor operaties niet altijd gewenst zijn

Welke patiënten komen in aanmerking voor een follow up afspraak en operaties aan de prostaat?
Het gaat er voornamelijk om dat de patiënt in goede conditie verkeerd.

Als dit bloedprikapparaat ontwikkeld wordt, wat is dan de voornaamste doelgroep?
Dat ligt eraan voor wie je allemaal wilt ontwerpen. Als iedereen gebruik zou moeten kunnen maken van het ontwerp moet er ook met de oudste personen rekening gehouden worden. Wanneer je voor de grootste doelgroep wilt ontwerpen ligt deze tussen de 50 en 75 jaar. Dit is ongeveer 95 % van de patiënten.

Hoe zou u dit bloedprikapparaat aanbieden aan de patiënt?
Na een consult bij de uroloog zou dit bloedprikapparaat aangeboden kunnen worden aan de patiënt. Ik zou aan de patiënt vragen of hij geïnteresseerd is in het gebruik van deze manier van bloedafname. We kunnen het principe dan kort doorspreken. Ook zou ik moeten inschatten of de patiënt in een zodanig goede conditie verkeert dat ik hem geschikt acht, gebruik te maken van dit systeem.

Hoe en wie zou de patiënt moeten informeren m.b.t. Het nemen van een eigen bloed sample?
Het lijkt mij het handigste wanneer de bloedafname deze taak op zich zou nemen. Zelf heb ik al uroloog een druk schema, waarbij het moeilijk zou zijn veel tijd te reserveren voor de uitleg van het bloedafname apparaat. Bij de bloedafname zouden ze ook een keer kunnen voordoen hoe de patiënt bij zichzelf bloed kan afnemen. De eerste bloed sample kan dan al mbv het nieuwe apparaat afgenomen worden bij de bloedafname in het ziekenhuis.

Wanneer u verwacht dat de patiënt prostaat kanker heeft, zou u de patient dan een vingerprik set mee naar huis mee geven, of wordt er eerst ter plaatse een venipuncture uitgevoerd?
In principe zou de patiënt dit zelf kunnen doen. Echter, als de patiënt zich al in het ziekenhuis bevindt, kost het niet veel extra moeite om langs de polikliniek te lopen voor een venipuncture. De patiënt kan hier terecht zonder afspraak. Het hangt van het moment af of het hier druk is of niet.

Ik zou graag in contact komen met mensen die bij zichzelf bloed afnemen met behulp van een vingerprik, heeft u tips?
Het gebeurt niet vaak in het ziekenhuis dat mensen bij zichzelf bloed afnemen. Misschien kun je het best op zoek naar mensen met diabetes. Deze mensen prikken zichzelf.

Ik zou graag in contact komen met patiënten die een prostatectomie hebben ondergaan, Heeft u hiervoor tips?
Dinsdagmiddag ben ik aanwezig op de polikliniek. Je kunt dan met het personeel van de polikliniek bespreken hoe je in contact kunt komen met patiënten. Aangezien het hier om patiëntinformatie gaat echter, moet je het onderzoek niet te groot maken. Normaal gesproken moet er om goedkeuring worden gevraagd binnen een juridische commissie. Wanneer het kleinschalig wordt gehouden kan het daarbuiten wel gedaan worden.
(zie “interview patiënten” voor het vervolg)

Appendix H - Dimensions of Heraeus centrifuge rack.

The Heraeus centrifuge rack is the standardized rack that is used for chemical centrifuges. The relevant dimensions are being displayed in figure 6.

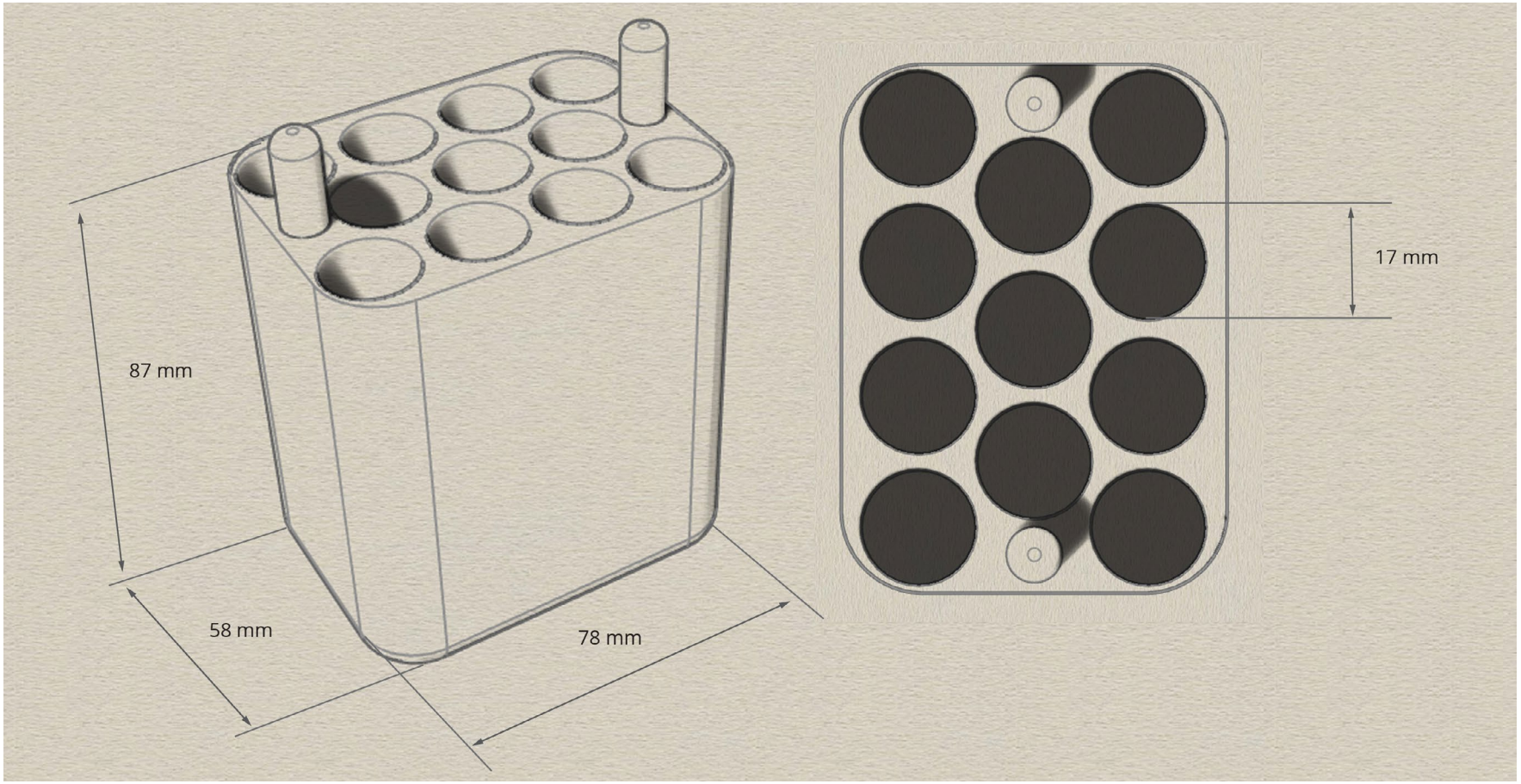


Figure 6 - dimensions of Heraeus centrifuge rack.

Appendix I - Comparison of 3D print techniques

Various 3D print techniques are out there that can be used for the production of the blood collection device. The techniques differ from each other in detail precision, surface finish, material properties and production price. The three most commonly used techniques are described in in order to make a well considered decision about production and material. (3Dhubs, 2017):

Fusion deposition modelling (FDM) printing

Pro's
Rapid turnaround time
Inexpensive
Form and fit prototyping

Con's
Tolerance of +/- 1mm
Overhangs require support which will affect surface finish
Print layers are visible
Anisotropic (weak in the Z direction)

Conclusion:
This technique is the cheapest option for the production of the blood collection device. However, material prices for ISO 10993 certificated materials are quite high. (Trimech, 2017) describes some FDM materials that have the ISO 10993 certification. The closing mechanism of the upper part with the test tube needs to be precise in order to make the parts fit together. It is questionable whether 1 mm precision is accurate enough. The surface finish is also not that smooth due to the visible layers. A smooth finish is something that is desired as the blood sample needs to flow as smooth as possible within the capillary tube without sticking against the plastic. The basis of the blood collection device could however be made from a non-ISO 10993 FDM material. This cuts the costs in the overall pricing.

Stereolithography (SLA) printing

This technique uses a laser that solidifies a polymer liquid in the shape that is desired.

Pro's
Smooth surface finish
Complicated designs and sculptures
Small, high detail models
Can be used for investment casting

Con's
Expensive
Can't handle large models
Can't handle extensive exposure to UV-light

Conclusion
This technique would be an ideal technique for the production of the blood collection device. The surface finish is very smooth and details and tolerances are precise. the only problem are the costs. The blood collection device will be a disposable, hence large production prices are not feasible.

Selective laser sintering (SLS)printing

This technique uses laser to melt tiny layers of polymer powder into the desired shape

Pro's
Functional prototypes and end products
Complex designs with complex details
Moving and assembled parts
Cases, holders, adapters

Con's
Cavities within design (unless making use of escape holes)

Conclusion
This technique would be ideal for the design of the upper part of the blood collection device, as the the tolerances are more critique. The surface is a bit grainy which could be solved by applying a surface treatment which preserves the ISO 10993 standard of the material. The technique is more expensive than FDM printing which means that material usage should be minimised in order to cut overall costs.

Appendix J - Ergonomic dimension target group

I1

age [years]	men n	s	P_5	$\bar{x}$	P_{95}
20 – 30	54	85	392	543	677
31 – 49		81		519	
50 – 54	35	78	373	507	647
55 – 59	46	74	353	482	608
60 – 64	44	66	353	452	559
65 – 69	50	64	334	422	540
70 – 74	59	74	275	392	510
75 – 79	36	81	235	373	510
80 +	33	57	226	328	432
total		78		497	

I1 - Gripping force (N). (Steenbekkers, 1998)

I2

age [years]	men n	s	P_5	$\bar{x}$	P_{95}
20 – 30	55	8	59	71	81
31 – 49					
50 – 54	34	9	55	70	83
55 – 59	46	8	55	66	78
60 – 64	44	10	51	66	82
65 – 69	50	11	47	65	80
70 – 74	59	9	51	64	79
75 – 79	36	11	42	59	73
80 +	32	11	44	61	83

I2 - Flexion of wrist (degrees). (Steenbekkers, 1998)

I3

age [years]	men n	s	P_5	$\bar{x}$	P_{95}
20 – 30	55	10	52	67	82
31 – 49					
50 – 54	35	9	46	64	78
55 – 59	46	11	41	60	75
60 – 64	44	10	45	59	75
65 – 69	50	12	34	59	77
70 – 74	59	11	34	58	75
75 – 79	36	13	26	53	73
80 +	32	12	33	53	70

I3 - Extension of wrist (degrees). (Steenbekkers, 1998)

I4

age [years]	men n	s	P_5	$\bar{x}$	P_{95}
20 – 30	55	6	32	44	55
31 – 49					
50 – 54	35	8	30	44	55
55 – 59	46	8	34	45	58
60 – 64	44	7	32	45	56
65 – 69	50	8	30	45	57
70 – 74	59	7	30	42	56
75 – 79	36	7	32	42	54
80 +	33	6	32	41	51

I4 - Ulnar deviation of wrist (degrees). (Steenbekkers, 1998)

I5

age [years]	men n	s	P_5	$\bar{x}$	P_{95}
20 – 30	55	7	13	21	33
31 – 49					
50 – 54	35	6	9	20	30
55 – 59	46	6	10	19	28
60 – 64	44	6	12	20	29
65 – 69	50	6	9	19	28
70 – 74	59	7	9	20	30
75 – 79	36	7	7	17	28
80 +	33	7	10	18	31

I5 - Radial deviation of wrist (degrees). (Steenbekkers, 1998

I6

age [years]	men n	s	P_5	$\bar{x}$	P_{95}
20 – 30	55	2.2	5.6	8.7	12.3
31 – 49		2.1		8.2	
50 – 54	35	1.9	4.5	7.7	10.8
55 – 59	46	2.2	4.7	7.5	10.6
60 – 64	44	1.8	4.3	6.4	9.6
65 – 69	50	2.1	4.1	6.5	10.4
70 – 74	59	2.1	2.5	5.3	8.9
75 – 79	35	1.7	2.5	5.1	7.8
80 +	33	1.7	2.5	4.9	7.9
total		2.1		7.7	

I6 - Static torque of two hands (Nm). (Steenbekkers, 1998)

I7

age [years]	men n	s	P_5	$\bar{x}$	P_{95}
20 – 30	55		64		
31 – 49					
50 – 54	35		46		
55 – 59	46		56		
60 – 64	44		62		
65 – 69	50		50		
70 – 74	59		51		
75 – 79	36		55		
80 +	33		37		

I7- Supination of wrist (degrees). (Steenbekkers, 1998)

I8

age [years]	men n	s	P_5	$\bar{x}$	P_{95}
20 – 30	55		75		
31 – 49					
50 – 54	35		76		
55 – 59	46		79		
60 – 64	44		84		
65 – 69	50		79		
70 – 74	59		80		
75 – 79	36		77		
80 +	33		78		

I8 - Pronation of wrist (degrees). (Steenbekkers, 1998)

Appendix K - Observation human-interaction usage

User observation
This user observation is meant to find out how a state of the art PSA kit is used by the target group. The test is done by a 66 year old male.

Material
-Medichecks blood sampling kit with capillary tube
-Medichecks blood sampling kit with gravitational container

Method
The user is given a Medichecks PSA sample kit and is asked to take his own blood sample without further instruction. Information should be taken from the manual.
After that, the user is asked to sample his blood by using a capillary tube instead of a gravitational container.

Observations
The actions of the user are recorded by making photos and notations. Observations are visualized in figure 7.

Conclusions
To summarize the main observation and recommendations:

- The user needs glasses to read the small font that is used in the manual.
- Words in the manual do not match with the actual parts that are included in the kit.
- It is not clear to the user why so many lancets are included in the kit.
- It is not clear what finger needs to be punctured by the user.
- It takes the user about 10 minutes to be able to collect the right amount of blood in the container that is included in the kit.
- Aiming for the gravitational container is hard, as the container is small and unstable.
- The closing lid in confusing as it needs to be pressed instead of screwed onto the container.
- The label that needs to be stuck onto the container is too large which results in overlap of information.
- The chance that the container turns over is big as both hands need to be used in order to cause a sufficient blood flow.
- The capillary is difficult to fill as both hands are needed to cause a sufficient blood flow.
- The drop of blood need to be big enough for the tube to cause capillary action.

These insight will be used to optimize the product user interaction. The test is only executed with one single participant, however, it is believed that significant information is gathered that can be used to formulate interaction criteria. Further on in the project more user observations will be done to both validate and formulate additional interaction requirements.

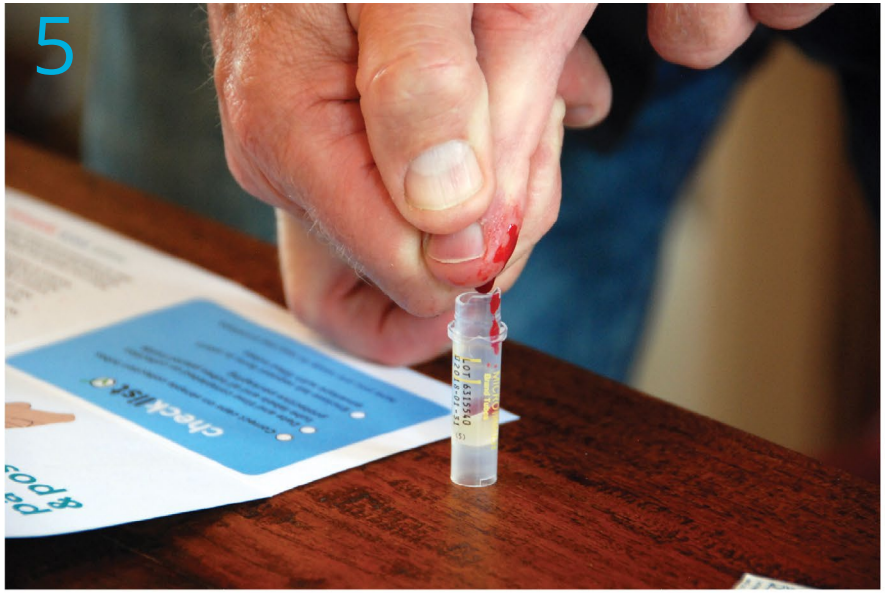
User is introduced to the Medichecks PSA kit.

The user first reads the whole manual before starting following the steps. The words in the manual and the parts do not match, which is confusing to the user.

The user removes the safety cap of the lancet.

The manual was not clear in explaining what finger to puncture. Extra instruction was needed to make the user puncture the right finger.

Figure 7 - User observations

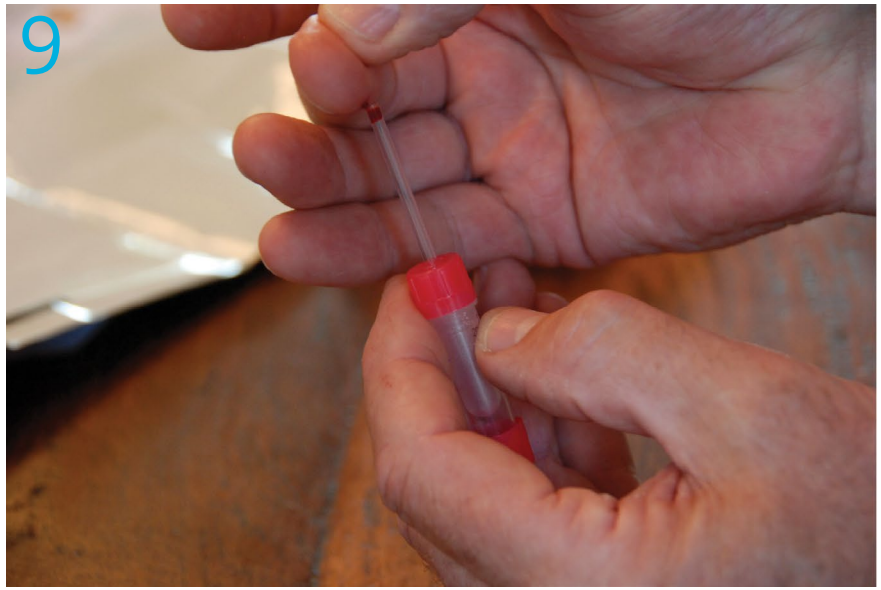


The user stimulates blood flow with the finger. The container is very instable and the user has difficulties in aiming the drops in the container.

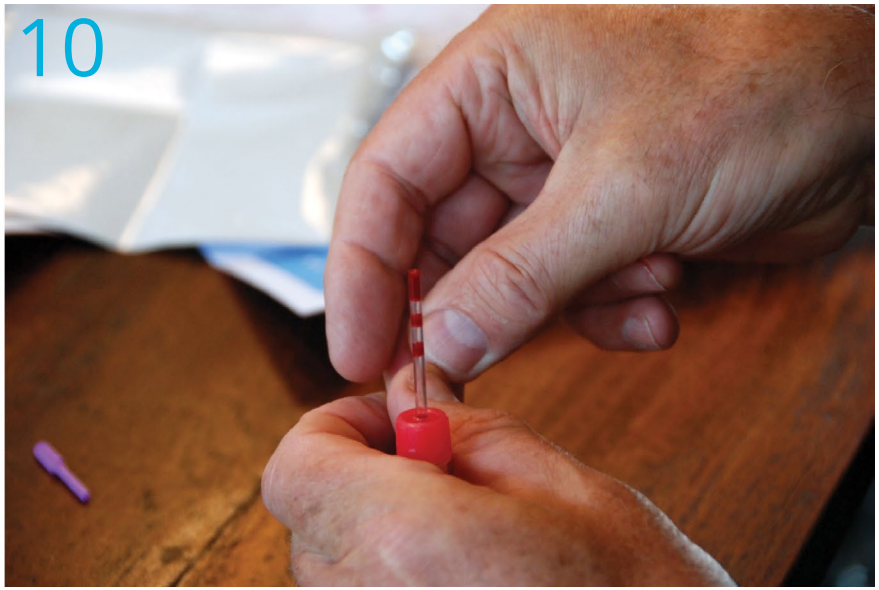
The container with blood sample falls down due to instability.

The user spills blood drops due to the container small inlet and instability of the hand.

The user closes the container with the lid. He thinks the lid needs to be screwed in place, however the lid closes by pressure, which is confusing to the user.



The user punctures another finger and tries to sample blood by using the capillary blood container.



The user has difficulties with the transportation of the blood. The tube seems to be constipated due to blood cluttering or high viscosity of the blood.

Appendix L - Process tree - Blood collection device

Main	Sub	Action
1. Originate		
	1.1 production & design	
		1.11 Design overal appearence of the blood collection device
		1.12 Determine materials that are used for the blood collection device
		1.13 Design the construction of the blood collection device
		1.14 Determine the dimensions of the blood collection device
		1.15 Integrate safety and sterilization in the design of the device
		1.16 The device is designed according to Dutch standardizations
		1.17 The test tube, microcontainer and capillar tube are purchased
		1.18 The base and top part are being SLS 3D printed
		1.19 All parts are being assembled within NKI-AVL
	1.2 packaging product	
		1.21 The components are packaged in a kit at NKI-AVL
	1.3 set price	
		1.31 The blood collection device will be used within the hospital. Commecial interests could potentially play a role
2. Use		
	2.1 Transport to the user	
		2,11 AKL prepares kit for patient
		2.12 NKI-AVL sends kit to user by mail
		2.13 patient recieves kit by mail
	2.2 use product	
		2.21 Patient opens the blood collection kit
		2.22 Read manual
		2.23 Wash the hands with warm water

		2.24 Sterilize the finger
		2.25 Punture the finger for blood flow
		2.26 Collect 200 microliter blood
		2.27 Cover the puncture with a plaster
		2.28 Seal the container that is filled with blood
	2.3 Send back collection device	2.31 Place the blood sample in an envelope (special for "in-vitro diagnostica")
		2.32 Send envelope back to NKI-AVL by mail
	2.4 Prepare sample	2.41 Sample arrives at the logistics of AKL
		2.42 Sample is placed in a refrigiator in order to hemalyse the blood sample
		2.43 Sample is placed outside refrigiator to make the blood sample thaw
		2.44 Sample is placed in centrifuge
	2.5 Analyse sample	2.51 Sample is placed in a test tube rack
		2.52 Test tube rack inc. sample is placed in the chemical analyser
		2.53 Sample is analysed for PSA
		2.54 Results are automatically send to urologist
	2.6 functions	
		2.61 Collect blood sample of 200 microliter
		2.62 Preserve bloods quality from sampling until analysis
		2.63 Makes sure sample does not coagulate
		2.64 Sampling is ergonomic for user
		2.65 Makes sure no blood is spilled during samping procedure
	2.7 Life span	2.71 Product is used once
	2.8 safety	2.81 Users safety is guaranteed by ISO 10993 regulation and the use of certified lancets
3. discard		
	3.1 Throw away	3.11 User throws away rest material of kit
		3.12 Analyst at NKI-AVL throws away sample and packaging

Appendix M - List of requirements - Blood collection device

PROCESS STEPS			CRITERIA			
Main	sub	Action	nr.	Requirements & wishes	met?(n/j)	SOURCE
				Requirement		
				Wish		
1. Originate						
	1.1 production and design					
		1.11 Appearence of design	1	The overal appearence should fit with the target group of men (50-80) years old	j	Chapter 2.3 - User
			2	The blood collection kit should give the user a feeling of personality / personal attention		Chapter 2.3 - User
		1.12 Materials	3	The material should be resistant against organic solvents	j	Chapter 4.2 - Material choice
			4	The material should meet up to the ISO 10993 standard	j	Chapter 4.2 - Material choice
			5	The material should be chemical resistant (EDTA)	j	Chapter 4.2 - Material choice
			6	The material shoud be hydrolytic	j	Chapter 4.2 - Material choice
			7	The material should be water resistant	j	Chapter 4.2 - Material choice
			8	The storage medium should be manufactured from a material which allows a clear view of its contents when subjected to visual inspection	j	NEN-EN 14820-2004 en
			9	The material shoud be hemocompatible (blood)	j	Chapter 4.2 - Material choice
		1.121 Production	10	The production method should be able to process polymers	j	Chapter 4.2 - Material choice
			11	The form freedom of the production technique should be large	j	Chapter 4.3 - Production
			12	The production technique should be suitable for a batchsize of 1000 pieces	j	Chapter 4.3 - Production
		1.13 Construction	13	The material/construction should withstand 1700 g centrifugal force	j	Chapter 2.4 - Journey of PSA analysis
			14	The container should be stabilized in the rack.	j	Chapter 2.4 - Journey of PSA analysis
			15	The product should be designed in such a way that it is stable and balanced when in use	j	Chapter 2.4 - Journey of PSA analysis
		1.14 Dimensions	16	The dimensions of the container should not interfere with the electromagnetic pulse of the chemical analyser	j	Chapter 2.4 - Journey of PSA analysis
			17	The container should fit the standard centrifuge rack	j	Chapter 2.4 - Journey of PSA analysis
			18	The container should be cilindrical in shape to fit the rack	j	Chapter 2.4 - Journey of PSA analysis
			19	The outer diameter of the cilinder should be 12 mm to fit the test tube rack	j	Chapter 2.4 - Journey of PSA analysis
			20	Dimensions of capillars should make the blood flow towards the container as fast as possible		
			21	The opening of the container should be broader than the diameter of the pipette	j	Chapter 2.4 - Journey of PSA analysis
			22	The depth of the puncture part of the device should not be longer than 2,2 mm	j	Chapter 2.4 - Journey of PSA analysis

			23	The fill line on the storage medium shall fill such that the meniscus of the blood does not exceed or fall below the position of the line by more than 10%	j	NEN-EN 14820-2004 en
			24	The dead volume within the container should be lower than 150 microliter	j	Chapter 2.4 - Journey of PSA analysis
		1.15 Safety & sterilization	25	The puncture part of the device should be designed in such a way that it can be only used once	j	Chapter 2.5 - State of the art
			26	The overal design should enhance hygienic storage of blood sample	j	Chapter 2.5 - State of the art
		1.16 Standardization	27	The closure shall not become loose when tested for leakage in accordance with the method specified in the NEN norms document	j	NEN-EN 14820-2004 en
			28	Product should facilitate mixing during the hemalisation of the sample. There shall be sufficient free space to allow mixing by mechanical or manual means.	j	NEN-EN 14820-2004 en
			29	When the product contains a microbe-supporting additive it shall have been subjected to a validated process to eliminate microbial contamination from the additive and the receptacle interior. Validation of the process is the responsibility of the manufacturer	j	NEN-EN 14820-2004 en
	1.2 packaging product					
		1.21 packiging	30	The product should be transported according to regulations described in IATA packaging instructions P650	j	Chapter 4.7 - Transportation
			31	The product should be transported according to regulations described in UN 3373	j	Chapter 4.7 - Transportation
			32	The package dimensions do not exceed: 38 x 26,5 x 3,2 cm in order to fit the users mailbox	j	Chapter 4.7 - Transportation
			33	The package should have a primary container/vial in which the blood sample is stored.	j	Chapter 4.7 - Transportation
			34	The package should have a secondary packaging that is leak proof and contains absorbing material	j	Chapter 4.7 - Transportation
			35	The package should have an outer packaging that protects the components inside. The packaging should be sealable.	j	Chapter 4.7 - Transportation
	1.3 set price					
		1.31 Set price	36	The price should be as low as possible		Chapter 4.9 - Implementation & costs
2. Use						
	2.1 Transport to the user					
			37	Kit should be personalised to the concerned user (adres, name etc)	j	Chapter 4.9 - Implementation & costs
	2.2 use product					
		2.21 Open the blood collection kit	38	The user should be able to open the kit in an easy, intuative way	j	Chapter 4.7 - Transportation
		2.22 Read manual	39	Text, if present, should be at least 12pt sans serif in size	j	Chapter 2.3 - User
			40	The user should understand the manual without assistance	j	Chapter 4.8 - instructions & package design

			41	The manual should be visual and textual	j	Chapter 2.6 - Extended user scenario
		2.24 Sterilize finger	42	The kit should contain a sterilization wipe	j	Chapter 2.6 - Extended user scenario
		2.25 puncture finger	43	The user should be able to create a small punture in the finger for blood flow	j	Chapter 2.4 - Journey of PSA analysis
			44	The tasks within blood sampling self-paced, in which the user is able to decide on his own when he wants to continue to the next step		Chapter 2.3 - User
		2.26 Collect blood sample	45	The product should demand a maximum gripping force that is lower than 226N.	j	Chapter 2.3 - User
			46	The product should demand a maximum extention of the wrist that is lower than 26 degrees	j	Chapter 2.3 - User
			47	The product should demand a maximum flexion of the wrist that is lower than 42 degrees	j	Chapter 2.3 - User
			48	The product should demand a maximumradial deviation of the wrist that is lower than 7 degrees	j	Chapter 2.3 - User
			49	The product should demand a maximum ulnar deviation of the wrist that is lower than 20 degrees	j	Chapter 2.3 - User
			50	The product should demand a maximum static torque of two hands that is lower than 2.5 Nm	j	Chapter 2.3 - User
			51	The product should demand a maximum supination of the wrist that is lower than 46 degrees	j	Chapter 2.3 - User
			52	The product should demand a maximum pronation of the wrist that is lower than 76 degrees	j	Chapter 2.3 - User
			53	The user should be able to hold the device in a comfortable way	j	Chapter 2.3 - User
			54	The product should give an indication whether enough blood is collected	j	Chapter 2.3 - User
			55	The product should support the hands that are needed in order to sample the blood.	j	Chapter 2.3 - User
			56	The presence and the orientation of the device should be clearly felt by the hands of the user	j	Chapter 2.3 - User
			57	The use of the product is as self-explanatory as possible		Chapter 2.3 - User
			58			
		2.27 Cover puncture with plaster	59	The kit should contain a plaster	j	Chapter 4.8 - instructions & package design
		2.28 Seal container with sample	60	The user should be able to seal the sample in a hygienic way	j	Chapter 2.6 - Extended user scenario
	2.3 Send collection device back		61	Mention in the manual that the blood sample should be posted on the same day the sample is taken.	j	Chapter 2.6 - Extended user scenario
			62	The retour packaging should contain the retour address of NKI-AVL	j	Chapter 4.9 - Implementation & costs
	2.4 Prepare sample					

		2.44 Sample is centrifuged	63	The container within the product should be designed to avoid spontaneous discharge of the contents when being opened,	j	NEN-EN 14820-2004 en
	2.6 functions					
			64	Product should be able to at least store 200 microliter of blood	j	Chapter 2.4 - Journey of PSA analysis
			65	The incision that the product makes should be as less invasive as possible		Chapter 2.4 - Journey of PSA analysis
			66	The product should be able to make a puncture in the patients finger	j	Chapter 2.4 - Journey of PSA analysis
			67	The storage medium of the product should be anticoagulant (EDTA)	j	Chapter 2.4 - Journey of PSA analysis
			68	The product should be able to transport blood from the puncture towards the blood container	j	Chapter 2.4 - Journey of PSA analysis
			69	The puncture part of the device should be able to at least result in a blood flow of 200 microliter	j	Chapter 2.4 - Journey of PSA analysis
			70	The product should be able to transport blood from the puncture towards the blood container as fast as possible.		Chapter 2.4 - Journey of PSA analysis
	2.7 life span					
			71	The product lifespan should be one time use	j	Chapter 2.4 - Journey of PSA analysis
	2.8 safety					
			72	The puncture part of the device cannot be used to harm the user in another way than its intended goal of a single-puncture of the finger	j	Chapter 2.5 - State of the art
			73	The parts of the product should not have sharp edges	j	Chapter 2.5 - State of the art
			74	The needle in the device can be only exposed once, when the user presses the button.	j	Chapter 2.5 - State of the art
3. Discard						
	3.1 Throw away					
			75	The user should throw away the rest materials of the blood collection kit after usage	j	Chapter 4.8 - instructions & package design
			76	An analyst throws away the blood sample including test tube after PSA analysis	j	Chapter 2.4 - Journey of PSA analysis

Appendix N - Briefing for creative session

Creating trust/confidence within prostate cancer patients during blood sampling.

Introduction:
Prostate cancer is the most common type of cancer for Dutch males. 1 out 9 males is diagnosed with prostate cancer during his life. 48% of the diagnosis is for man older than 70. Due to aging of the Dutch population and increase in life expectancy, more patients with this disease are expected in the future. To test a patient on prostate cancer, a blood sample is extracted and tested on PSA (prostate specific antigen). In current practice this is done within the hospital by venipuncture (figure 8)

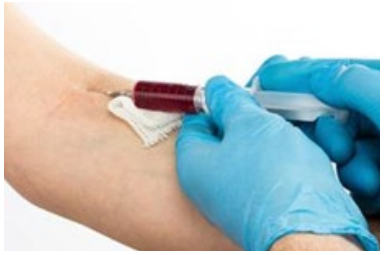


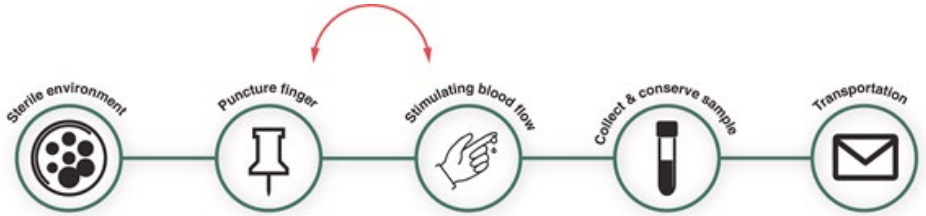
Figure 8 – specialist performs a venipuncture.

A new form of sampling is being developed: "Blood sampling by finger prick at home". The patient can take his own blood sample where and whenever he wants after which he sends the sample to the hospital for PSA analysis (figure 9). The puncture is made by a device called "lancet" (figure 10).
Figure 11 shows the sampling procedure.

Figure 9 – finger prick home sampling

Figure 10 – puncture the finger with lancet

Figure 11 – finger prick sampling procedure



Problem description:
When patients go to the hospital to test their PSA level, they will first meet the doctor and have an appointment with specialist to take a blood sample by venipuncture. In the new system, the patients have to perform the procedure all themselves without actual contact with the doctor or specialist. This leads to lack in trust and confidence. Patients feel insecure whether they do the procedure the right way and lack personal contact with someone they trust like a doctor or specialist.
Problem statement for the facilitator:

- "How to create trust/confidence within patients during home sampling for a PSA test?"
- "How to bring the feeling of trust/confidence that is experienced during blood sampling in the hospital to the patients' home"
  Design goal
- System or product that creates confidence/trust within the patient.

Keep in mind: You can optimize steps within the finger prick sampling procedure to meet the design goal.

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Appendix O - Ergonomic variables

Physical variables

Exertion of force

It is proven that the ability to exert static force decreases with age. It is interesting for the development of the finger prick device to find out what the maximum gripping force of the target group is. The user should be able to hold the blood collection device and puncture the finger with a device. Both scenarios require gripping force of the hands. The p5 patient within the age group 50-80 years has a maximum gripping force of 226N (figure 12). This value would be lower when a comfortable gripping force is desired instead of a maximum (Appendix J). This maximum gripping force should be taken into account while designing the blood collection device during the next phase

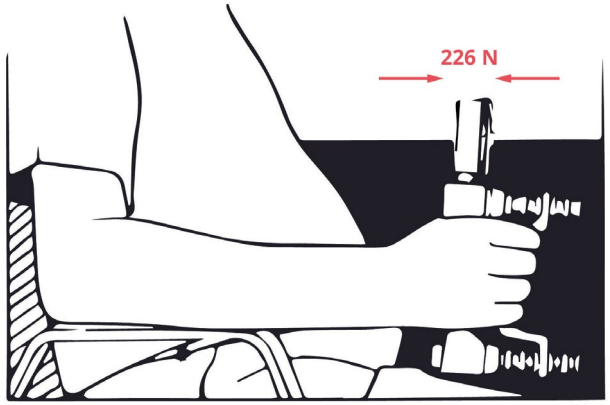


Figure 12 - maximum gripping force p5 user

Ranges of movements of joints

It is known that the range of movements of joins decreases when people age (Staff, 1983). For the design of the blood collection device, it is needed to examine the range of movement of the wrist and fingers of the user group. Figure 13 - 19 show the maximum force that can be exerted by a p5 user within the targetgroup.

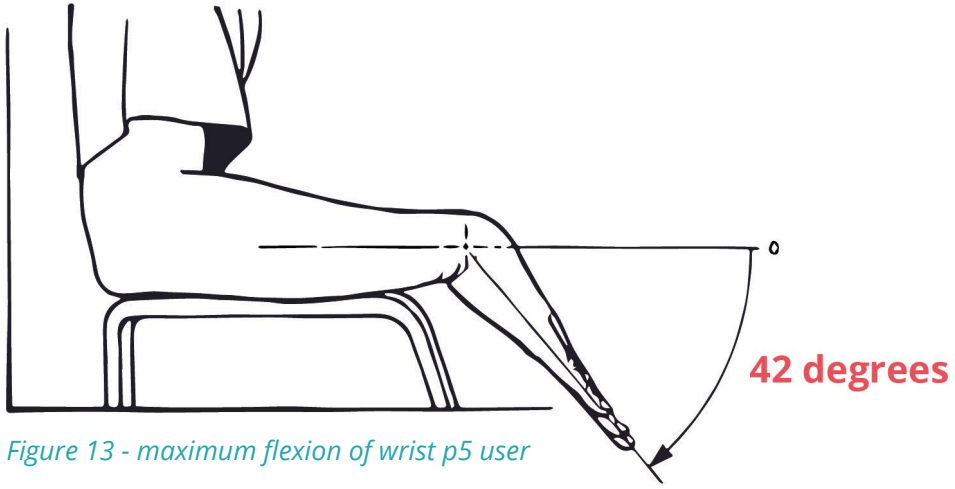


Figure 13 - maximum flexion of wrist p5 user

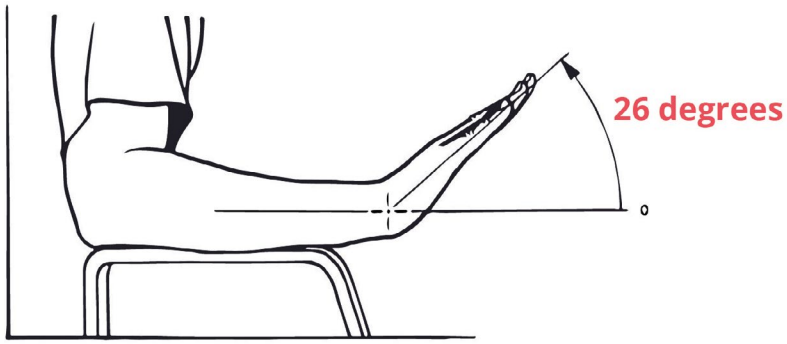


Figure 14 - maximum extention of wrist p5 user

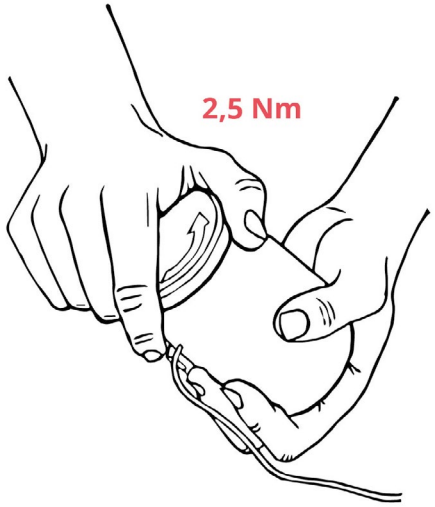


Figure 15 - maximum static torque with 2 hands p5 user

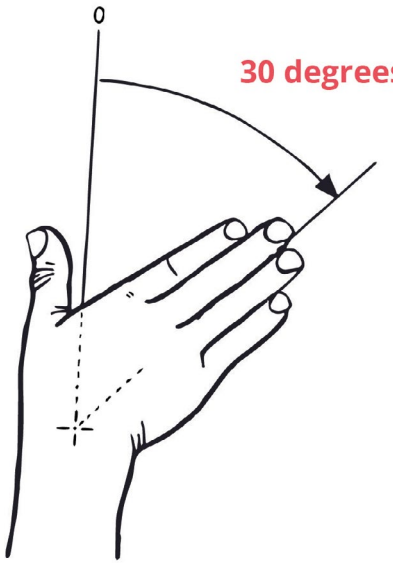


Figure 16- maximum ulnar deviation wrist p5 user

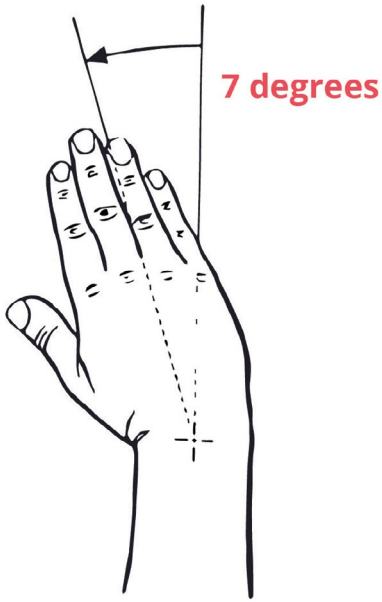


Figure 17 - maximum ulnar deviation wrist p5 user

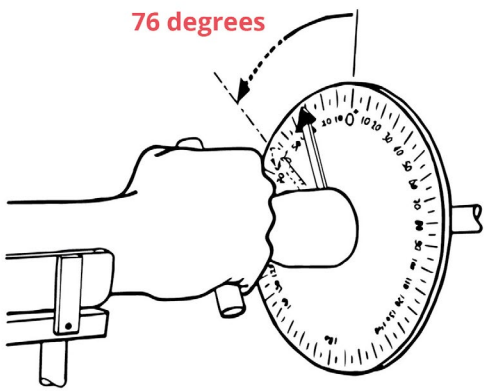


Figure 18 - maximum pronation of wrist p5 user

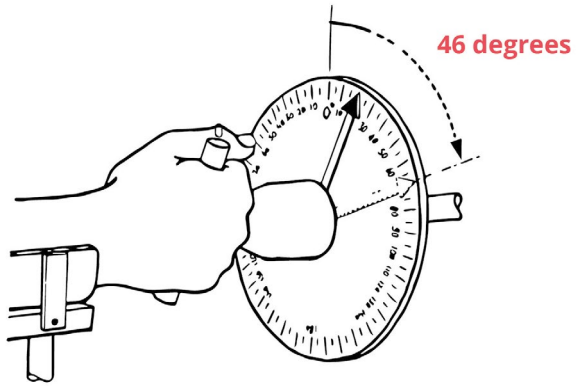


Figure 19 - maximum supination of wrist p5 user

Psychomotor variables

Hand steadiness

Hand steadiness diminishes with age and needs to be considered when designing a blood collection device. The use of the blood collection device requires accurate positioning. It is desirable to design a controllable solution in which the hands of the user are supported. The user should be able to hold the device in an comfortable way. Large dimensions, form and colour can help the user to recognize depth and distances. Old people have diminished hand steadiness compared to young people (Steenbekkers, 1998). Also tremor is a condition that is frequently seen within the age range of the target group.

Tremor

About 5 % of people in the Netherlands over 40 years old suffer from essential tremor (Hersenstichting, 2017). Essential tremor can cause severe shaking of the hands, which is obviously not desired considering blood sampling. Support of the hand can stabilize the hand when performing a task.

Eye-hand coordination

Accurate positioning of the blood collection device is required, which means that the presence and the orientation of the device should be clearly felt by the hands of the user. Older people tend to be slower in performing tasks that require hand eye coordination (Steenbekkers, 1998).

Reaction time

The time needed to react on a visual stimulus decreases when someone becomes older. It is recommended to make the tasks within blood sampling self-paced, in which the user is able to decide on his own when he wants to continue to the next step.

Sensory variables

Tactile discrimination
It is important to take into account the decrease of ability in tactile discrimination when shapes, surfaces and sizes are used to communicate features of the device.

Size, Shapes, Line thickness
Shapes and lines give haptic feedback to a user. It is desired to design product features in a way that the user can easily understand what is meant by such a usecue of the product. It is recommended to make product features concerning size shape and line thickness pronounced for optimal communication towards the user.

Near-reading acuity
Older people have a diminished visual acuity which means that attention should be paid to the design of labels (text and visuals). It is recommended to use at least a 12pt sans serif font (Steenbekkers, 1998)

Cognitive variables

Preferences for colour
Colours can be used tas usecue in a product. High contrast makes something stand out. It is recommended to make use of colours in conveying certain product features

Conclusion

The ergonomic variables described in this chapter from an overview and should be taken into account while designing the blood collection device. The exact values for each variable should be used to evaluate whether certain ideas that are generated are feasible. User tests can be performed when a variable turns out to be critical in the future of this project.

Appendix P - User test manuals & package design

User test & setup

Setup
Three participants are asked to behave the same way as if the blood collection package arrived in the mailbox. The user should perform all tasks that are presented except for the puncture and blood collection itself. Hence, the test will not be invasive to the participant in any way. The participant is presented two different packages with slightly different instructions that are described in the manual. The user test and manual are executed in Dutch as this is the leading language for the target group. Manual(s) in other languages can be added when that appears to be beneficial to the target group. Afterwards is asked what the better instruction was and whether the manual(s) where clear to the user and what improvements could be made in order to improve the design of the manual and package.

Materials
All materials described in figure x of chapter 4.5 are present within the package that is given to the participant

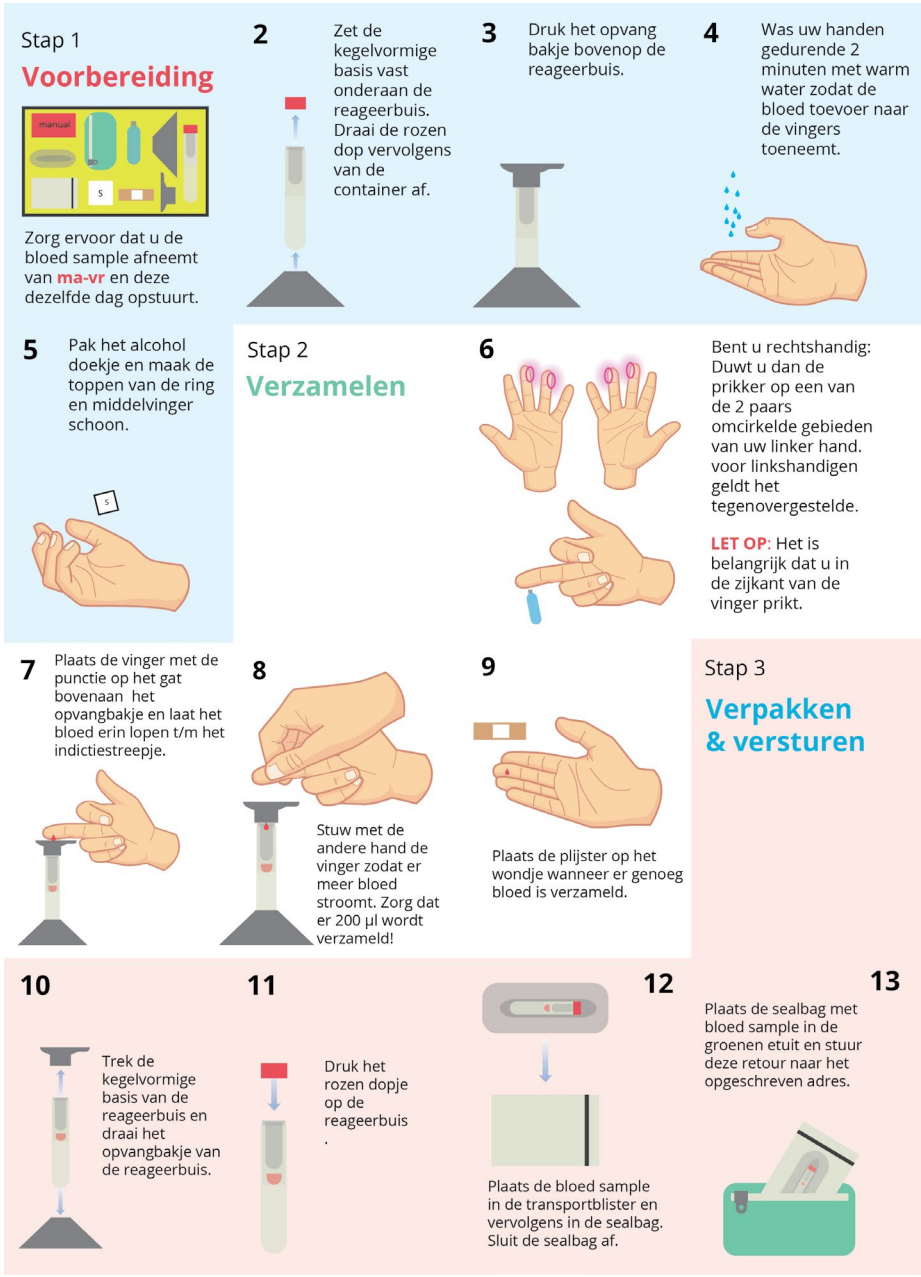
Manual 1 (figure 20)

Number of actions
This manual consists of 13 points of actions

Clearness of actions
The idea is to let the user assemble and disassemble all components first in order to get them acquainted with the product. In step 2, the user is asked to take of the pink cap first and replace it by the collection tray. In this way, the user knows how to place and remove the lids which might diminish chance on spilling blood sample. More elaborate explanation might result in better communication or it might turn out to be too much.

Chance of failure during actions
Increasing the number of actions might diminish chance of failure.

▼ *Figure 20 - Manual 1*

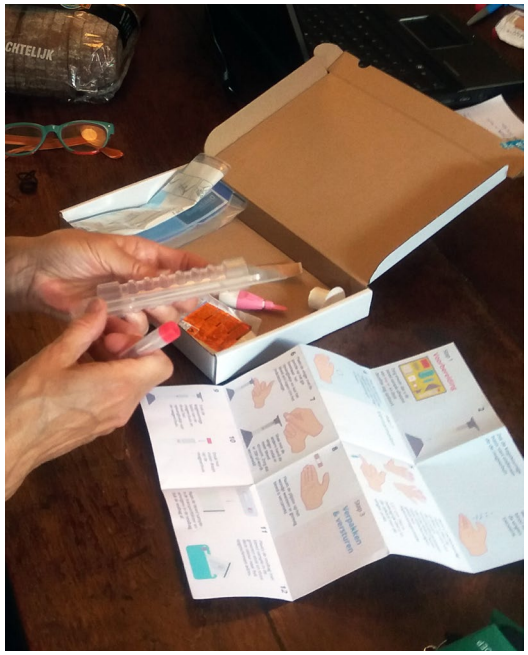


Manual 2 (figure 21)

Number of actions
This manual consists of 12 points of actions

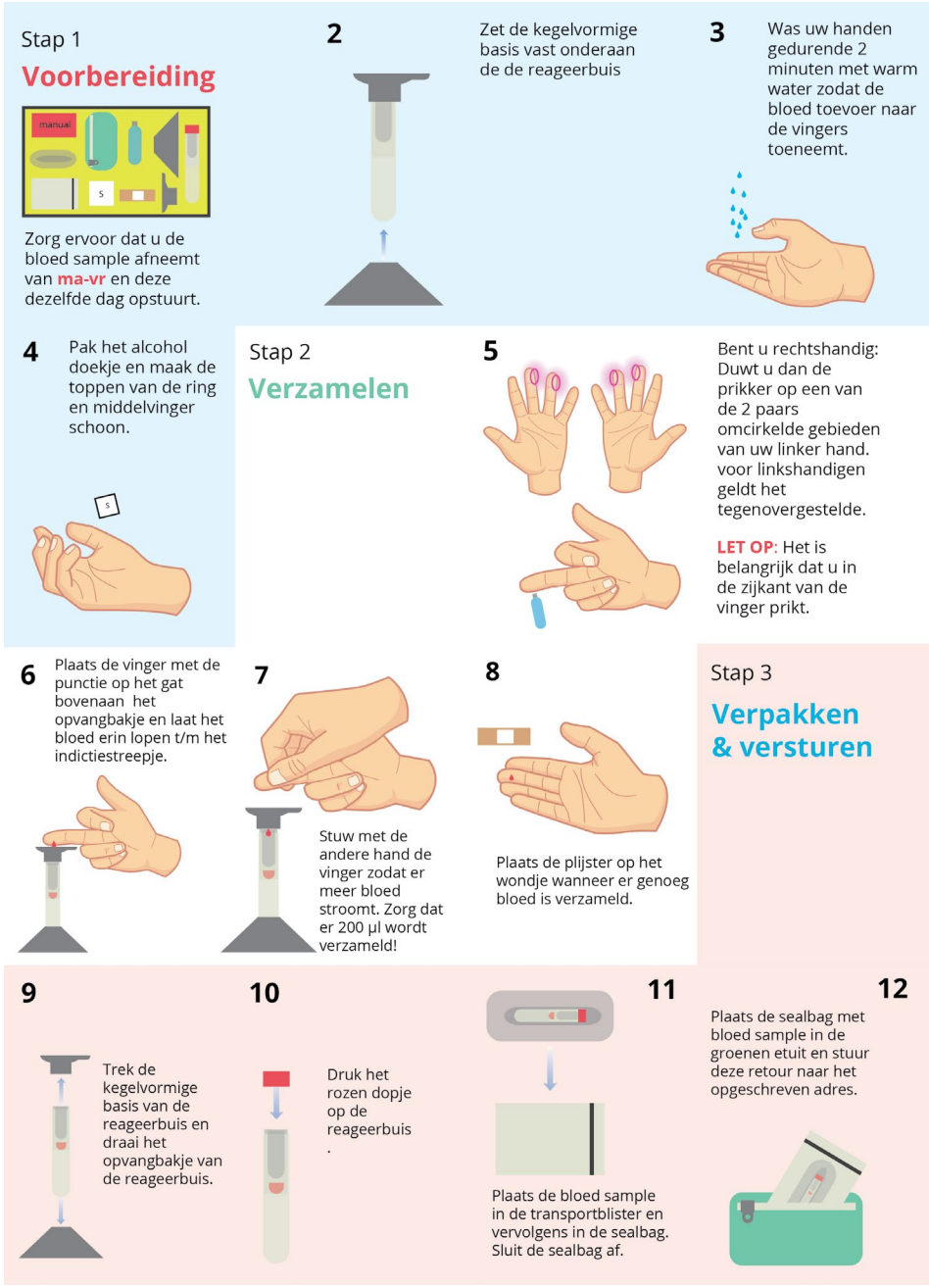
Clearness of actions
The collection tray has already been pushed on the container which results in less actions to perform for the user that could turn out to be efficient and clear. However, the disassembly of the collection tray and assembly of the pink cap might be confusing for the user as these actions have not been performed in the beginning of the process.

Chance of failure during actions
There might be a chance that user have difficulties in disassembling and assembling parts of the device which could potentially result in blood spilling.



◀ *Figure 22 - Participant uses kit*

▼ *Figure 21 - Manual 2*



Results

General
The participants thought that the first manual was better because all parts where introduced separately. The manual is also better from a hygienic perspective as the container can be transported with the lid that makes sure noting comes in and out. It is possible that impurities could enter the container with the 3D printed part pre-assembled (manual 2).

Names of parts
The users suggest to give the separate parts and procedures more simplistic names in order to communicate better. For example: puncture could be explained as prick or hole.

Graphic
It would be clearer when the stages 1,2 and 3 would be horizontally visualized instead of current Tetris like shape.

Iteration 1

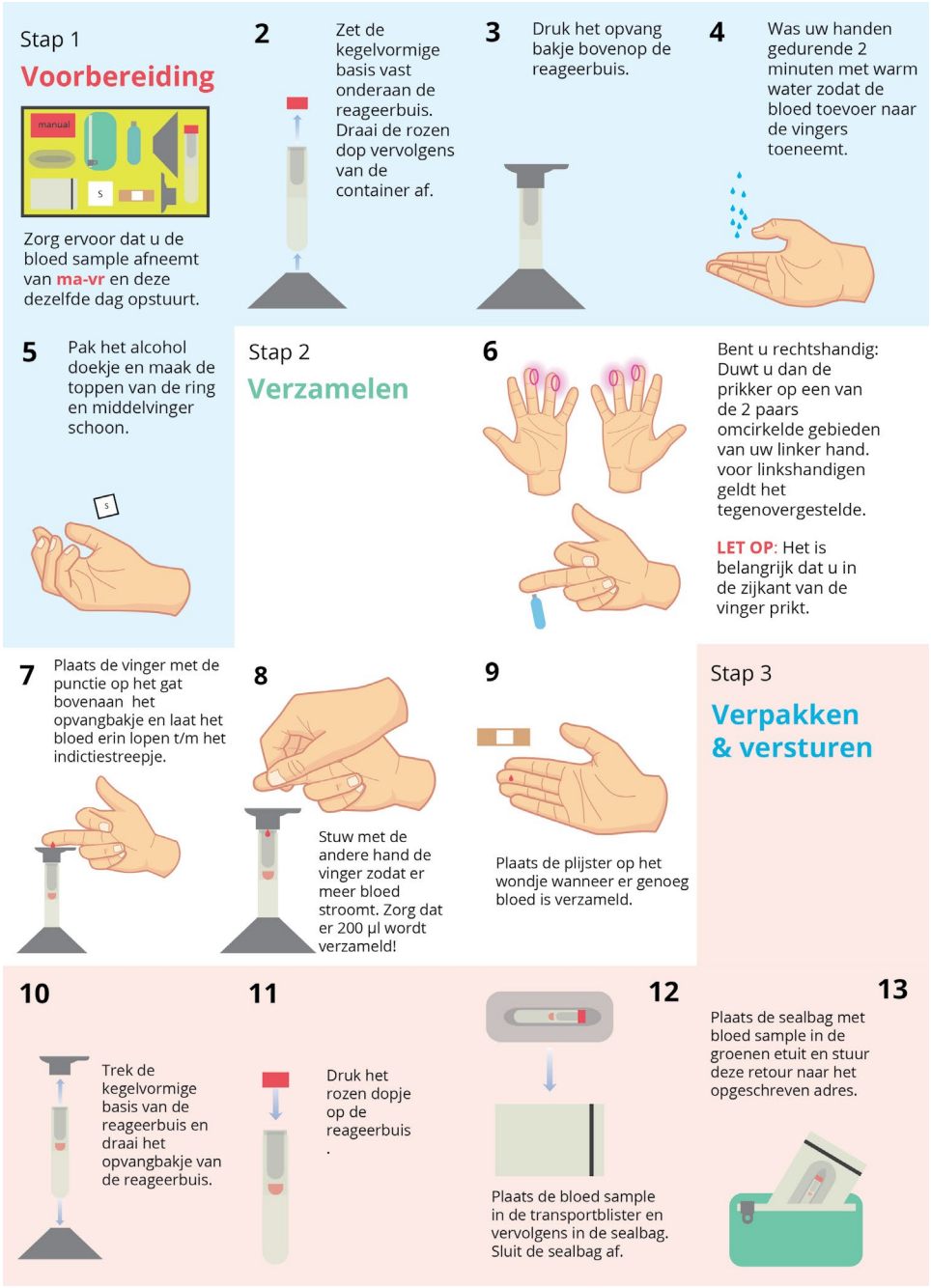


Figure 23 - Users manual front (left) back (right)

Iteration 2

Feedback from a test partcipant was to make the fonts larger to make communication easier.

This model integrates the manual and the packaging to make the instructions more intuative. The introduction of parts is now located at the inside of the package.

This compartment can be used to place the “verzamelen” parts as the manual will be placed on top in the next model.

Deviders create 3 compartment for different parts and actions within the blood sampling process.

Feedback from a test participant was to place the manual as a cover over the complete set. The manual will be the first thing that the user sees during opening of the package. He will then intuitively open the manual first before seeing the other parts of te kit.

Iteration 3

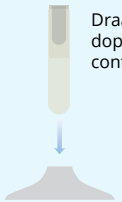
Stap 1

Voorbereiding

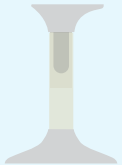
1
Zorg ervoor dat u de bloed sample afneemt van **ma-vr** en deze dezelfde dag opstuurt.

2
Zet de basis vast onderaan de reageerbuis.

Draai de rozen dop van de container af.



3
Druk het opvang bakje bovenop de reageerbuis.



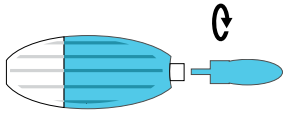
4
Was uw handen gedurende 2 minuten met warm water.

5
Pak het alcohol doekje en maak uw handen schoon.

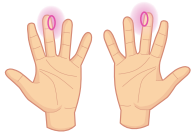
Stap 2

Verzamelen

6
Draai het veiligheids dopje van de prikker



7
Duw de prikker op de binnenkant van de middelvinger, zoals aangegeven in de afbeelding

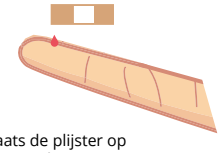


LET OP: Het is belangrijk dat u in de zijkant van de vinger prikt.

8
Plaats de vinger met het wondje op het gat bovenaan het opvangbakje en laat het bloed erin lopen t/m het streepje.

Stuw met de andere hand de vinger zodat er meer bloed stroomt.

9



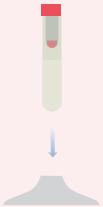
Plaats de plijster op het wondje.

Stap 3

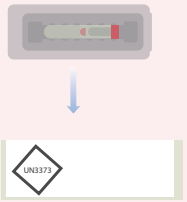
Verpakken & versturen

10
Draai het opvangbakje van de reageerbuis en druk de rozen dop erop.

11
Trek de basis los van de reageerbuis.



12



Plaats de bloed sample in de beschermkap en vervolgens in de seal bag. Sluit de seal bag af.

13
Stuur het pakketje naar het retouradres dat gedrukt staat op de seal bag.

Packaging design

Iteration 3

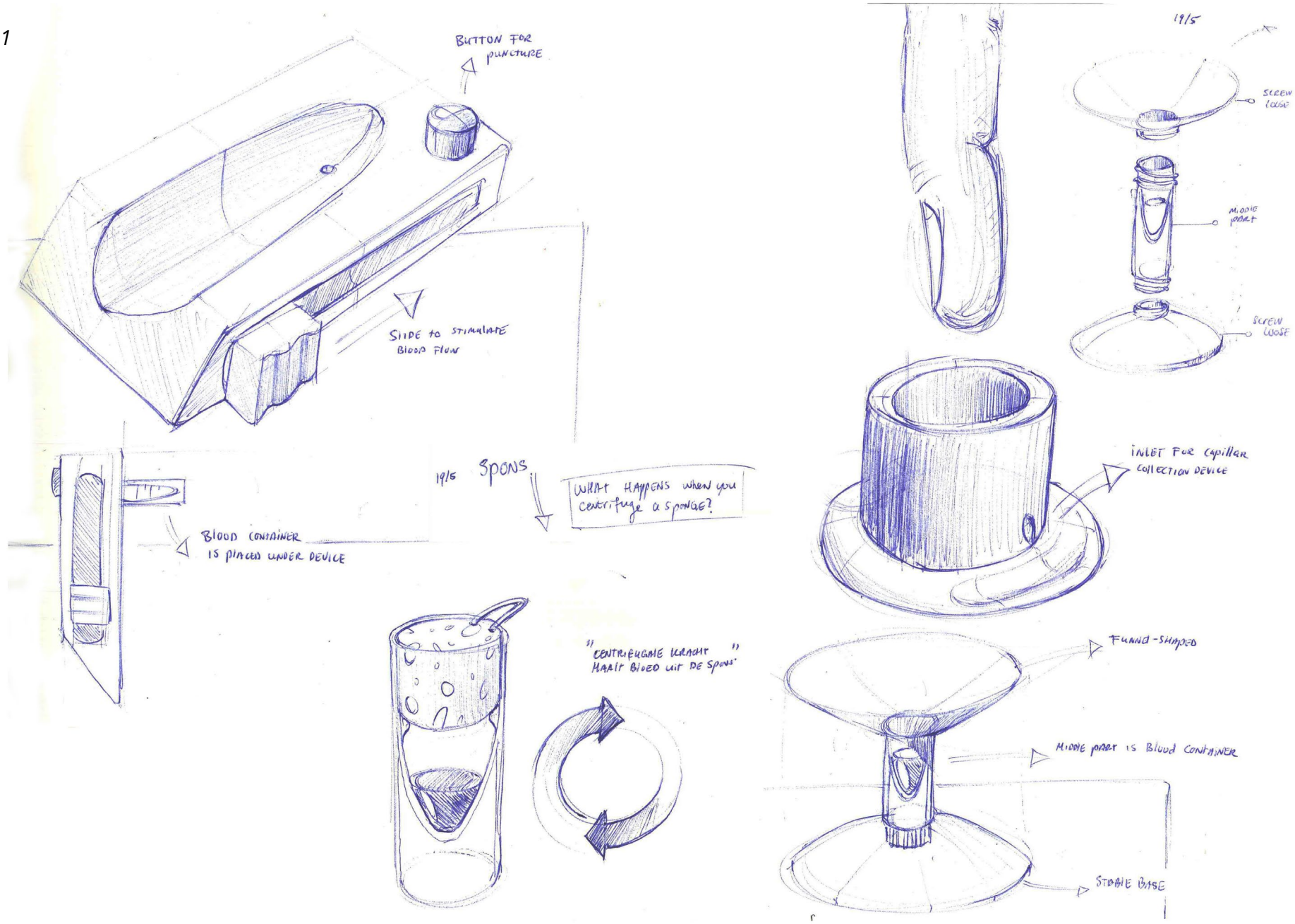
Colours and parts correspond with the manual and actual parts located at the lower part of the kit

Deviders create 3 compartment for different parts and actions within the blood sampling process.

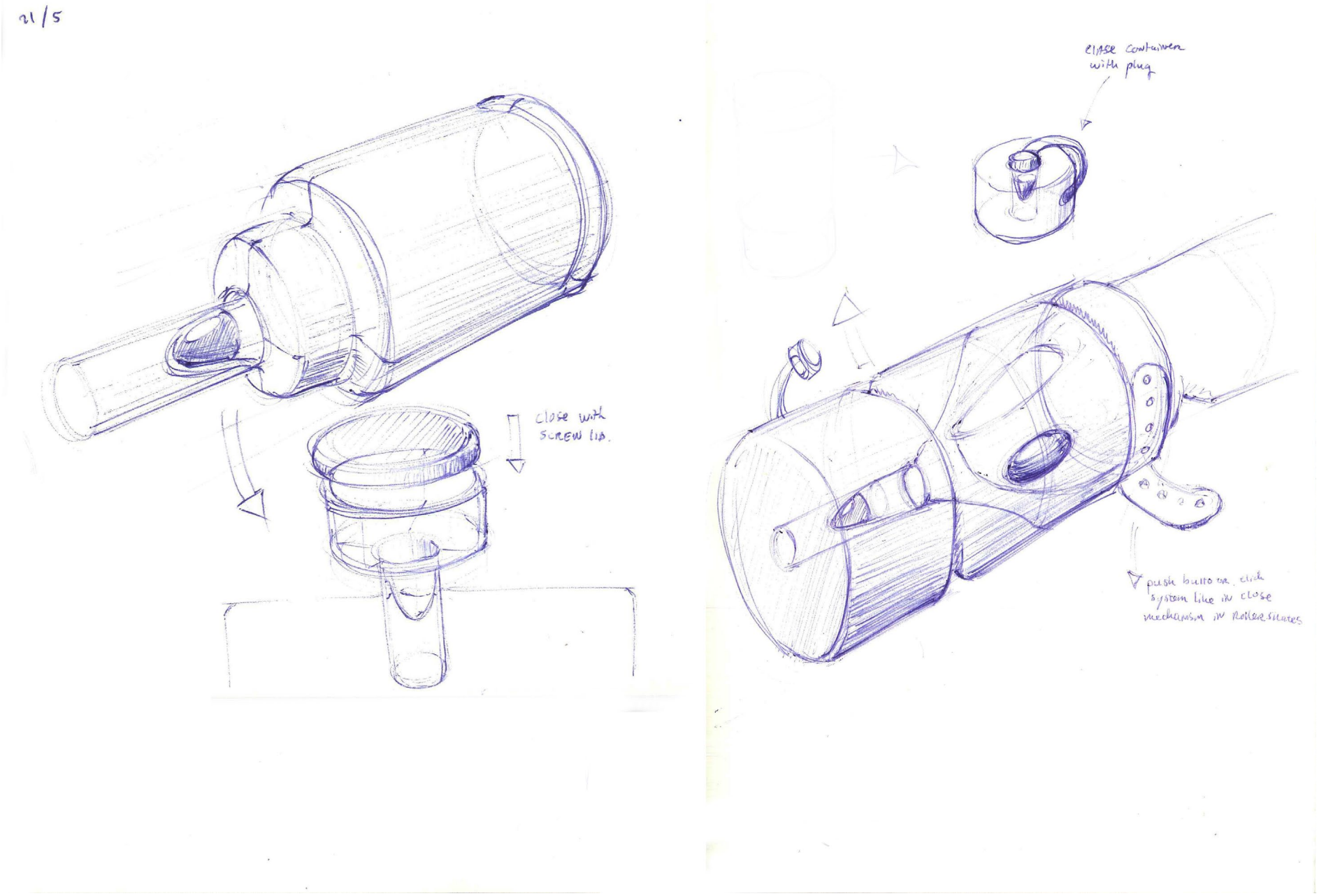
This model integrates the manual and the packaging to make the instructions more intuative. The introduction of parts is now located at the inside of the package.

Appendix Q - Sketches

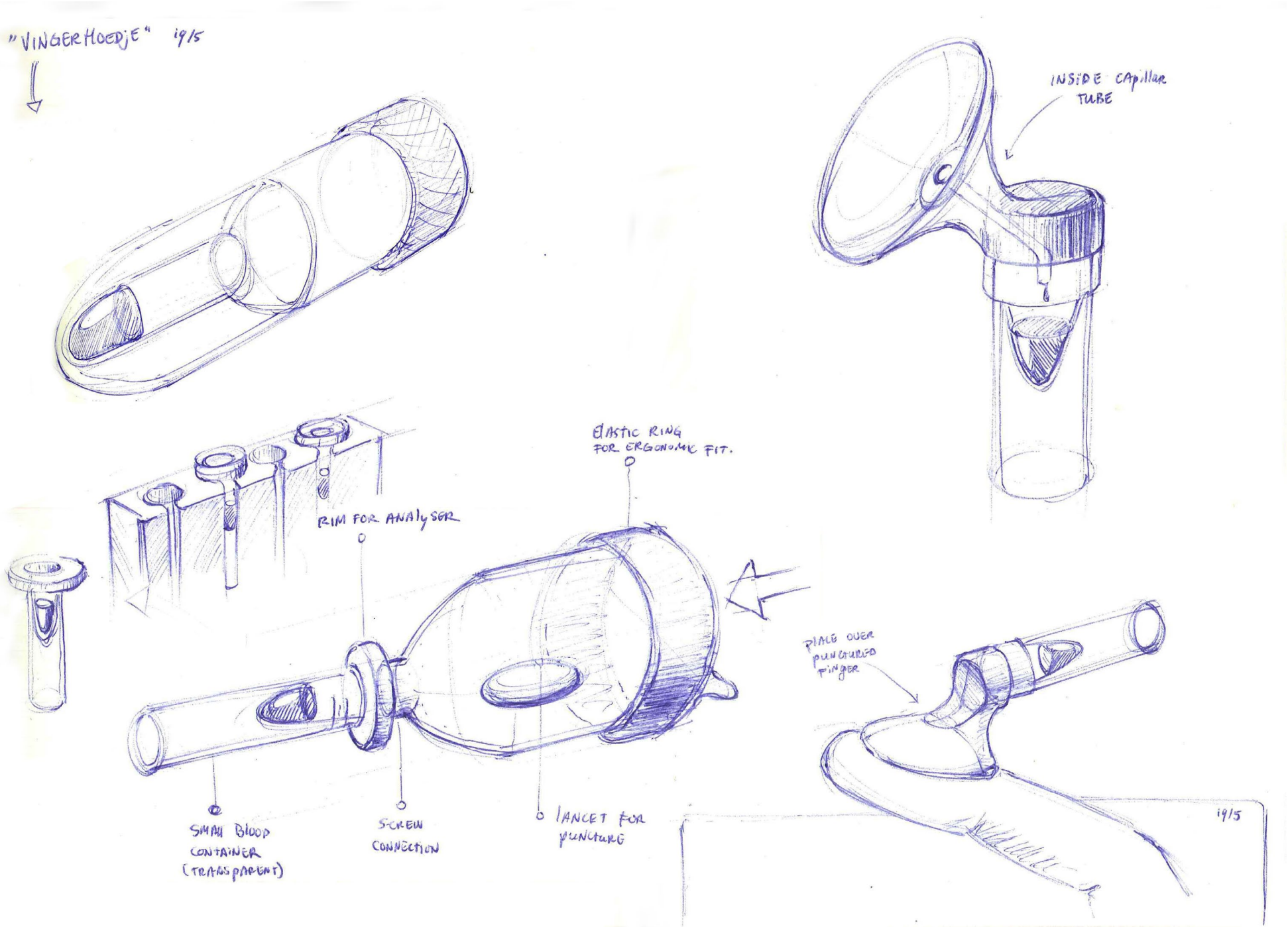
Sketch 1

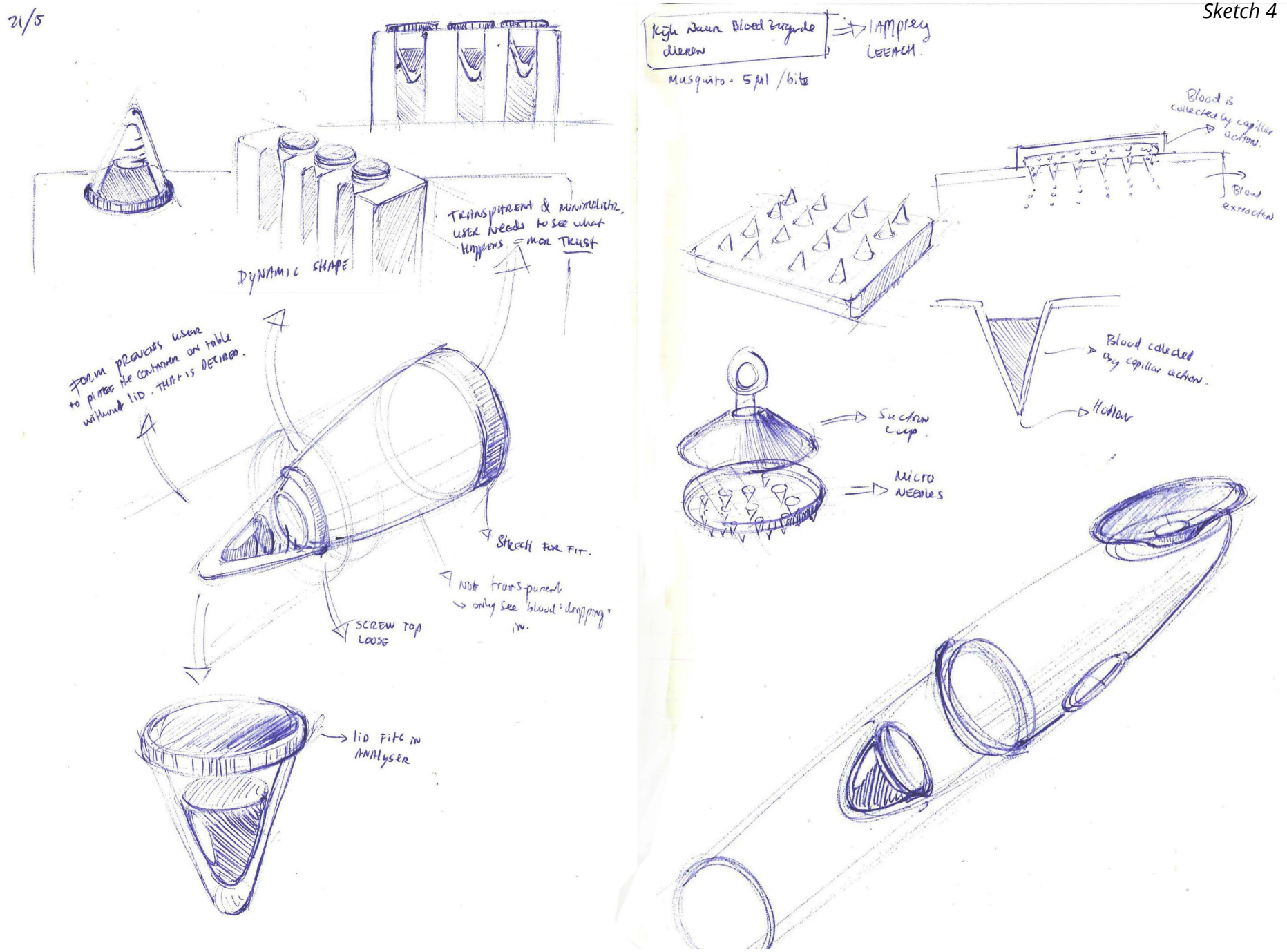


Sketch 2

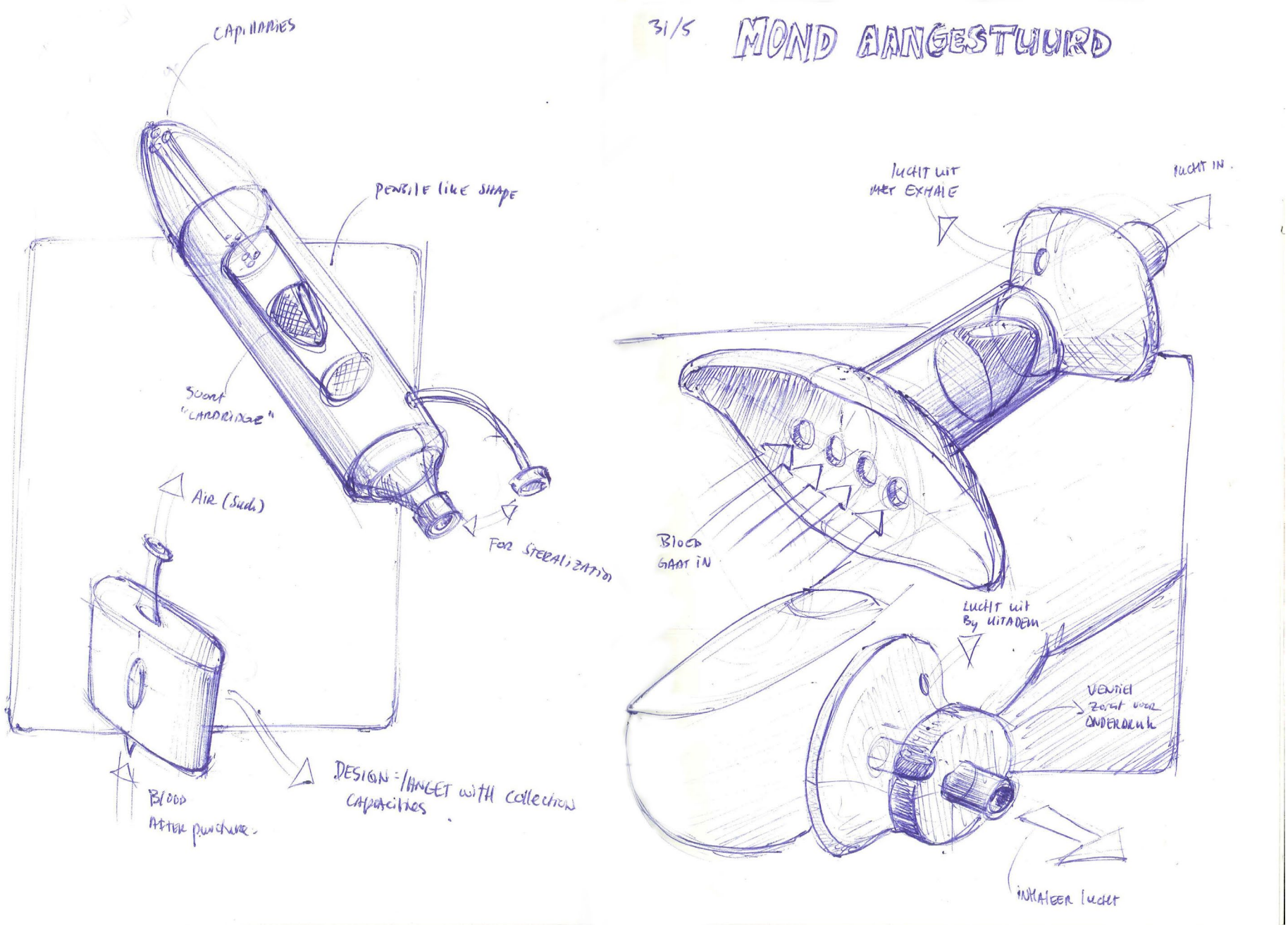

21/5
close with screw lid.
GLASS container with plug
push button or click system like in close mechanism in Rollerskates

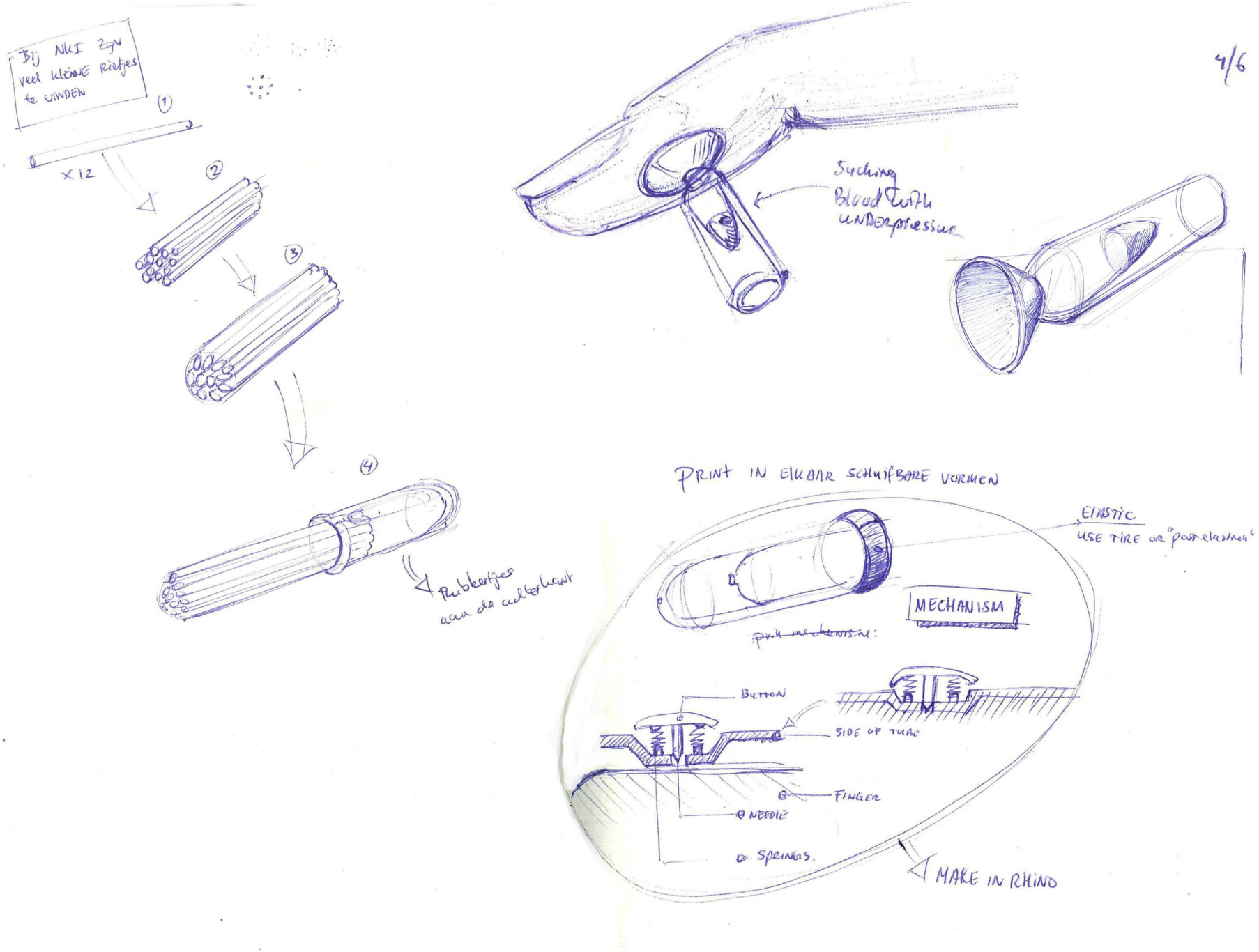
Sketch 3


"VINGERHOEDJE" 1915
INSIDE capillar TUBE
ELASTIC RING FOR ERGONOMIC FIT.
RIM FOR ANALYSER
PLACE OVER PUNCTURED FINGER
SMALL BLOOD CONTAINER (TRANSPARENT)
SCREW CONNECTION
LANCET FOR PUNCTURE
1915

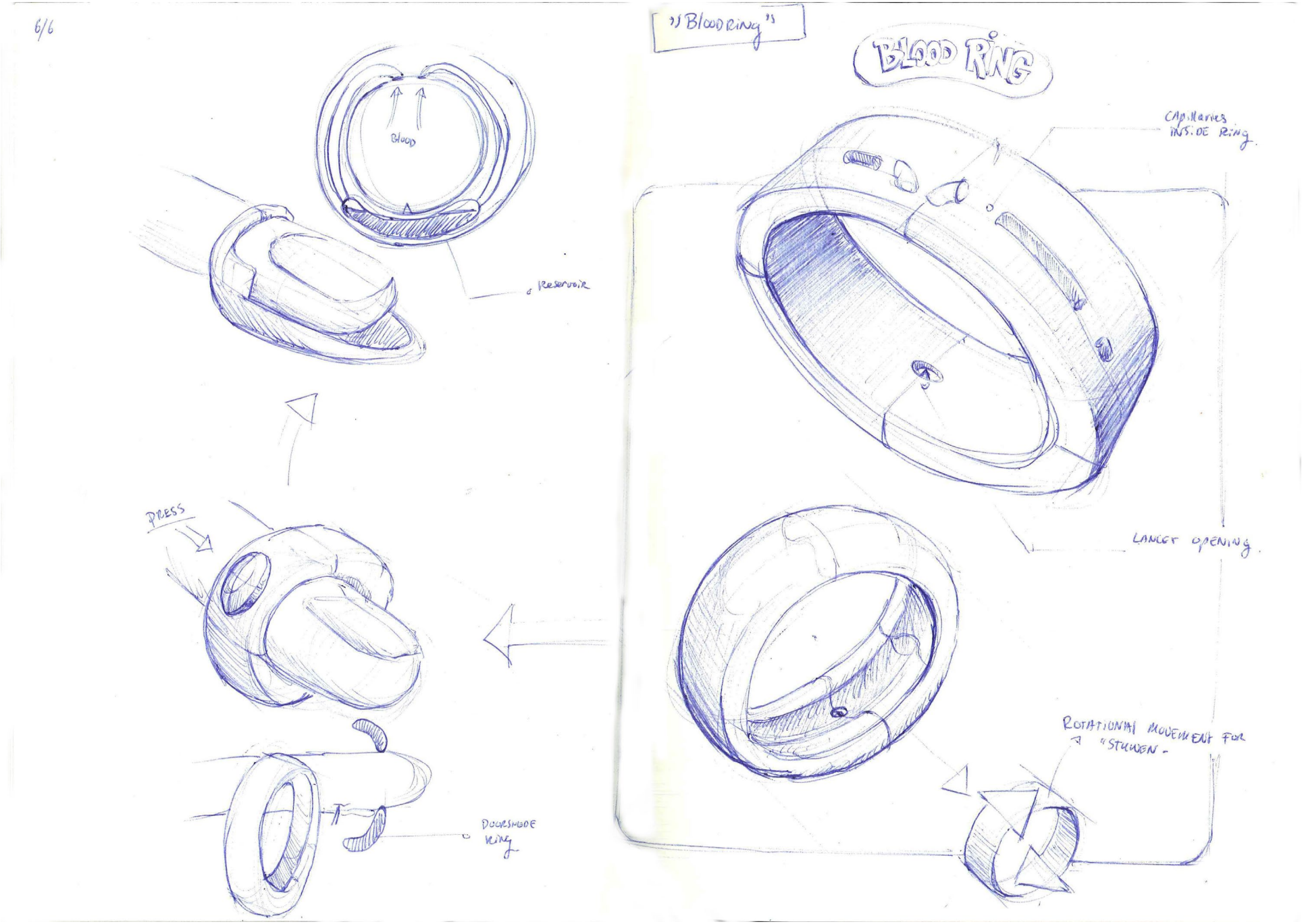

21/5
DYNAMIC SHAPE
TRANSPARENT & MINIMALISTIC. USER NEEDS TO SEE WHAT HAPPENS = MORE TRUST
FORM PREVENTS USER TO PLACE THE CONTAINER ON TABLE WITHOUT LID. THAT IS DESIRED.
STRETCH FOR FIT.
NOT TRANSPARENT → ONLY SEE 'BLOOD' DROPPING IN.
SCREW TOP LOOSE
LID FITS IN ANALYSER
Kyla Swan Blood Bugsde dieren
→ LAMPREY LEECH.
Musquito - 5µl / bite
Blood is collected by capillar action.
Blood extraction
Blood collected by capillar action.
Hollow
Suction cup
Micro NEEDLES

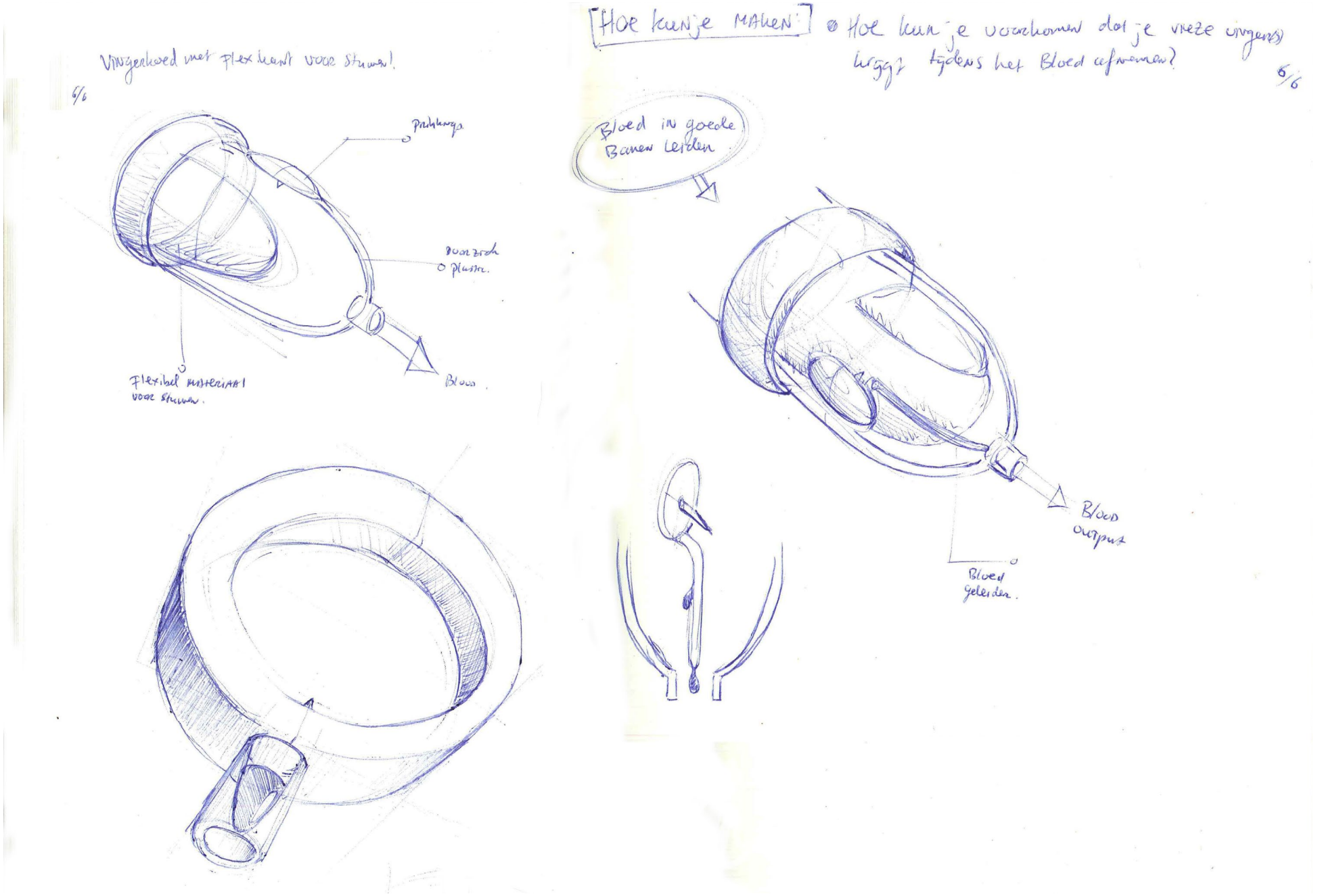
Sketch 5


CAPILLARIES
PENCIL like SHAPE
SWAP "CARTRIDGE"
AIR (Suck)
FOR STERALIZATION
BLOOD after puncture.
DESIGN = HANGET with collection capacities
31/5
MOND AANGESTUURD
LUCHT UIT met EXHALE
LUCHT IN.
BLOED GAAT IN
LUCHT uit By UITADEM
VENTIEL zorgt voor ONDERDRUK
INHALEER lucht

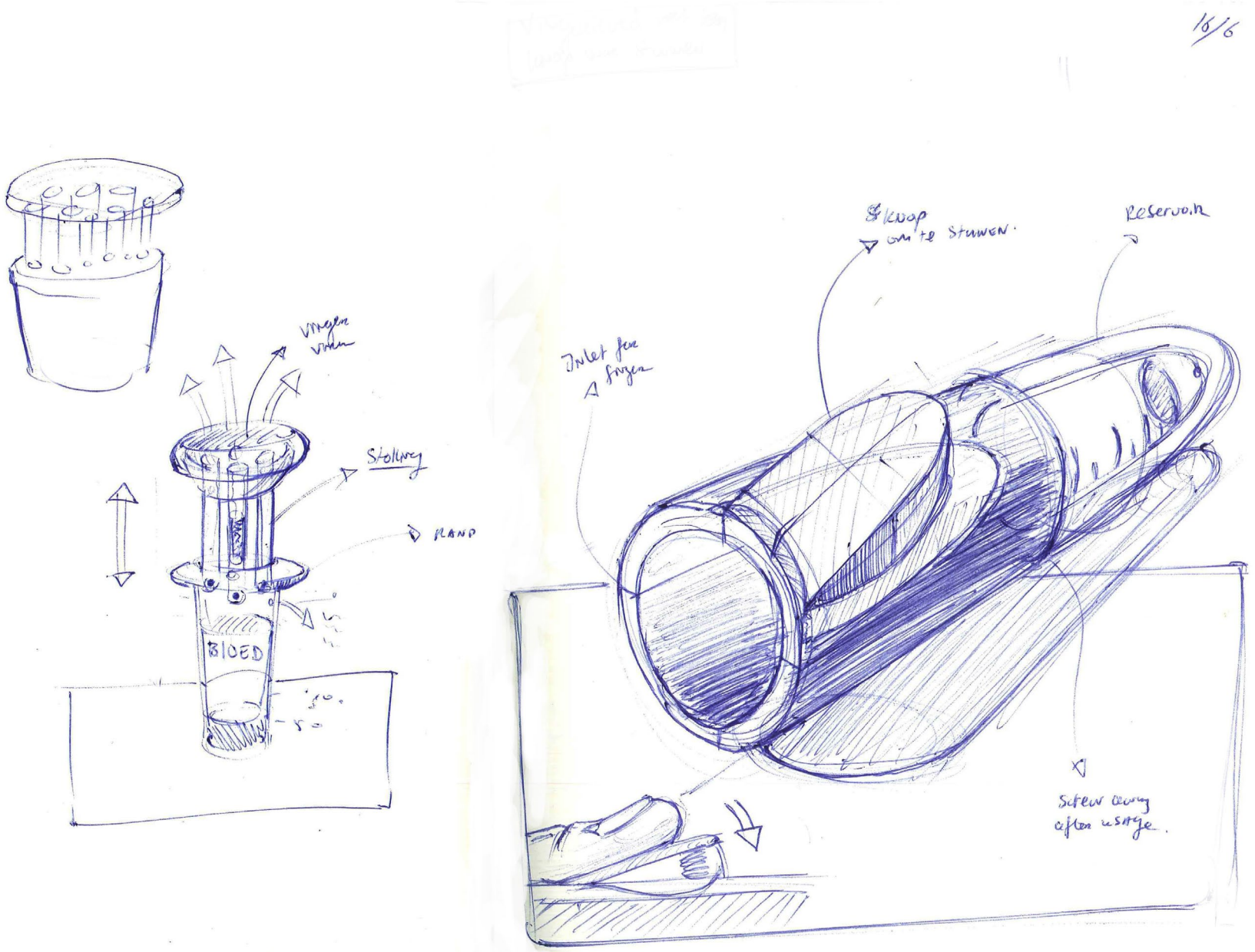

Bij NKI zijn veel kleine Ribjes te VINDEN
1
X 12
2
3
4
Rubbertjes aan de achterkant
4/6
Sucking Blood with underpressure
PRINT IN ELKAAR SCHUIFBARE VORMEN
ELASTIC
USE TIRE OR "post elastiek"
MECHANISM
Button
SIDE OF TUBE
FINGER
NEEDLE
SPRINGS.
MAKE IN RHINO

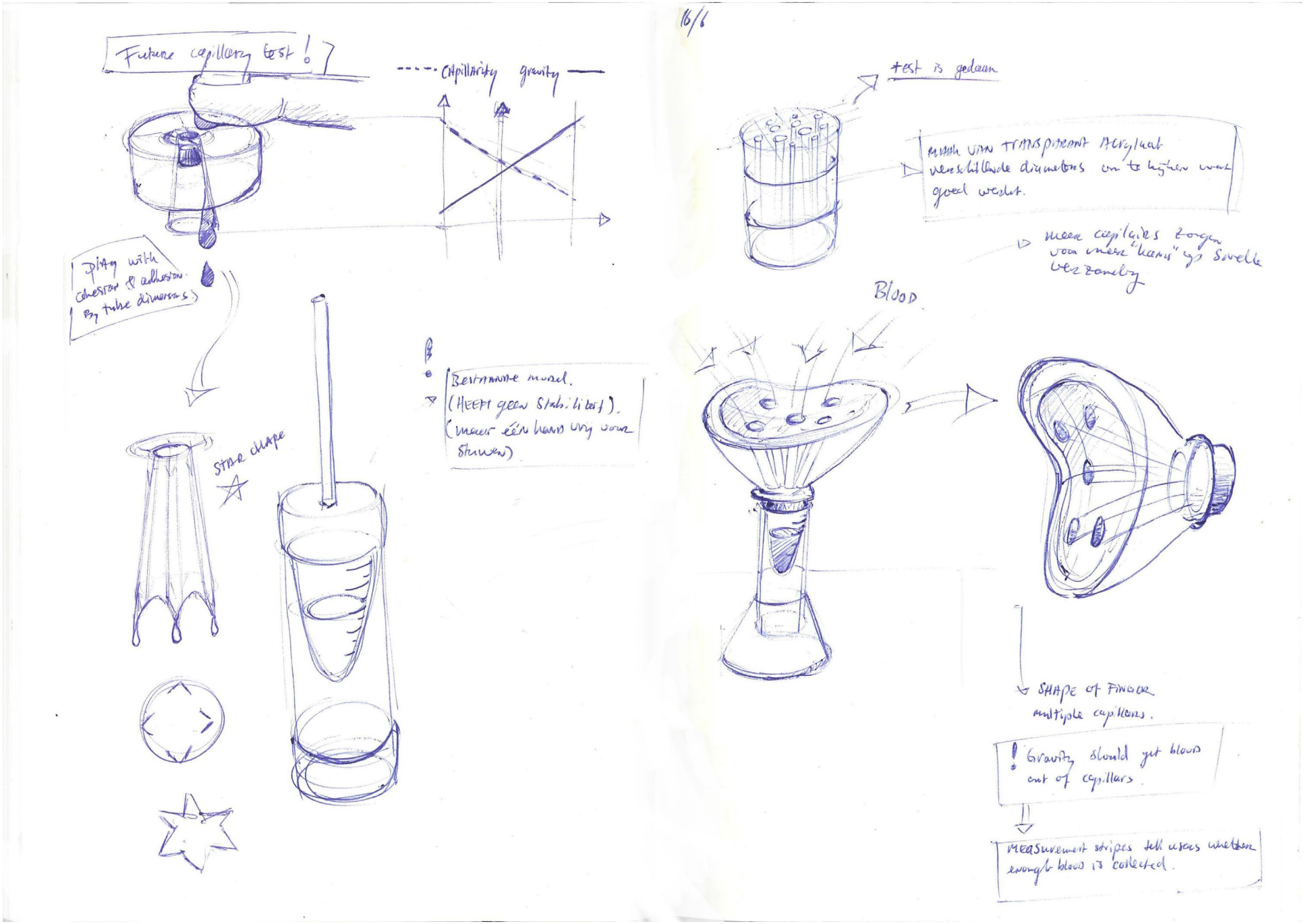
Sketch 7


6/6
"Blood Ring"
BLOOD RING
Blood
Reservoir
Capillaries inside Ring
PRESS
Lancet opening
Rotational movement for "stuwen"
Doorsnede Ring

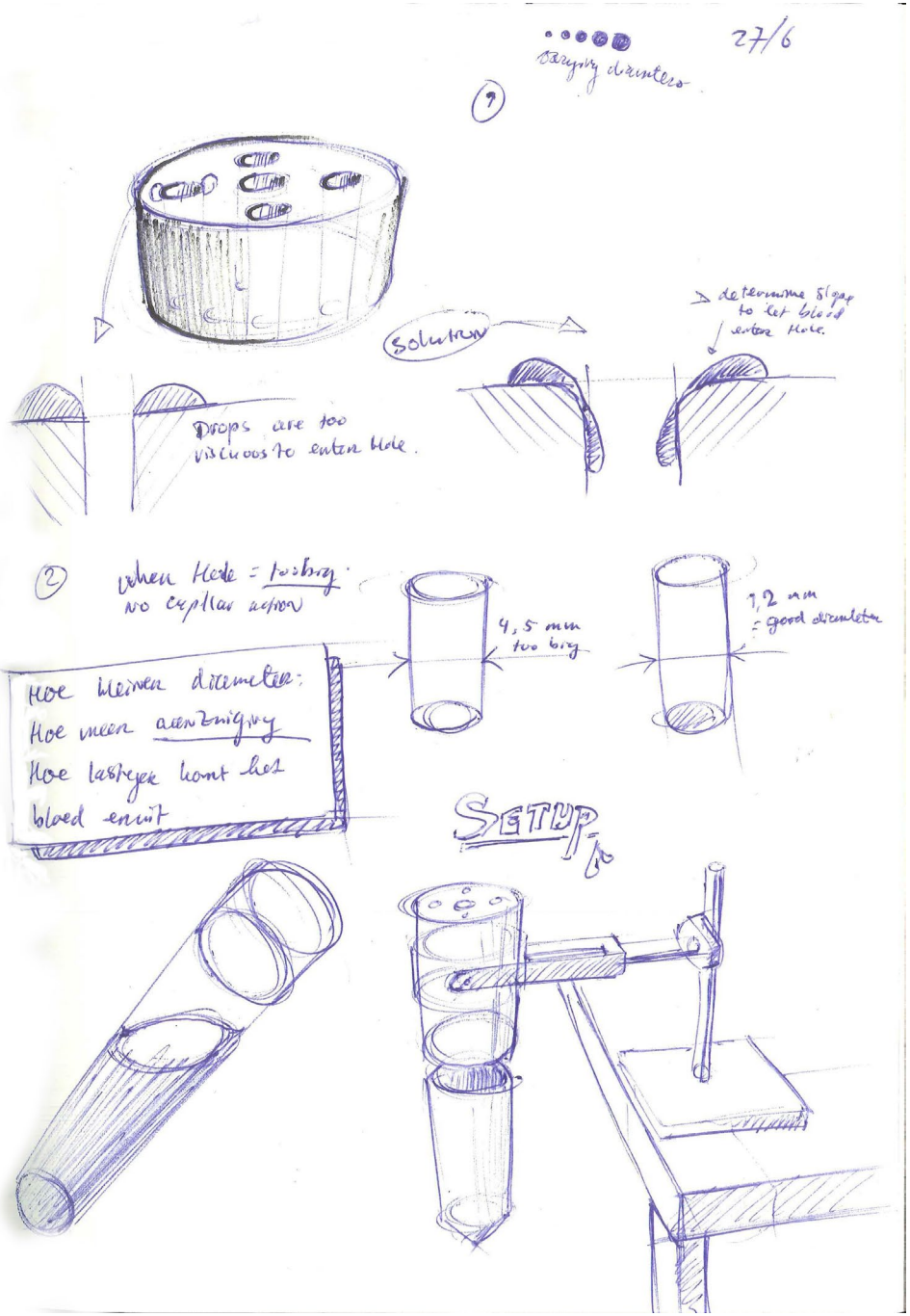

Vingerhoed met flexibel vlak voor sturen!
6/6
Prikkertje
Doorzicht plastic.
Flexibel materiaal voor sturen.
Blood
[Hoe kun je maken?]
Hoe kun je voorkomen dat je vreze vingers krijgt tijdens het Blood afnemen?
6/6
Blood in goede Banen leiden
Blood output
Blood geleiden.

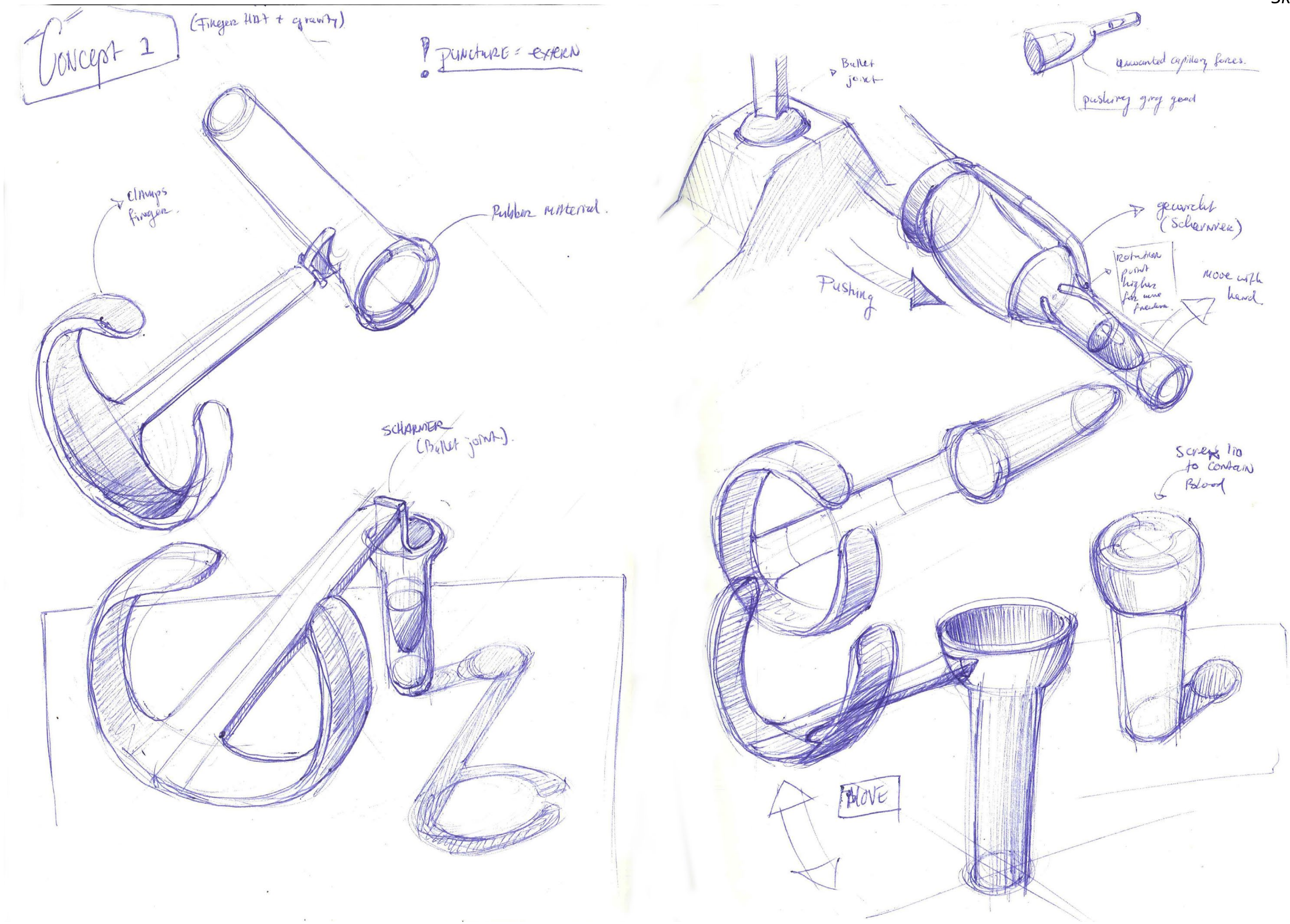
Sketch 9


16/6
Vingers voelen
Stolling
BLOED
Inlet for finger
Reservoir
Screw away after usage.


Future capillary test!
Capillarity
gravity
play with cohesion & adhesion by tube dimensions
Determine model.
(Keep open stability).
(never een hand over shower)
star shape
16/6
test is gedaan
made with transparant Acrylaat verschillende diameters om te kijken wat goed werkt.
meer capilaires zorgen voor meer "kans" op sneller verzamelen
Blood
SHAPE of FINGER
multiple capillaires.
! Gravity should get blood out of capillars.
measurement stripes tell users whether enough blood is collected.

Sketch 11


27/6
varying diameters
1
Solution
determine slope to let blood enter Hole.
Drops are too viscous to enter Hole.
2
when Hole = too big
no capillar action
Hoe kleiner diameter:
Hoe meer aantrekking
Hoe lastiger komt het
bloed eruit
4,5 mm too big
1,2 mm = good diameter
SETUP



Concept 1
PUNCTURE = EXTERN
Clamps finger.
Rubber material.
SCHARNIER (Bullet joint).
Bullet joint
unwanted capillary forces.
pushing going good
gewricht (Scharnier)
Rotation point higher for more freedom
Move with hand
Pushing
Screw lid to contain blood
MOVE

Appendix R - Diving deeper in capillary action

This chapter dives deeper in the principle of capillary action. What parameters in the design of the blood collection device can be adjusted to optimize the blood flow from the finger puncture towards the container?

"It is desired to increase the volume of the blood sample while diminishing surface tension to the tube's walls.

Capillary action

It is decided to continue working on "The Capillar". The working principle, as the name of the concept indicates, has to do with capillary action. Some testing has been done during the proof of principles of different blood collection techniques. Attraction of the blood with the aid of capillary forces appeared to be effective, This chapter dives deeper in the concept of capillatity to create an understanding of all its variables that are of any significance. The purpose is to find out what variables can be changed within the tube to maximize blood flow.

Figure 24 shows the different variables within capillary action. Surface tension, and tube diameter influence the upwards force of the fluid, whereas the total volume and density of the liquid determine the downwards force. The formula (Jurins law) shows the importance of the diameter of the tube, as this variable influences Fd quadratically and Fu just linear. The wider the tube, the less capillary action.
When blood is being collected inside the capillary tubes, it will sink downwards and drip into the container until an equilibrium is reached between Fu and Fd. This will result in stagnation of the blood flow and blood sample loss. The question is how we can manage to change dimensions in the tubes dimensions to keep the blood flowing until the last tiny bit. According to the formula it is desired to increase the volume of the blood sample while diminishing surface tension to the tube's walls.

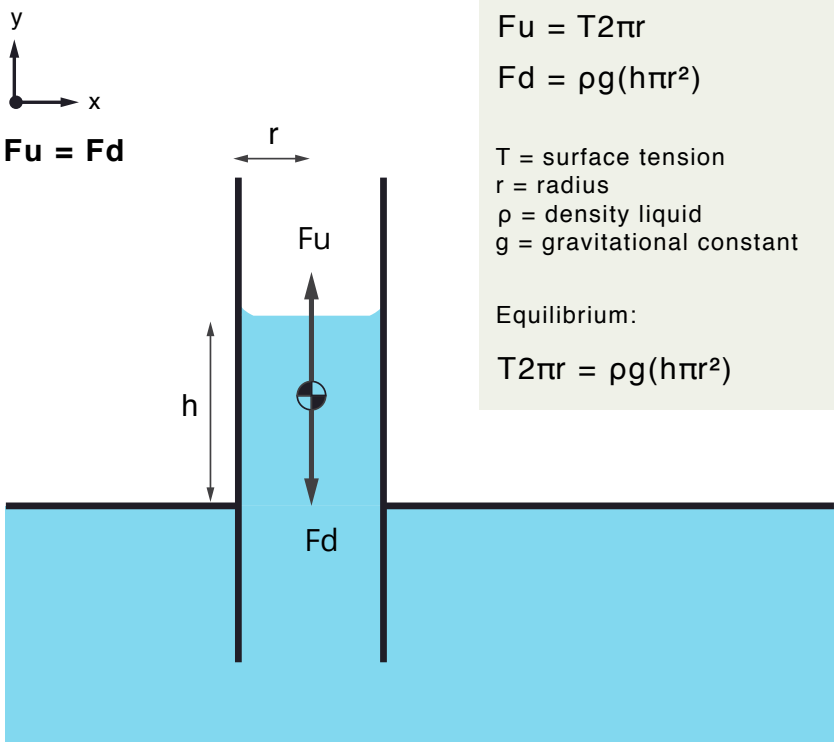


figure 24 - Free body diagram of capillary action (Nave.R, 2017)

Surface tension

Capillary force is mainly caused by surface tension. Figure 25 shows an equilibrium in which an object that is heavier than water is still able to float on the water. The surface tension (Ft) is strong enough to compensate to the object's mass (Fz). When cohesion between water molecules is stronger than the adhesion to the bodies molecules, the object will not sink (figure 26). The outer water molecules act like a membrane on which the body can float. When the object becomes too heavy for the membrane, it will penetrate to the outer water molecules membrane and therefore sink. In this way, the surface tension is broken. The contact angle of Ft & the water is very unstable due to movement of the object which could result in sinking of the object. This is an interesting insight for the problem of blood loss as surface tension prevents the stagnated blood from falling through (figure 27).

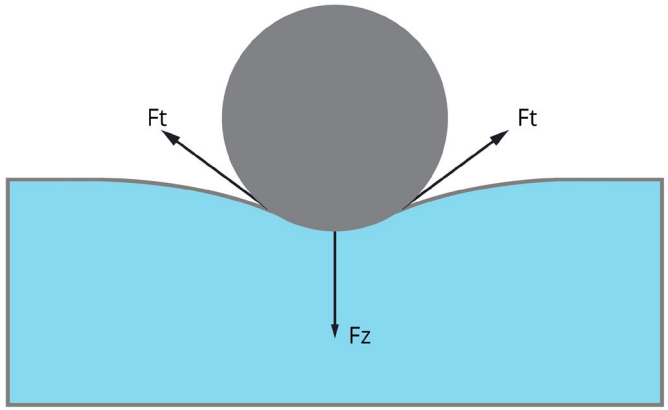


figure 25 - heavy object floats on water due to surface tension

Figure 26 - Water strider that walks on water

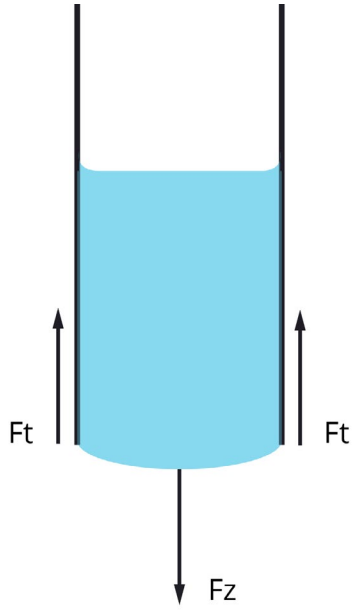
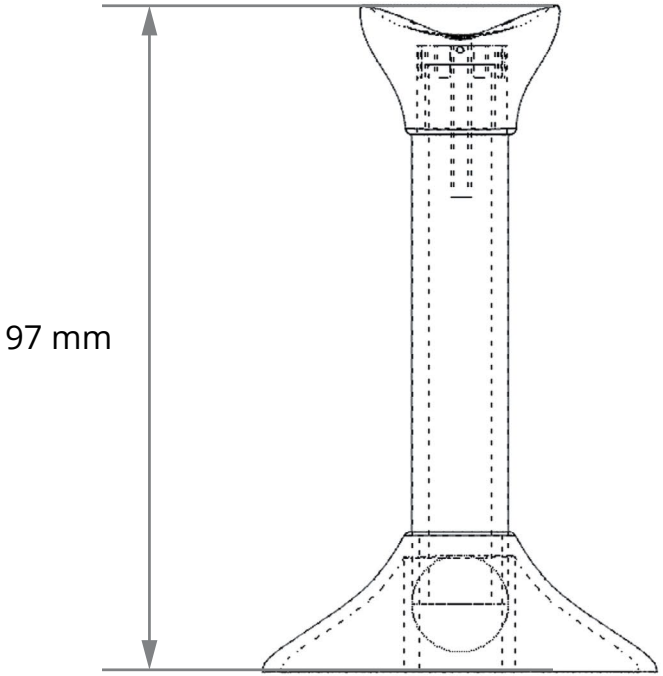


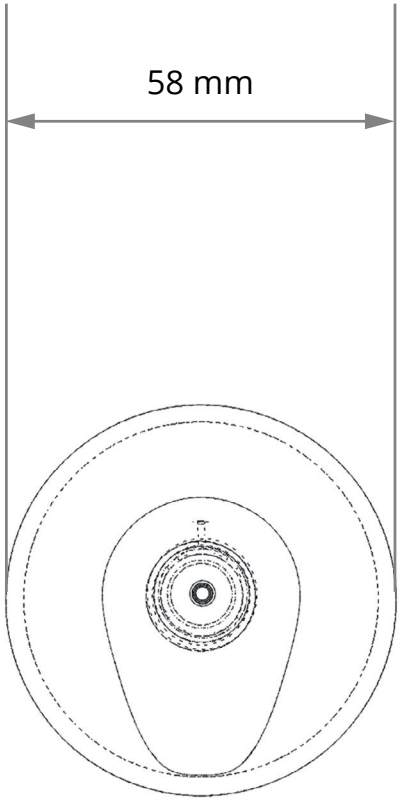
Figure 27 - Surface tension in stagnated blood sample

" The contact angle between blood and the tubes wall is an important parameter for capillary action."

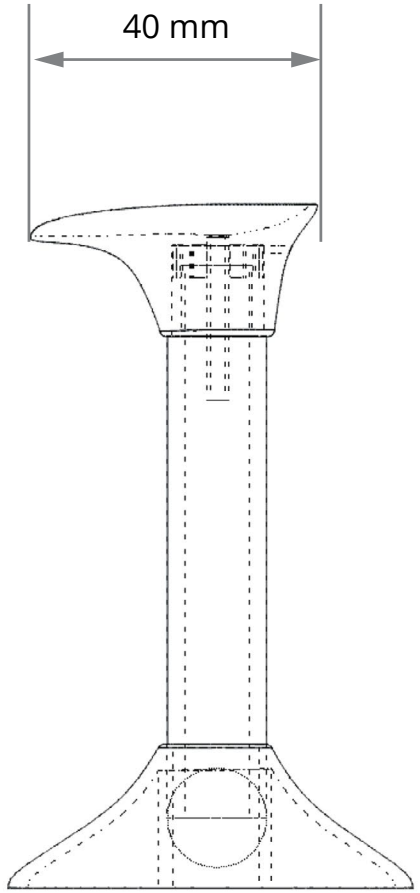
Appendix S - Dimensions of The Capillar



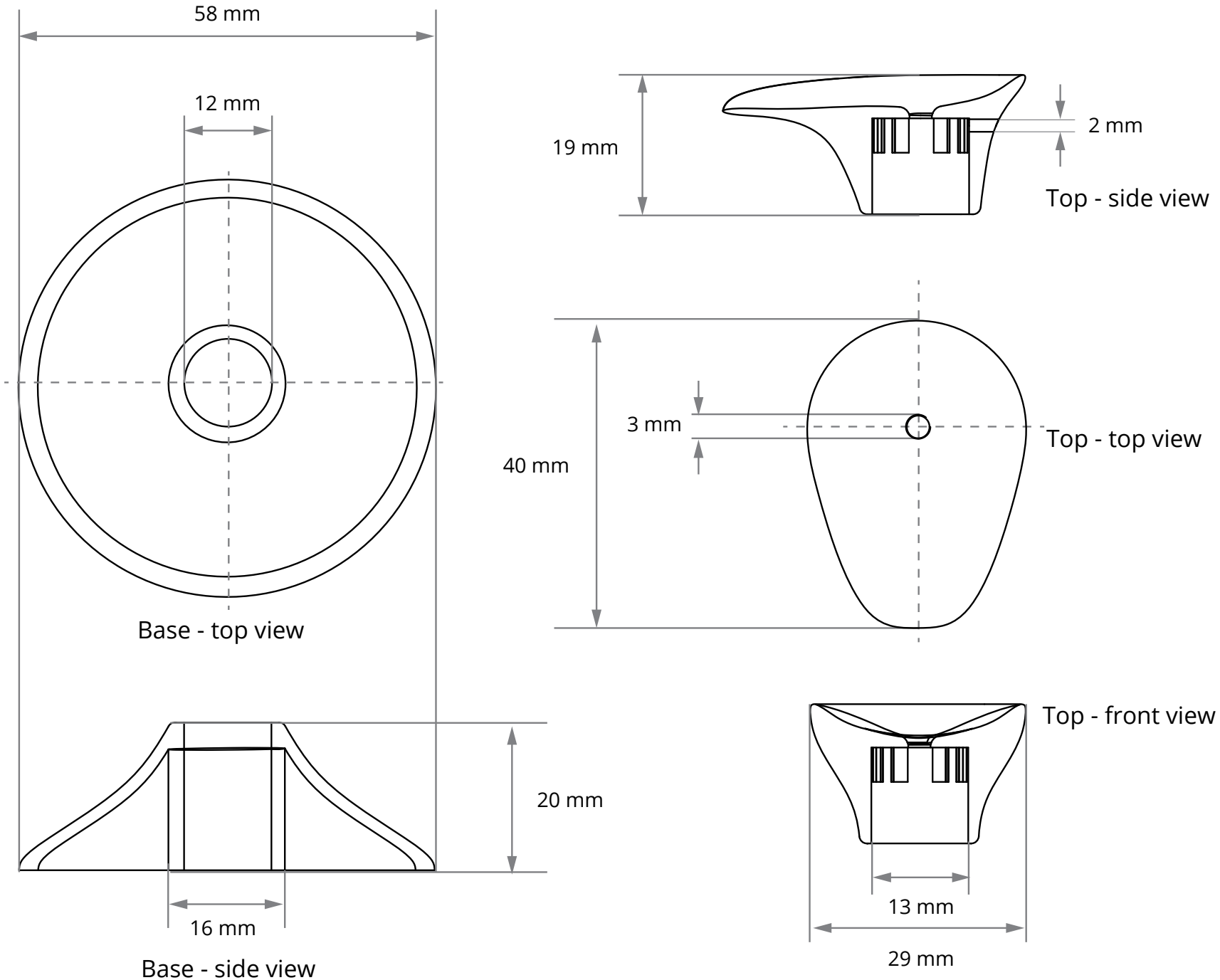
The Capillar - front view



The Capillar - top view



The Capillar - Side view


58 mm
12 mm
Base - top view
19 mm
2 mm
Top - side view
40 mm
3 mm
Top - top view
20 mm
16 mm
Base - side view
Top - front view
13 mm
29 mm

Appendix T - Final user test

Final user test 12-10-2017

Setup
The kit that has been shown at the end of chapter "packaging and instructions has been used during this final user test. This packages includes The Capillar. A situation is simulated in which the package arrives in the mailbox of the participant. The participant is asked to speak out loud while he performs the blood sampling procedure as is described in the manual. Participants were selected that had no affinity with blood sampling. Preferably, the participants had no medical knowledge whatsoever.

Some differences with the real situations were noticed during the user test. The The fact that the participant was observed during the test resulted in pressure and rushed actions. In the real situation, the patient has all time to concentrate himself on the task
Another point of attention is the commitment to the test. In the real situation, the blood sampling kit is part of the treatment and diagnostics of the patient's cancer, which probably results in improved motivation while collecting his blood. The test person's health is not at stake, which probably makes the test person more indifferent when it comes down to reading the manual and understanding the blood sampling procedure.

Materials
2x Lancet
1x Test tube
1x Base
1x Top
1x Lid
1x Alcohol swipe
1x Transport blister
1x Safety back
1x manual
1x Parts inventory
1x Plaster
1x packaging

The following observations were found in test persons that participated during the final user test

Man - 64 years (Working in kitchen NKI-AVL)

- Participant doesn't use the manual at all
- Participant doesn't follow the action that is described at number 2 in the manual. As a result he presses the top with force in the red lid which eventually breaks.
- Participant looks as the visualisations
- Participant doesn't bleed sufficiently
- Participant doesn't push the finger
- Participant doesn't understand that the package needs to be thrown away. He wants to place the test tube back in the package.
- Participant wants to puncture the finger on the thumb side instead of the pink side

Q: Why did you have difficulties in understanding the actions?
A: Too much pressure from people watching by back. Normally I would take more time to get to understand such a kit.
Q:Why didn't you read the manual?
A: I'm too impatient to read everything. I am visually focussed.
Q (at phlebotomist): Why did the participant bleed not sufficient?
A: The participant did not hold his hand long enough in warm water. It is needed to keep your hand for 5 minutes in warm water.
Q: Why did you press the top through the test tubes lid?
A: In the inventory list, it looked like that the lid should be placed in hear. I confused this information with the actual manual.
Q: How did you experience the ergonomics of the use of the device?
The actions itself were easy to perform without physical difficulties.

An other reason is the type of lancet that is being used. This BD lancet needs to be pressed at the finger with force in order to deliver the 500 microliter, A puncture can be performed badly when the user is hesitant in the use of the lancet as he can withdraw his hand. Another lancet is recommended that has an activation button. This will make puncture failure less likely as the patient has no time to withdraw his hand.

Communicate better that the patient needs to puncture the pink side of the hand.

Man - 62 years (working in another department of NKI-AVL) high education

- Participant misses first step preparation. He doesn't understand that the red lid needs to be removed first.
- Participant skips step 4 (washing in with warm water) and wants to puncture the finger already.
- Participant holds finger on the hole on the top and doesn't push and waits for the blood to flow inside the test tube
- Participant is frequently licking the blood from his finger instead of placing droplet of blood inside the test tube.
- Participant uses the alcohol swab to clean the blood from his finger, instead of before the puncture. Participant is aware of the fact that he didn't use the swab in the proposed order.

Q: Why did you skip the first stage of "Voorbereiding"?
A: The background colour caused low contrast in the visualisations. My attention went to the other two stages. I would prefer a clearer distinction between the phases.
Q: I notice that you had difficulties with pushing the finger, how come?
A: As a person that has no affinity with the medical field, I did not know about pushing the finger for increased blood flow. The visualisation showed me a finger resting on the hole, which was basically the action I also performed as result.
Q: How could the action be better communicated towards you in order to clarify the use of the blood sampling kit?
A: An instructor or instruction video would help, as I am very visually focussed and too impatient to read manuals.

Man - 53 years (cleaner at NKI-AVL) -migrant background

- Participant puts on glasses to read the manual
- "ma-vr" in step 1 "voorbereiding" is confusing to participant. Does doubts whether he has to perform the test 5 times in a row.
- It is unclear to the participant that he has to hold his hand for a long time in warm water. He thinks that he just has to wash his hands with soap, which results in hands that are not warm enough for the puncture.
- Participant is able to built The Capillar without difficulties
- Participant holds finger on the hole and waits for the blood to come out. He needs additional instructions in pushing the finger for improved blood flow.
- Participant understands that he should send the test tube in the safety bag towards NKI-AVL and that the package needs to be thrown away after usage.
- Participant missed that the test tube needs to be filled until the red line.

Q: Why did you misunderstood the step in which you had to hold your hands in warm water for washing your hands?
A: It's about the formulation of the action. It says: "Was uw handen gedurende 2 minuten met warm water". The word "wash" insinuates that I should clean my hands. A better formulation would be: "Verwarm uw handen onder de warme kraan gedurende 2 minuten"
Q: Why did you not understand that you had to fill the test tube until the red line?
A: This was not emphasised enough in the visualisation. It was mentioned somewhere in the text, but I missed that. I could have filled the complete test tube.

Man - 26 years (colleague within AKL)

This test person was used to check whether warming the hands with warm water and puncturing the finger in the right way resulted in better blood flow.
The test person provided sufficient blood and the claim of 500 microliter was met.

Recommendations & insights for blood collection kit

These user tests led to a lot of insights concerning the blood collection kit.

1: The Capllar itself worked flawless. When the participants understood how to sample their blood, the test tube was filled quick and clean.

2: The communication on how to perform the blood collection leaves the most room for improvement. Some major recurring communication difficulties were noticed.

2.1: Problem: Manual was not read

Solution: Mention on the backside of the manual in a bigger font that the manual should be read. Use red letters on a white background for more contrast. Use a STOP sign for attention. Also mention in the inventory list that the manual should be read

2.2: Problem: Participant doesn't understand that the lid needs to be removed from the test tube.

Solution: Change the drawing in the inventory list. It looks like an exploded view instead of parts list. Mention in bold text about the importance of removing the lid.

2.3: Problem: Participant doesn't understand the importance of warming the hands in warm water.

Solution: Change formulation in :"Verwarm uw handen onder de warme kraan gedurende 5 minuten" Also change the icon to make it more like warming instead of washing the hands. Place a " let op" sign to emphasise the importance of this action.

2.4: Problem: Participant is hesitant in puncturing the finger, which results in a bad puncture

Solution: Change lancet. Choose the "Sarstedt super flow purple" This lancet has a button that "shoots" a lancet in the person's finger, in this situation the user has no time to withdraw his finger.

2.5: Problem: Test person did not understand that the test tube needed to be filled until the red line

Solution: Emphasize in text and visualisation that the line is the limit

2.6: Problem: Participant did not understand how to pressure the finger. It was often skipped.

Solution: Add a visualisation in which the motion of "stuwen" is clarified. Current visual looks static. Add a instruction video on youtube on how to sample blood to inform the user on how to best sample the blood. This video would be a supportive tool to complement the manual and physical instructions of the kit.

2.7: Problem: Participant is confused which side of the middle finger needs to be punctured (thumb side or pink side)

Solution: Mention that the pink side needs to be punctured.

2.8: Problem: Participant thought that the test tube (including the blood sample) needed to be put back in the packaging.

Solution: Formulate the last phrase of the manual differently: "Gooi alle materialen inclusief de doos weg".

The participants didn't have problems with step 10,11,12 within "verpakken en versturen"

These solutions will be implemented in the design of the instructions and new tests with participants will be executed.

Final user test 16-10-2017

All recommendations from latter tests have been integrated in the design of the new package.

Man 66 years - retired

-Participant doesn't understand how to push the finger. The visualisations alone do not convey the message
-Participant had initial problems with placing the top on the test tube, When he looked better at the manual he found out how to do it.
-The manual is read

Woman 60 years - Physiotherapist

-Participant doesn't understand how to push the finger. The visualisations alone do not convey the message
-The manual is read
-It is unclear that the user should place the drop of blood gently against the hole of the device. Participant places finger firmly against the hole and starts pushing

Man 68 years

-Participant doesn't understand how to push the finger. The visualisations alone do not convey the message
-The manual is read
-It is unclear that the user should place the drop of blood gently against the hole of the device. Participant places finger firmly against the hole and starts pushing

Recommendations

It Would have been nice when more variety in test persons were found. Only participants ranging from 53 - 68 were found.

Intentionally white

Appendix U - Decision making for concept

This appendix shows the results for the decision making process for the final concept. 1 person from NKI-AVL, 2 persons from TU Delft and myself participate in this decision making.

Criteria for decision making that was given to the participants, ▶

Decision criteria

1. Feedback to user on how much blood is sampled (200 microliter) is good

1	2	3	4	5
Disagree				Agree

2. The amount of blood loss during samping is low

1	2	3	4	5
Disagree				Agree

3. The use of the device is intuative (easy to understand)

1	2	3	4	5
Disagree				Agree

4. The design is feasible (easy to develop and implement)

1	2	3	4	5
Disagree				Agree

5. The device is easy to use

1	2	3	4	5
Disagree				Agree

6. The 200 microliter blood is quickly sampled (speed of action)

1	2	3	4	5
Disagree				Agree

7. The chance on contamination of blood sample is low

1	2	3	4	5
Disagree				Agree

Criteria	Scraper	Thimble	Capillar
1	4	5	4
2	4	5	4
3	5	4	4
4	5	3	3
5	4	4	3
6	3	3	3
7	5	5	5
total:	30	29	26

Criteria	Scraper	Thimble	Capillar
1	5	5	4
2	3	5	3
3	4	3	3
4	4	3	3
5	4	3	3
6	3	4	2
7	2	4	2
total:	25	27	20

Criteria	Scraper	Thimble	Capillar
1	5	5	5
2	4	2	3
3	5	2	5
4	4	3	5
5	5	3	5
6	5	3	4
7	3	3	5
total:	31	21	32

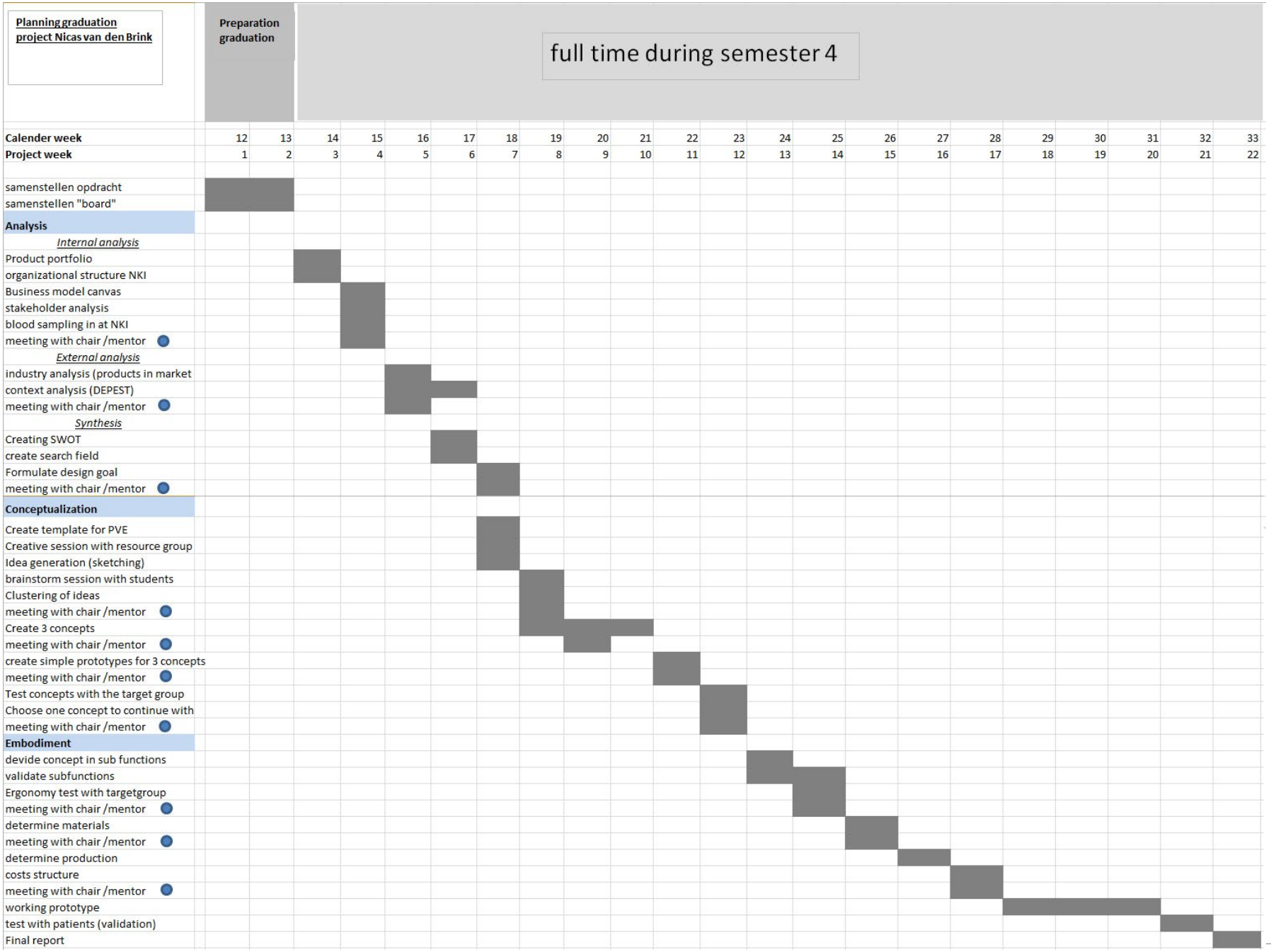
Criteria	Scraper	Thimble	Capillar
1	4	4	4
2	3	3	3
3	3	2	4
4	5	2	5
5	3	3	5
6	3	3	5
7	3	4	5
total:	24	21	31

Scraper	Thimble	Capillar
110	98	109

Outcomes of decision criteria ▲

Appendix V - Schedules

Figure 28 - Full planning for graduation



Planning conceptualization fase

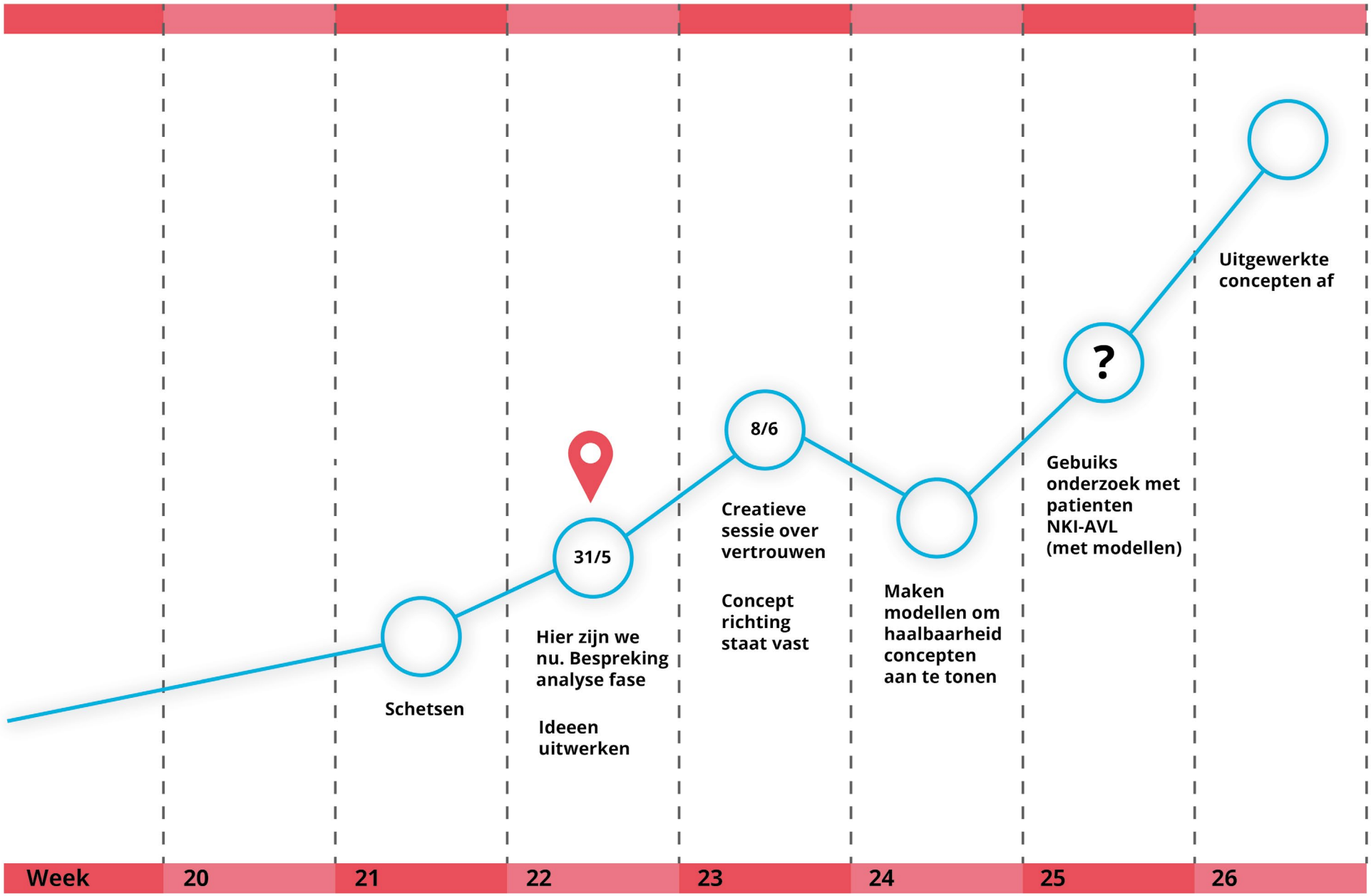
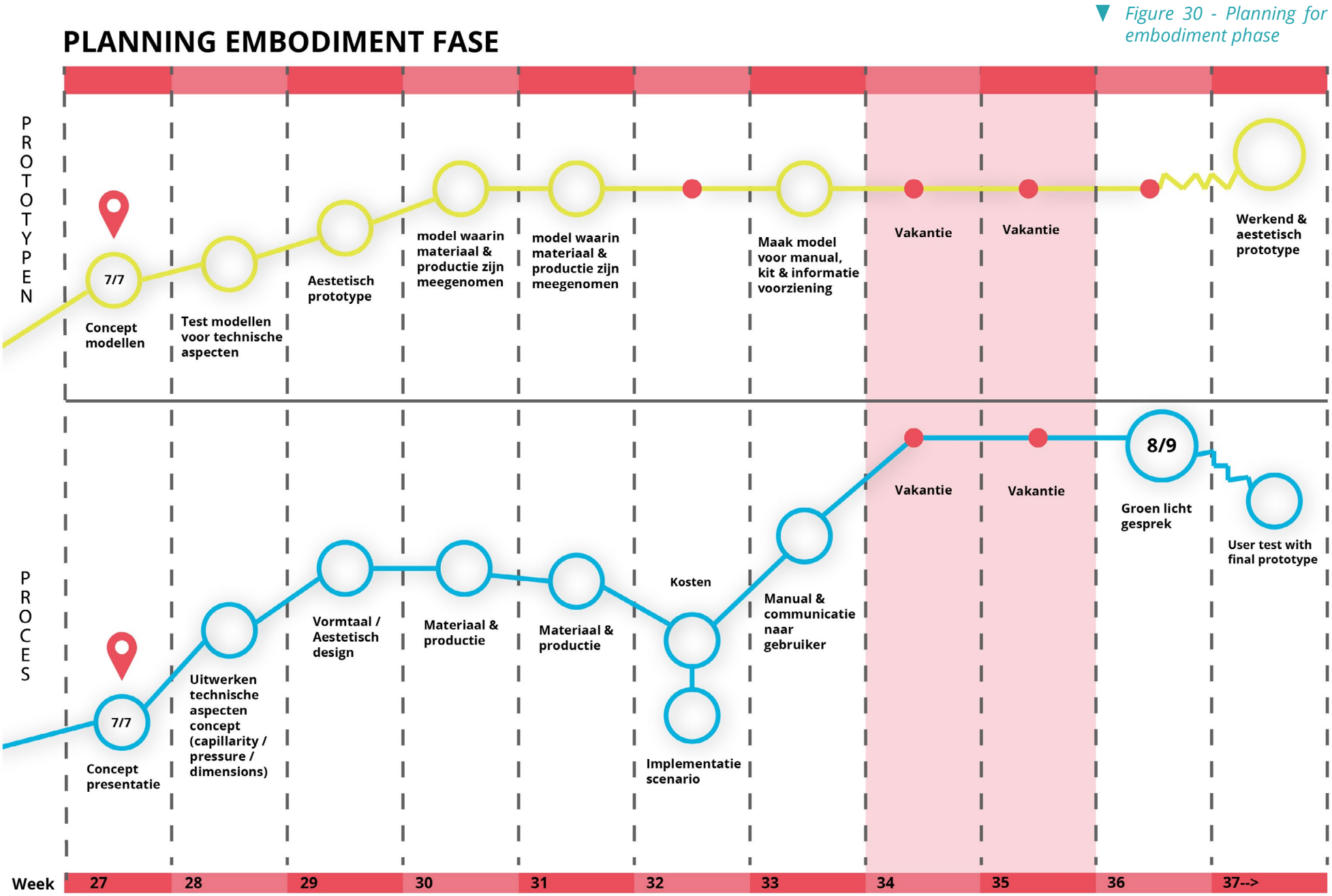


Figure 29 - Planning for conceptualization phase

Figure 30 - Planning for embodiment phase



PLANNING GROENLICHT

Figure 31 - Planning for Green light meeting