Augmented Reality to Support Artery Localization in Breast Reconstruction

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I declare that this document is an original work of my own authorship and that it fulfils all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

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Abstract

The use of Augmented Reality (AR) in the medical field has been vastly studied and developed in the last decade to help professionals in surgical matters. However, limited evidence has been shown for the use of AR in breast reconstruction surgeries using deep inferior epigastric perforators (DIEPs). Such surgeries rely on the use of computed tomography angiography (CTA) for preoperative imagery and, for professionals to make use of this data, a time-consuming manual task has to be performed. The purpose of this work is to understand if AR can aid users during the pre-operative and intraoperative processes of breast reconstruction surgeries using DIEPs, namely in locating the perforators and their tracing process, by reducing surgery time and increasing user satisfaction and communication. To validate these hypotheses, BREAST FLAPPAR - an ecosystem composed of AR systems, a report, and a data visualization - was proposed. This prototype was designed to assist professionals during these procedures, relying on data from CTA imagery used as input for the AR systems and allowing surgeons to analyze crucial information in a simpler way than before. Informal observation and co-design sessions were conducted, together with a user study with seven specialists in this surgery to test the ecosystem. The results obtained indicate a reduction in the tracing process time of up to 95% and an overall 88% positive feedback in the satisfaction questionnaires. With these results, we can conclude that the ecosystem proposed reduces surgery time and is useful for breast reconstruction surgeries using DIEPs.

Keywords

Augmented Reality; Deep Inferior Epigastric Perforator Flap; Breast Reconstruction; Computed Tomography with Angiography

Resumo

O uso de Realidade Aumentada (RA) na medicina tem sido bastante estudado na última década. No entanto, poucos resultados foram apresentados sobre a sua aplicação em cirurgias de reconstrução mamária usando perfurantes epigástricas inferiores profundas (DIEPs). Estas cirurgias dependem do uso de angiotomografias computadorizadas (ATC) para obter imagens pré-operatórias mas para os profissionais utilizarem esta informação, é necessário efetuar um processo manual e demorado de marcação. O objetivo deste trabalho é perceber se RA pode ajudar estes profissionais durante os processos pré e intraoperatórios de cirurgias de reconstrução mamária utilizando DIEPs, nomeadamente na localização das perfurantes e na sua marcação, reduzindo o tempo cirúrgico e aumentando a satisfação e a comunicação entre utilizadores. Para validar estas hipóteses, propusemos o BREAST FLAPPAR - um ecossistema composto por sistemas de RA, um relatório e uma visualização de dados. Este protótipo foi criado para auxiliar os profissionais durante os procedimentos anteriormente mencionados, utilizando imagens da TAC como input para os sistemas de RA para permitir que os cirurgiões analisem informações importantes de uma forma mais simples. Foram ainda realizadas sessões informais de observação e de co-design, juntamente com um estudo de utilizadores com sete especialistas neste tipo de cirurgia para testar o ecossistema. Os resultados obtidos indicam uma redução no tempo do processo de marcação de até 95% e um feedback geral positivo de 88% nos questionários de satisfação. Com esses resultados, podemos concluir que o ecossistema proposto reduz o tempo de cirurgia e é útil para cirurgias de reconstrução mamária utilizando DIEPs.

Palavras Chave

Realidade Aumentada; Perfurantes Epigástricas Inferiores Profundas; Reconstrução Mamária; Angiotomografias Computadorizada

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Acronyms

AR	Augmented Reality
VR	Virtual Reality
OR	Operating Room
CTA	Computed Tomography with Angiography
CT	Computed Tomography
DIEP	Deep Inferior Epigastric Perforator
XML	Extensible Markup Language
OST-AR	Optical See-through Augmented Reality
SAR	Spatial Augmented Reality
HMD	Head-Mounted Display

1

Introduction

Contents

1.1 Motivation

To perform microsurgery, in particular, breast reconstruction using Deep Inferior Epigastric Perforator (DIEP)s, all planning is crucial to increase the intervention's success and reduce possible errors in order to proceed with the correct identification of the vascular network that will supply the flap to be transplanted [17]. Given this, it is important to acknowledge the fundamental role that preparation has on the surgery, and also the importance of Computed Tomography with Angiography (CTA) scans to identify this vascular network [11]. Previously developed methods for this type of surgery include the use of Doppler ultrasound to identify small arteries that emerge from the main vessel, cross the muscle and irrigate the skin, called perforators; however, due to the basic functions of such technology, surgeons cannot obtain the specific characteristics of each perforator. This led to the wide adoption of CTA scan - a gold standard for this type of surgery [11].

The need for technological advancements lead to the development of systems focused on aiding surgeons' navigation throughout the surgery. Even though these systems have been applied to different areas of medicine, those developed for breast reconstruction surgeries have achieved great results and have been widely accepted by surgeons, even if currently facing some limitations [18]. Most of the developed systems contain clear limitations when it comes to the stability of the visualization, the lack of automation, and the support to the preoperative process. All these limitations must be mitigated in order to elevate technological standards and achieve the best outcome possible for medicine and for society. With this in mind, it is important to develop a system that eliminates the manual annotation process [1], in order to decrease surgery time and subjectivity. It is also important to overlay virtual information on the patient's skin, allowing surgeons to visualize important information regarding perforators' identification and location, effectively and accurately [8]. When it comes to other ways of analyzing data during surgery, such as with a report, it is important to develop a smooth transition by using the same layout to create a seamless experience between the elements of the ecosystem. The graphical elements and data encodings should be optimized to allow professionals to analyze this data efficiently and effectively.

1.2 Problem Statement

In this work, the considered problem is the current surgery pipeline for breast reconstruction surgery using DIEPs. The current model requires professionals to perform a time-consuming manual task, consisting of tracing on the patient's skin the possible perforators' location using conventional markers and a ruler to use information obtained from the CTA scan. This task is usually performed by two professionals, with one reading the information from a non-graphical report and the other performing the tracing process. The lack of graphical elements and well-thought data encodings in the current report, together with the iterative and long-lasting process, makes this task unnecessarily hard, leading to extended surgery time and subjectivity [1]. It is also important to mention that subjectivity can lead to wrong-site surgery - a rare phenomenon that rarely leads to major injuries, but is still an unacceptable event [19].

1.3 Scopes and Objectives

The goal of this project is to verify if the use of an Augmented Reality (AR) ecosystem, together with a well-designed medical report, and a data visualization developed for the Operating Room (OR) screens, can help identifying and locating perforators in breast reconstruction surgery using DIEPs, ultimately reducing surgery time, eliminating manual tasks, and creating a semi-automatic pipeline. With this in mind, we developed BREAST FLAPPAR - an ecosystem that allows surgeons to analyze information about the identification, location, and key characteristics of the perforators in a simpler way than before. We developed multiple visualizations where surgeons can instantaneously obtain qualitative and quantitative information through data encoding and graphical elements. The visualizations will simultaneously be used to augment the patient space and as a relevant graphical (infovis) element to improve medical report reading.

BREAST FLAPPAR is composed by:

- A Spatial Augmented Reality (SAR) system that is able to project vital information regarding perforators on top of the patient's abdomen;
- A Mobile-AR application for iOS devices that allows professionals to analyze the same data directly on any flat surface;
- An Optical See-through Augmented Reality (OST-AR) system that merges CTA scan's data with a surface scan of the patient's skin, allowing healthcare professionals to analyze this vital information in a hands-free way;
- A report re-design containing graphical elements to improve the user's analysis of the data presented;
- A data visualization for the OR screens that allows users to visualize this information as a team during surgery, instead of reading the report.

The elements within BREAST FLAPPAR were developed to aid healthcare professionals in different stages of this procedure, particularly, the pre-operative and intraoperative processes. The report and the Mobile-AR system were developed for the pre-operative process as they allow users to quickly obtain important information about the patient in an office setup. The remaining systems and data visualization were developed for the intraoperative process as they provide the users with a hands-free experience - a crucial feature for surgeries.

This work intends to answer the following research questions:

- Can an AR ecosystem assist surgeons trace, understand, and reduce time when it comes to the localization of perforators during a DIEP flap surgery?
- Can the proposed visual encoding that represents the localization of perforators bring benefits to the early understanding and communication during surgical planning?

These questions lead us to the following hypotheses:

- If an AR ecosystem is useful during this type of surgery, then a system can reduce surgery time and increase user's satisfaction.
- If the information is analysed effectively through a well-designed interface and visual encodings, then there will be an increased efficiency and communication between professionals.

1.4 Thesis Organization

This work is separated into seven distinct chapters, starting by providing detailed insights regarding breast reconstruction surgery using the DIEP flap, AR and the AR technologies approached in BREAST FLAPPAR, the development and implementation of all prototypes within BREAST FLAPPAR, the methods used on our user studies needed to develop and assure the maximum quality of our prototypes, and finally, the results and conclusions of our work. In the introduction (Chapter 1), we state the motivation, problems, and objectives of this work. Chapter 2 contains concepts regarding anatomy and breast reconstruction surgery, particularly, using DIEPs, while also exploring the fundamentals of AR and some important AR technologies. We later present a review of the state of the art containing mainly information about AR, Virtual Reality (VR), and Datavis technologies/techniques previously developed, which aim at aiding healthcare professionals during different kinds of procedures (Chapter 3). Furthermore, we explain the methods used in our user studies that allowed us to develop our prototype, always focusing on the users (Chapter 4), together with a detailed description of our methods and developed system - BREAST FLAPPAR (Chapter 5). Chapter 6 presents the methods of our user study, together with its results and a brief discussion of this evaluation. Finally, in Chapter 7, the conclusions, limitations, and future improvements of our work are presented, allowing researchers in this field to further explore the topics stated in this chapter.

2

Background

Contents

The following sections contain a description of the fundamental concepts used in this work, namely the description of breast reconstruction surgery using DIEPs and important concepts regarding AR.

2.1 Breast Reconstruction Surgery using DIEPs

Breast reconstruction surgery using DIEPs currently represents a state of the art technique within breast reconstruction [20], being the first choice for many breast cancer patients, particularly patients treated with mastectomy and radiation therapy [1, 21]. The DIEP flap is currently the most common flap used in breast construction surgery, containing fat, skin, and blood vessels, being harvested from the patient's lower abdomen. The new breast is then built by reattaching the flap's vessels, to the internal mammary vessels, located on the mastectomy site. As the DIEP flap does not contain any muscle, patients end up recovering more quickly, with very low rates of abdominal wall complications. This procedure can be done either during a mastectomy or in a following surgery [1, 22, 23]. In Fig. 2.1 we can see a representation of this surgery, particularly the flap harvested and the reconstruction process.

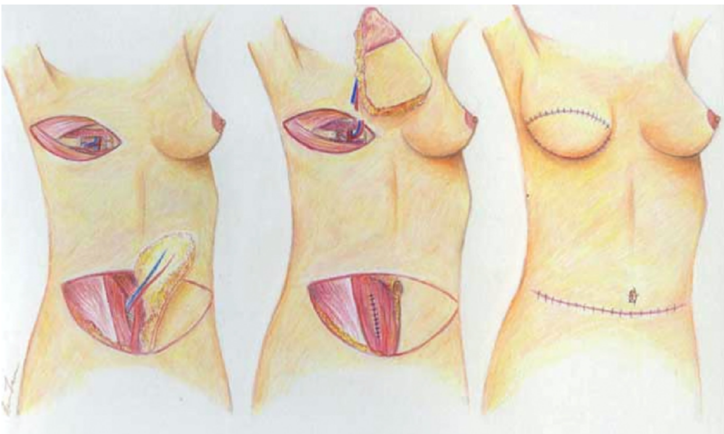


Figure 2.1: Representation of a DIEP flap procedure [1].

The blood vessels/perforators play a fundamental part in this surgery, meaning that obtaining information about these is crucial to the surgery's success. To do so, preoperative imagery is required, with the standard being a CTA scan. A CTA scan is a medical test which combines a regular Computed Tomography (CT) scan with the injection of a contrast material. The special dye used in this test, combined with the normal CT scan procedure, allows to identify and obtain information regarding the blood vessels and tissues present on the lower abdomen. In this type of surgery, the information retrieved regarding the patient's perforators, such as the caliber, location, and intramuscular and subcutaneous courses, is particularly important. [1, 24]. In the current surgery model, when CTA data is obtained, the radiologist team manually identifies each perforator and its key characteristics. A map identifying the best vascular support for each reconstruction is also drawn to support the surgery. After this report is obtained, the surgeons (at the beginning of the surgery) trace on the patient's abdomen the location of each perforator using the information from the report. During this process they use a ruler and regular markers. In Fig. 2.2 it is possible to visualize an example of the result of this process.

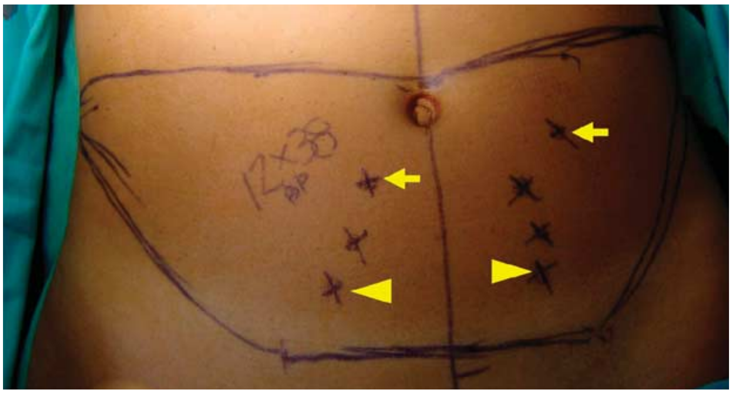


Figure 2.2: Example of the result of the tracing process [2]

2.2 Augmented Reality

AR can be defined as [25] a system that adds to the real world computer-generated objects that, to the user, appear to coexist in the real world. All this is made in real-time, with real and virtual objects being aligned with each other. An interesting interaction paradigm within AR is SAR, also known as Projection-based AR. SAR can be defined as a technology that augments real world objects and scenes without the use of special displays such as monitors, head mounted displays or hand-held devices [26]. This type of AR [27] allows a detachment between the user and the display which leads to higher integration between the environment and the user. By doing a direct comparison between this technology and head/body displays, some advantages arise, such as visual quality, technical issues, and even human factors. Furthermore, SAR also allows a reduction in costs when compared with other AR systems, mainly due to the availability of projection technologies.

Contrarily to SAR, OST-AR [28] requires an Head-Mounted Display (HMD) that merges the virtual scene with the real world, giving the user a view of the virtual content simultaneously with the real world, by using a semi-transparent display. The HMD brings advantages especially when it comes to manual tasks, since the ergonomic design allows the user to work hands-free while visualizing the content and to focus directly on the task given that the scene will be visualized directly on the user's viewpoint.

Another paradigm within AR is Mobile-AR [29], which applies the concepts of AR explained above by simply using a smartphone and its camera. These systems allow users to add a virtual scene into the real world whenever they desire without the need for other types of equipment/technologies or a specially equipped area.

In Fig. 2.3 we can observe some examples of projects developed with the technologies mentioned in this section.

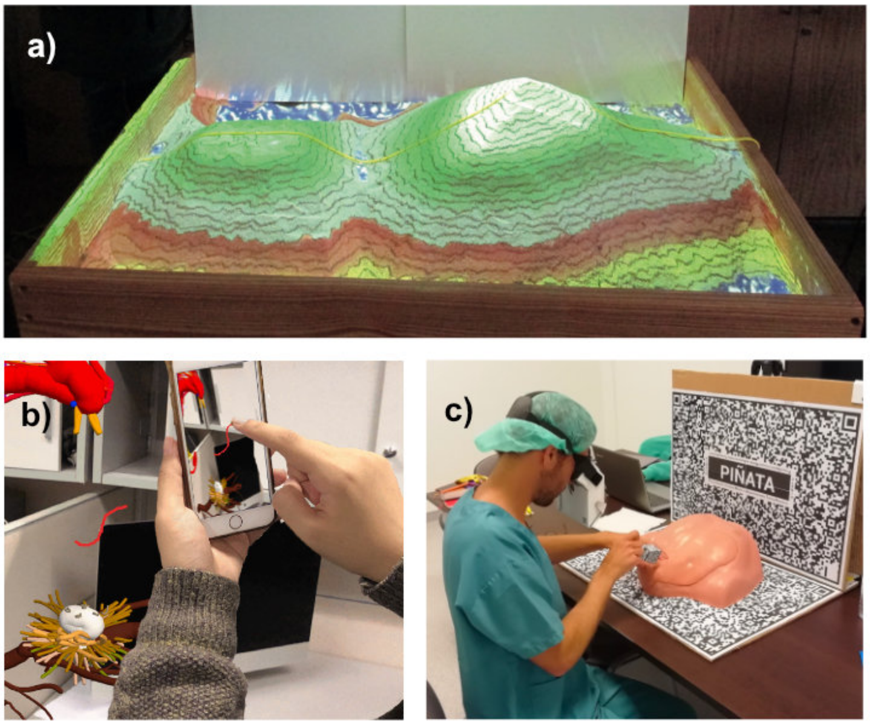


Figure 2.3: Examples of AR technologies: **(a)** SAR system used to display different heights in a sandbox [3]; **(b)** Mobile-AR system that allows the users to draw three-dimensionally using their smartphone [4]; **(c)** OST-AR system to aid health care professionals during needle insertion [5]

3

Related Work

Contents

3.1 Automatic Detection of Deep Inferior Epigastric Perforators

Even though there is a lot more to accomplish over the next decades, new technologies are already helping surgeons and patients on a daily basis, particularly when it comes to breast reconstruction surgery using DIEPs. One particular technology that has already been proven useful to the medical staff is automatic detection of DIEPs which focuses on improving both the time spent on this process and the human error associated with it during breast reconstruction after a mastectomy [1].

To solve this problem, the authors propose a semi-automatic methodology that aims at reducing the time and subjectivity inherent to the manual annotation performed upon CTA images, which at the moment represents a high standard for this surgery when it comes to preoperative imaging [11]. By comparing the Doppler ultrasound with the CTA scan, a reduction in surgery time and on partial flap failure can be achieved with the use of a CTA scan [30]. The detection of the DIEPs entails two independent challenges: obtaining both the subcutaneous and intramuscular courses. The solution found for the first challenge relies on a centerline tracking which analyses the gradient vectors of the local vessel direction, with the second challenge (extraction of the intramuscular) being addressed by using a Frangi vesselness based minimum cost path approach. By solving these two problems, the authors were able to create a system that successfully detects the perforators with a minimum error and significantly faster than before (3.5 s to perform this task). Even though this system was able to successfully perform the detection task using the previously developed AVAOFF technology, the tracking method can be unstable in this region if the perforators present a significant course along the fascia.

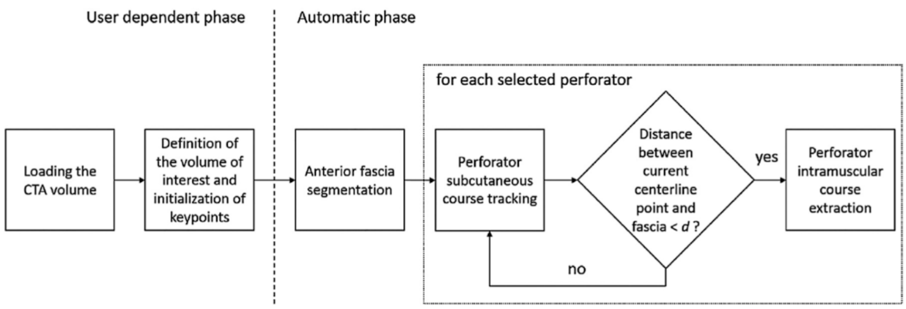


Figure 3.1: The proposed pipeline for the semi-automatic detection and characterization of DIEAPs from a CTA dataset [1].

By using a centerline-based approach to perform the blood vessel segmentation to detect the perforators, the authors were able to develop a successful system that co-identified 88 percent of the perforators (compared with a non-automatic task) and achieved a reduction of 2 hours during a surgery of this type. By analyzing these results, we can observe the difference between the location of the manual report and the automatic system, with the average absolute error difference vertically being of 3.2 ± 2.4 mm and 2.5 $\pm$ 2.0 mm horizontally. Also, we can understand that the difference regarding the caliber of the perforators between the manual report and the automatic system is normally between -0,25 and 0,25 mm. We can conclude that, even if the system delivers accurate results for large perforators, it overestimates the caliber of the smallest ones. The system also presents a small margin of error regarding the vertical position of the perforators. Because this margin is around 2-3mm, this presents no problem in performing the surgery since surgeons approach the identified area with caution [15].

3.2 Augmented Reality in the Operating Room

This section explores already developed Medical AR projects, allowing us to obtain significant insights regarding design, interface and interaction, which are crucial to develop an efficient system that is able to meet users' needs.

3.2.1 Applications in Medicine

Augmented reality in medicine [31] arose from the need to visualize and analyze medical data, simultaneously with the patient, within the same space. This need drove professionals to build Medical AR systems such as PIÑATA [5]. PIÑATA is an AR system that focuses on improving medical training for needle-based interventions. This system intends to improve the current training of central venous catheterization (CVC) by placing AR targets in the needle and a dummy to display information such as internal anatomical structure and position/orientation of the needle (Fig. 3.2). To understand if this new system could bring advantages, the author conducted user tests with 18 professionals using the current CVC system and PIÑATA, measuring metrics such as task completion time and number of errors. By analyzing these results, the authors were able to conclude that effectiveness and efficiency are not affected by this new system. Furthermore, PIÑATA resembles a real-world environment, and the educational content displayed is adequate, attesting the validity of the new system. This proves that this AR system can complement conventional training models while reducing instructors' dependence, without affecting the quality of training [5].

Due to the lack of research regarding navigation visualizations on Medicine AR, a comparison on three existing navigation concepts using a SAR set up regarding needle placement was performed. To compare these three navigation concepts, a user study was conducted where each participant performed multiple needle insertion tasks on 18 prototypes. These prototypes were obtained by creating three different scales for accuracy-to-color mapping and two for navigation indicator scaling for each different navigation concept. Furthermore, user metrics such as insertion angle and depth, task completion time, and difficulty perceived by the participants, were obtained. After analyzing the results obtained from the user study conducted, the authors were able to conclude that the results indicate a significant

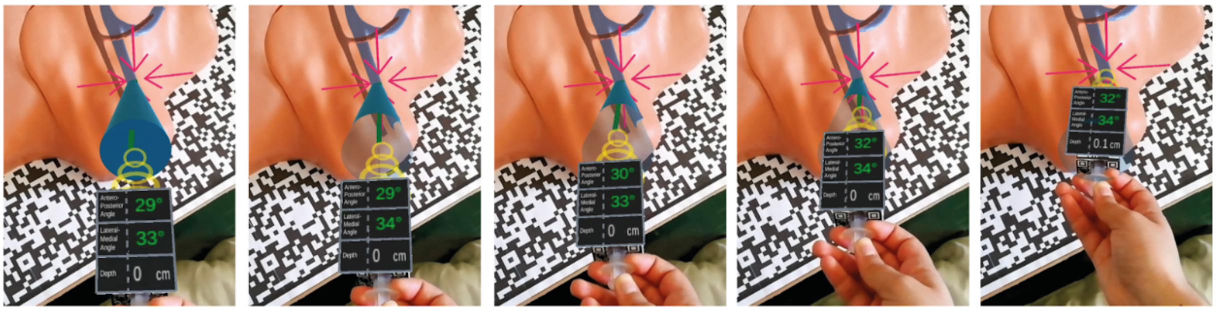


Figure 3.2: User visualization during a CVC procedure using PIÑATA AR system [5].

advantage to the use of explicit navigation aids, more particularly to the use of crosshairs-shaped visualization. This system guides the insertion process and presents the user with a progress bar regarding the depth of the needle. Furthermore, the needle needs to be aligned with the handle projections at the crosshairs' center. Even though other concepts may be useful for other areas, this concept has revealed to be more useful in medicine when compared to other concepts presented during this study [32].

After analyzing the navigation visualization on such systems, Heinrich [33] developed a prototype of an AR system to guide professionals during spinal needle insertion using Microsoft HoloLens. To evaluate this prototype, user testing was conducted and metrics such as accuracy were obtained. The results obtained showed that a high accuracy was achieved, and by using this AR system, specialists were able to reduce out-of-plane orientation errors while performing the insertion. Even though these results prove the advantages that an AR system can bring to medicine, and in particular, to needle insertion, the results obtained are not yet sufficient to allow a prototype like this to be used in clinical trials.

When developing a Medical AR system, it is important to understand the importance of measurements, distances or angles, as medical professionals must perform both a qualitative and a quantitative inspection of the data presented. For this, developers should choose the measurement tool that fits the respective data the best. During a surgical procedure, such as removing a tumor, point-to-point distance measurements are important to define safety distances around the tumor. By emulating a real-life environment, a ruler (Fig. 3.3) can be an outstanding prop to determine distances quickly, while allowing professionals to measure both considerable and minimal distances, making it a great tool for point-to-point measurements [6].

As explained before, Medical AR can bring many advantages when it comes to medical training, and another great example of this is REFLECT [7]. This system was developed with the purpose of enhancing knowledge retention and student engagement by superimposing the patient's anatomical structure, using a large display, allowing the user to see relevant anatomical structures inside the patient's body (Fig. 3.4). All this is possible using augmented reality magic mirror paradigm. To understand if this new

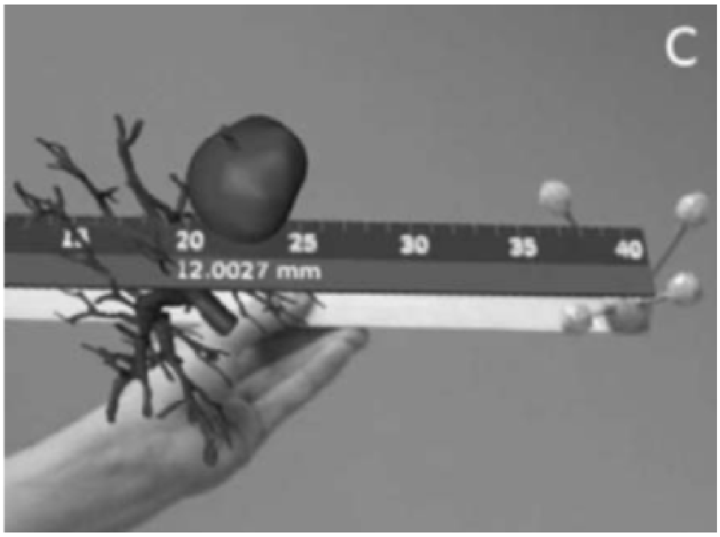


Figure 3.3: AR ruler as a point-to-point measurement toll [6].

system is beneficial for the students' training, a large-scale study was conducted where subjects were asked to perform a team-based muscle painting exercise, an activity that consists of illustrating anatomical structures on the model's skin using paint. The subjects were asked to perform this exercise using either the REFLECT system or using an anatomy textbook. Prior to this activity, a knowledge baseline was defined, and by separating the subjects into two groups, they were able to obtain metrics that can compare the classic model with the new system. The results obtained clearly show that REFLECT outperformed the old model (anatomy textbook) on every single category tested (knowledge retention, time, painting outcomes, and level of engagement). These results clearly outline the advantages that AR can bring into medicine and, in particular, to medical training, and that further development and use of these technologies should be made.

3.2.2 DIEP and AR

Planning plays an important role in microsurgery, making it easier to reduce possible errors. With this in mind, ARM-PS [17] was developed - a simple mobile AR system that allows users to superimpose virtual information as a dissection route map, using their smartphones. To do so, the user needs to upload the three-dimensional imagery obtained from the CTA into the AR app, and by opening the camera, the virtual scene will be superimposed over the real-world. Furthermore, to increase the system's vessel location accuracy, the superimposed images are fixed to some of the patient's anatomical parts such as the umbilicus. To verify the accuracy of the ARM-PS, a study was conducted where the authors compared the results obtained from the system with the results obtained from a traditional handheld Doppler, using data from thirty patients and sixty inguinal areas. With this, they were able to verify a

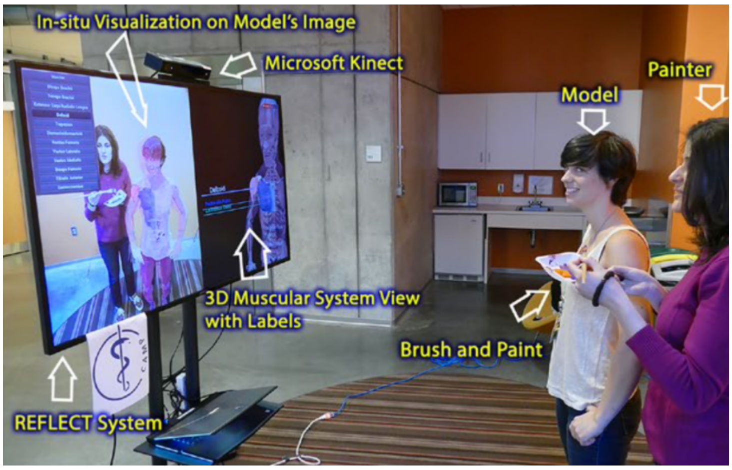


Figure 3.4: Study setup for the body painting exercise using REFLECT [7].

correlation of 100 percent with the ARM-PS drawings and the location of the vessels and lymph nodes. The authors were also able to verify that the flap harvest time, using ARM-PS, was 72 minutes, while the harvest time without using this new technology was 90 minutes, leading to an average time of harvest decrease of 20 percent. By defining a dissection route map in an easy, non-invasive, and more accurate way, ARM-PS is able to reduce surgery time while improving operative results, leading to a decreasing donor site morbidity.

Similarly to ARM-PS [17], another medical AR system [34] was developed, overlaying a vascular map on top of the patient using the CTA collected data in order to help guide surgeons prior, and during the perforator flap transplantation procedure. This new system was developed using ARToolKit, and instead of using the umbilicus as an anchor to place the virtual scene, the authors used screw-fixation markers as tracking tools for the system. This method assures the fixation of the marker throughout the surgery, allowing professionals to trust the imagery projected and not to worry about possible displacements of the markers. The study conducted to understand the impacts of such technology within this surgery consisted of projecting the navigation system on top of an animal and measuring the system error. By analyzing the results obtained from this study, the authors were able to validate the success of the navigation system in identifying and projecting the correct caliber and location for each perforator. Furthermore, the navigation system obtained a mean error value of 3.474 mm $\pm$ 1.546 mm regarding the perforators' location. Even though further improvements and clinical trials need to be made, these initial prototype results validate the advantages that an AR navigation system can bring, such as precise navigation information displayed in real-time, that allows a rapid and safe dissection of the perforators during a flap transplantation surgery.

It is important to explore other technologies within the Milgram's reality virtuality continuum [35], such as see-through AR. Gijs Luijten [8, 9] developed a see-through AR system (Fig. 3.5), using Microsoft's

HoloLens, that allows the user to identify, locate and understand the intramuscular course of the perforators and epigastric arteries, which are crucial to the success of this medical procedure. By extracting data collected from the patient's CTA scan, and by using a marker placed on the abdominal nevi as a landmark for the system, the author was able to register an anatomy hologram for each patient, that can be used prior to and during the procedure. To guarantee the correct visualization throughout the procedure, real-time patient tracking can be obtained from the quick response marker attached to the abdominal nevi. The accuracy of this HoloLens system has been tested by conducting a study with twenty patients and two observers. From the 961 accuracy measurements conducted, 70 percent were below the clinically relevant threshold, meaning that the margin of error was less than 10 mm. Although the system contains some limitations when it comes to perceiving the depth of the hologram, the results obtained lead to the conclusion that a see-through AR system can be useful to display a patient's relevant anatomy for the free flap harvest procedure, leading to a more intuitive and accurate way compared to the normal model. It is also important to refer that further improvements and studies should be conducted to show that a system such as the one presented can be used to improve perforators localization and identification, and ultimately lead to a decrease in surgery time and in complications associated with this surgery.

Figure 3.5: HoloLens application view [8, 9].

See-through AR allows the visualization of three-dimensional virtual objects during surgery by overlaying the anatomy of the patient on top of the patient, in real-time. By doing this, it allows the surgeon to focus on the patient instead of having the need to look at a screen when in need of guidance, damaging the surgical vision field. To achieve this goal, an AR system [36] was developed that is able to superimpose three-dimensional data collected from a patient's CT-scan using only stereoscopic smart glasses.

To guarantee the correct placement and stability maintenance of the virtual scene, a tracker is placed on the patient's skin, allowing the smart glasses to track correctly and in real-time. This technology was used during twelve surgeries with twelve different patients, simultaneously with the conventional model for preoperative planning and perforating vessels selection. By doing this procedure, they were able to conclude the advantages that such a system can bring, especially compared to the well-known Doppler and X-rays model. It is important to recognize the need and advantages that this system brought to this particular type of surgery, but it is also important to understand that a system like this can be easily developed for other kinds of surgery and even for educational purposes.

AR is a particularly useful technology when it comes to bringing CTA collected imaging to life, as it allows surgeons to analyze the patient's anatomy with zero incisions. The work developed by the authors [10] intends to prove the usefulness of AR within identification, dissection, and execution of surgery using flaps. To do this, they developed a system that creates three-dimensional images from the CTA scan, which are then converted into polygonal models, and finally rendered into the Microsoft HoloLens (Fig. 3.6). This system intends to aid navigation and increase the accuracy of dissection during surgery, using a combination of hand gestures tracking and voice commands. It is important also to mention that system alignment is a manual process since it is believed that this method is fast and accurate enough. This system was compared with the previously used model (Doppler ultrasound) during six different surgeries with six different subjects. All the surgeries were reconstructive surgeries using flap transplantation. For all these surgeries it was stated, and proven according to the surgeons' feedback, that the new system yields higher reliability and a decrease in surgery time. Moreover, this system leads to the possibility of reducing the morbidity associated with this type of surgeries, and also for improvements when it comes to medical training and remote support for the surgeon. Further work should also be conducted, especially to allow automatic alignment and to obtain quantitative data while compared to the previous model.

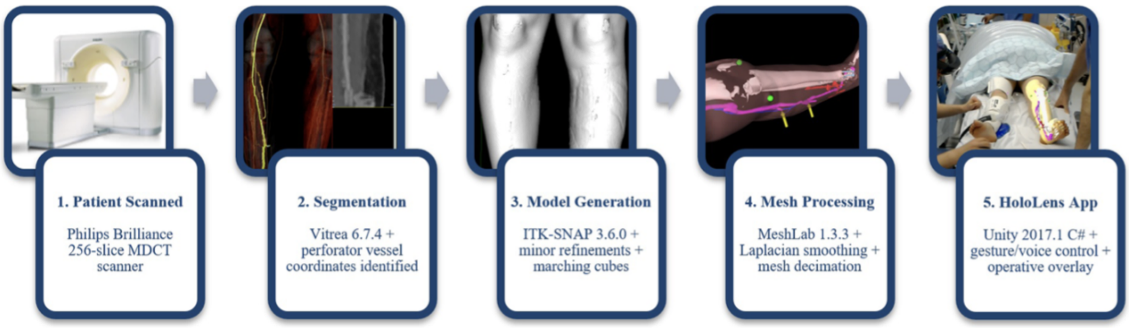


Figure 3.6: New system's pipeline [10].

When it comes to SAR to help DIEP identification during a breast reconstruction procedure, a new system [11] was developed that allows users to visualize superimposed virtual images over the patient's abdomen. By using a video projector, information such as intramuscular course, perforating locations, and subcutaneous branching can be displayed prior to the surgery in order to provide visual aids to the user (Fig. 3.7). Similarly to other AR systems such as ARM-PS [17], the umbilicus was used as an anchor for the superimposed images to guarantee their correct placement. To verify the accuracy of this new system, a study with nine patients was conducted, verifying the validity of the projected data collected from the three-dimensional reconstruction of the CTA by comparing it with data collected using a Doppler. Preliminary results showed that by using Doppler ultrasound, 88 locations were marked, whereas with the new system, information regarding 100 perforators was projected. More importantly, from the 34 perforators transplanted, the Doppler and the new system were able to find 19 and 29 locations, respectively. By comparing both methods, it is clear that this new system adds more important information to the users, such as intramuscular course and subcutaneous branching, while decreasing surgery time. Furthermore, by analyzing the study's results, the projection system was able to identify more perforators in a more accurate way when compared to the Doppler. It is also important to mention that this system contains limitations when it comes to the operator dependent method, which might lead to unaligned results [11].

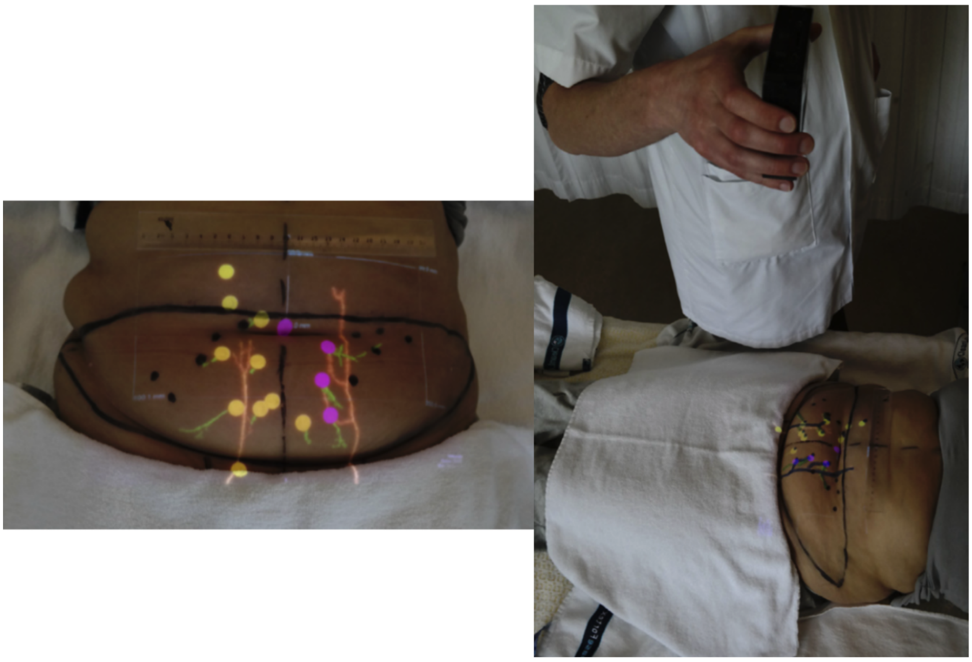


Figure 3.7: Projected information on top of the patient's abdomen [11].

Even though there are currently vast technological advancements within medicine, when it comes to surgical markings the "best estimate" is still widely used. Given that the flaps used in plastic surgery contain specific geometries that are hard to replicate, a SAR system was developed to create a novel approach to surgical marking to increase the accuracy associated with this procedure. To achieve this, a pico-projector was used to project a stencil in the form of a prefabricated flap designed previously on Google Sketchup. To test this system, the authors conducted a study where they compared the results of flap transplantation, using cadavers, achieved by the projected and hand-drawn systems. The results of this experiment yield that, for both flaps (Rhomboid and Bilobed), there was a fifty percent deviation in each angle and a twenty percent deviation in length in the drawn exercise, while in the projected exercise, a zero percent deviation was achieved. Furthermore, it was also stated that when it comes to the movement of the flaps, it was easier to move the projected ones. These results infer the quantitative advantage that a projection-based system brings to such a procedure. Even though the results obtained were limited to one surgeon, and performed in cadavers, this system proved its usefulness not only as a teaching tool but also for all kinds of surgery [37].

3.3 Surgical Site Marking

Medical errors represents one of the most popular topics within the last decade. One particularly interesting area within medical errors is wrong-site surgery [38], which has attracted attention over the last few years, not only by medical publishers, but also in mainstream media. From these mistakes, an area called surgical site marking arose, which consists of presenting to the surgeons information related to the surgery in order to decrease the possibility of human errors, in particular, wrong-site related errors. The information presented normally intends to display the placement where the surgery should occur or points of interest to the surgery. A simple surgery site marking solution was developed with the purpose of marking, correlating, and verifying the correct surgical site. To do so, a cut-out with an adhesive layer on one side was developed, containing information about the patient, the surgery, and its location (Fig. 3.8), that should be placed on the correct surgical site. By using an incise material, surgery can be performed on top of this cut-out without negatively affecting the normal course of the surgery. By using this system prior to surgery, a new surgery pipeline is created, allowing professionals to perform such tasks with higher certainty while maintaining its simplicity [12].

Given the importance of such topic, a study [39] was conducted to understand the impact of different skin preparation solutions during surgery, and its impact to the surgical site marking system. The study involved twenty patients who were going to be submitted to a hip arthroplasty surgery, where the surgical site marking system consisted of marking information on the patient's skin using a black permanent marker. Different skin preparation was assigned randomly to each patient, and to allow a direct comparison, a photograph of the marking system was taken prior to, and after surgery. After analyzing the results, it was clear that the iodine-based solution presented better results compared to

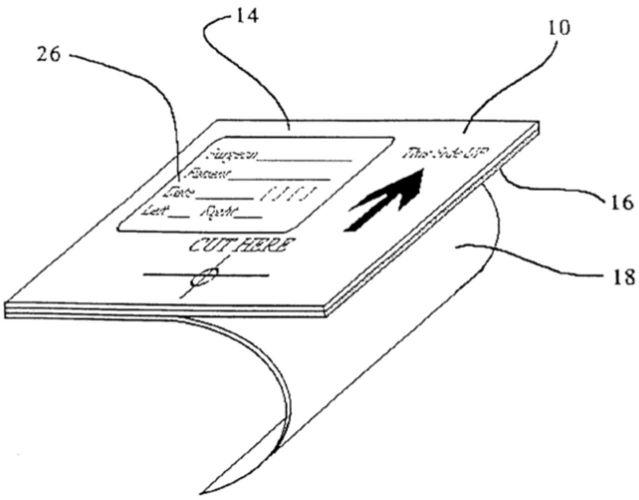


Figure 3.8: Representation of the surgical site marking system [12].

the chlorhexidine-based solution. The second one presented a significant erasure of the information presented on the patient's skin, which in some situations might lead to a misunderstanding of the information and ultimately to a surgery error [39].

3.4 Medical Reports for DIEPs Related Surgeries

This section aims at exploring how different interfaces, graphical elements and types of data affect efficiency when it comes to data analysis.

The amount of data available to health professionals is constantly increasing given technology and storage capacity enhancement, even if the human capacity to analyze the respective data has not suffered any changes. One way to help healthcare professionals deal with this issue is with the use of information visualization, in particular, when trying to achieve the goal of representing medical data in an understandable, recognizable, and intuitive way. This can be achieved by using the right type of technology for the type of data at hand, for example, a table can be used to represent multidimensional data, or a virtual-reality system for 3D data can be used to represent a patient's anatomical parts [40].

3.4.1 Data Tables

Tables allow users to read and understand information represented in rows and columns in a fast and efficient way, bringing advantages like simplicity regarding its structure, which can be adapted with the mutation of data, and its understandability, as it can represent complex information in a simple way that allows the general public to understand it. These advantages support the use of tables for medical data, as they allow both specialists and patients to analyze and understand data [41]. One example that portrays the usefulness of tables is when these are used to simplify the language of fetal monitoring [13]. Healthcare professionals in Australia and New Zealand use intrapartum fetal surveillance (IFS) guidelines as a structured prose-based traffic-light matrix, where the colors green, blue, amber and red, encode the meaning of unlikely, maybe, possible, and likely, respectively. To understand if it is possible to improve the current system and create a data visualization that can be unambiguous regarding how the information is presented, a comparison between the current system with a data table (Fig. 3.9) was made.

Classification			Baseline	Variability	Decelerations	Accelerations	Actions
Normal	Low probability fetal compromise	GREEN	110–160 bpm	6–25 bpm	Nil	15 bpm* for 15 s	Nil
Abnormal	Unlikely fetal compromise	BLUE	100–109 bpm		Early OR Variable	Absent*	Continue CTG
	May be fetal compromise	YELLOW	>160 bpm OR Rising	3–5 bpm for >30 min	Complicated variable** OR Late		Correct reversible causes
	Likely fetal compromise	RED	≥2 YELLOW features = RED				Persistent YELLOW = RED
			<100 bpm for >5 min	<3 bpm for >30 min OR Sinusoidal			FBS OR Expedite birth

Figure 3.9: Table format of the IFS guidelines [13].

The authors have decided to conduct this study with clinicians with more than 10 years of experience and no previous experience with the current guideline system for CTG classification. We can now observe the accuracy obtained by clinicians after analyzing content on the prose-based format of the guidelines versus the table format. Professionals obtained a higher accuracy while using the table format to analyze the respective data. Furthermore, the study also revealed that clinicians were able to analyze data in a quicker and more accurate way, but also more effortlessly than when compared to the previous version.

3.4.2 Graphical Visualization

In medicine [42] there are two parts of the practical work - analysing data and planning the next steps. Even though these crucial steps are based on data recorded previously, both of them should be supported by graphical visualization of the respective data since it is easier to analyze and plan. It is also important to refer that in the case of complex data, it is crucial to use more advanced techniques that allow an effortless analysis of the information presented. All data dealt by Infovis represents abstract data displayed effectively, in contrast to information such as MRI or CT scans. This creates an advantage for healthcare professionals since most of the time non-abstract data is hard to understand and analyze.

When it comes to measured data, it is important to focus on topics such as: intuitiveness to allow users who are unfamiliar with the visualization to understand the presented data without the need for help; focus+context is crucial when it comes to large data i.e. many data points; finding patterns must be an easy task (when they exist), since this can help to find the patient's underlying problem.

One example where graphical visualization has revealed to be useful in the past is [14] Florence Nightingale's polar area graph. While nursing during the Crimean War, Florence decided to analyze each cause of death in her hospital and trace a graph with this information. This allowed people to understand that the majority of the soldiers' deaths were caused by diseases related to the unsanitary conditions they lived in and not by the war itself.

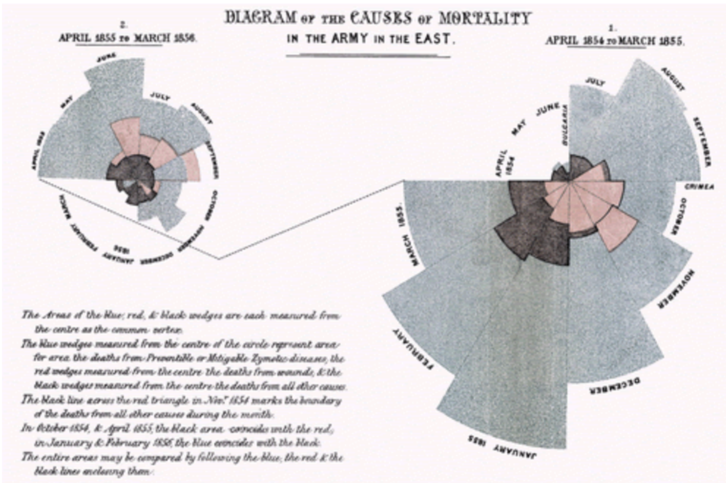


Figure 3.10: Florence Nightingale's polar area graph [14].

It is important to understand that the visualization should be adapted to data and requirements while creating a display that is not overloaded with information and focus on the topics mentioned above.

3.4.3 Spatial Data

Before understanding the possible applications of spatial data in today's world, it is important to acknowledge its advantages to medicine in the past. To understand the cholera outbreak [43], a London physician decided to plot in a map both the location of the cases of the disease and the water pumps in the city. This led to the understanding that water was spreading the disease, allowing for authorities to control the outbreak and eventually stop it.

Nowadays, when it comes to possible applications of these methods, a study has been conducted to understand how a catastrophe can impact self-care routine in patients with a chronic disease. Interviews conclude that during a catastrophic event such as a flood, patients have stated that it is difficult to maintain their self-care routine. To prevent this phenomenon, the authors suggested that spatial data should be directly linked with the patient's information, more particularly, linking geographic information system (GIS), which provides socio-spatial information, to enrich EHR. By doing this, health professionals would be able to give personalized care to each patient, since this new information allows professionals to analyze patient's proximity to medical providers, walkability index, air quality, amongst many other advantages. Furthermore, during a catastrophe, the spatial data collected using GIS can identify impacted patients so that medical teams can give an accurate and efficient response to these patients instead of a generic one. All the advantages mentioned above are only possible by linking the patient's spatial data to the EHR, allowing healthcare professionals to analyze a map with all the patients' information [44].

3.5 Discussion

We started this section by understanding the current gold standards regarding breast reconstruction using DIEPs [1, 15], an automatic system that given the patient's CTA scan data can automatically identify and locate DIEPs. By analyzing the results obtained from this system, it is clear that this new pipeline for this kind of surgery can achieve equal or better results regarding perforators' identification and location, compared to the previous manual pipeline. By deeply understanding the definition of AR [25] and SAR [27], we can instantaneously understand the great fit that overlaying virtual information can be in medicine. Following this idea, a vast number of projects were developed in multiple areas of medicine. This includes complex projects such as PIÑATA [5] - an AR system for needle insertion, or even simpler projects that allow surgeons to overlay a virtual ruler [6], allowing them to obtain quantitative data during the procedure. One particularly interesting area where AR showed great results in the last few years is within free flap transplantation. Due to the vastness of the area, multiple systems using different technologies and for different areas were developed. Nonetheless, there is still a lack of studies, specially when it comes to clinical outcomes [45]. Focusing now on breast reconstruction, see-through AR systems [5, 36] were developed, allowing surgeons to visualize CTA collected data three-dimensionally, using markers to perform real-time tracking. When it comes to SAR systems, most of them relied on CTA data for preoperative imagery (similarly to the see-through systems mentioned) [11, 17, 34]. By using this data as input, and by projecting this information (using a portable projector), they were able to provide the surgeon with virtual information needed for the surgery, while maintaining the surgeon's field of view focused on the most important tasks. These systems focused only in the intraoperative process, neglecting the pre-operative process. Furthermore, most of these systems only focused on a specific interface created for the surgeon, limiting the remaining elements of the team to access this information, and leading to a decrease in communication between the team members - a crucial task to the outcome of the surgery. These limitations should be addressed. These systems should be created to be useful during the pre-operative and intraoperative process, and should allow the team to access the same information to increase the team communication.

Nowadays, data is crucial to achieve good results in medicine, leading to the importance of its visualization and interpretation [40]. Even though the choice of ways to represent data is vast, it is crucial to make the right choice for each scenario. We understood that data tables [41] normally represent a great way to present data since they allows users to read and understand information represented in rows and columns in a fast and efficient way while maintaining simplicity and adaptability. Another great way to represent data is through graphical visualization [42] as it allows users to obtain insights effortlessly from an abstract visualization when the encoding is done right.

After this analysis, it is important to understand that further contributions should be made to develop this area. This conclusion lead to the development of AR systems, a report, and a data visualization that, when combined, will create an ecosystem that allows surgeons to obtain key insights of each perforator efficiently and effectively. The ecosystem also aims at reducing surgery time and subjectivity by eliminating the long-lasting manual annotation process during breast reconstruction surgery using DIEPs, while addressing the limitations identified in previously developed systems, such as the lack of focus on the pre-operative process, the lack of communication between team members, as well as the difficulty in making information available to all team members.

4

Observation & Co-design sessions

Contents

Creating a new solution is never an easy goal, especially in medicine, due to the high risks that are at stake [46]. Achieving a revolutionary solution is not a straightforward task that can be directly solved with technology, we have to understand the task, the problems that need to be solved, and most importantly the users' needs, and then, translate this information into palpable solutions that can be useful to the users and to society. As you can see in Fig. 4.1, we started by performing an observation session and some informal interviews that allowed us to obtain important information that led us to a pre-prototype. This pre-prototype was then presented to some users during the co-design sessions who gave us vital feedback for us to reiterate the first prototype and reach the final prototype - BREAST FLAPPAR.

Figure 4.1: Representation of the design process and tasks needed to create the final prototype.

4.1 Observation sessions

Before the creation of the first prototype of our work, we decided to conduct an observation session to understand the surgery, the current pipeline used for this type of surgery, the problems associated with this surgery and/or pipeline, and the OR setup.

This information is crucial to understand the context to which our solution must fit, in order to revolutionize this surgery and change the current model. This would also allow us to develop a prototype that would meet the users' needs.

4.1.1 Methodology

The observation session took place during a real breast reconstruction surgery using DIEPs, in one of Fundação Champalimaud's ORs. In this session, 4 surgeons were present, together with a nursing team. In this surgery, the conventional model for breast reconstruction surgery using DIEPs was used. This model starts with a CTA scan of the patient in order to obtain data regarding the patient's perforators. This data is then sent to the radiologist team which analyses the data and creates a report that is then sent to the surgical team, containing all the needed information to perform the surgery. In the OR, this data is analyzed by the surgeons and the slow manual task of tracing the perforators' location on the patient's skin starts. To do this, the team uses conventional markers and a ruler, in order to translate the information obtained from the CTA scan into the patient's abdomen. This task was performed by two professionals, with one reading the information from a non-graphical report and the other performing the tracing process. It is also important to refer that this process is made without the help of any kind of graphical element in the report that might aid and guide professionals during this long-lasting and hard process. In this particular surgery, a photo of the final result of the tracing process was taken, using a smartphone, in order to send it to the OR screens and allow all the team to observe this information.

In this session, no photos, video, or audio was obtained to protect the patient's privacy. All the information was obtained by taking notes and by conducting interviews with two of the surgeons. The main objective of this session was to fully understand the surgery and its current model, in order to infer the problems and find the best possible solution.

4.1.2 Results

From this observation session, we were able to obtain valuable information to achieve our final work - BREAST FLAPPAR. In this session, we started by observing the OR setup to understand the environment where our solution would fit in. This setup was composed by two screens fixed on a wall, one computer connected to the screens, and a horizontal stretcher where the patient was laying.

By analyzing this setup, we understood that the computer and the two screens were being used only to display a regular A4-sized PDF and a smartphone photography of the tracing process' result. Since none of these are optimized for the OR screens, this space was not being used efficiently. Furthermore, to allow the team to observe the visualization displayed on top of the patient's abdomen, one of the surgeons took a photo of the patient, sent it to the computer, and then send it to the display. We believe that a graphical visualization of the key elements to the surgery should be present on these displays from the beginning of the surgery.

The second relevant step of this observation was the tracing process, where two different problems were found.

- The time consumed to perform this task, which leads to a much higher surgery time and tiredness of the medical team;
- The subjectivity and higher margins of error that can occur during the manual tracing process.

These two factors alone lead to a harder than needed surgery and possibly represent the main reasons why the pipeline of the current model should suffer changes. In Figure 4.2 we can observe the final result of a tracing process.

These results, combined with the work presented in chapter 2, allowed us to create a strong basis of information for the development and idealization of our work.

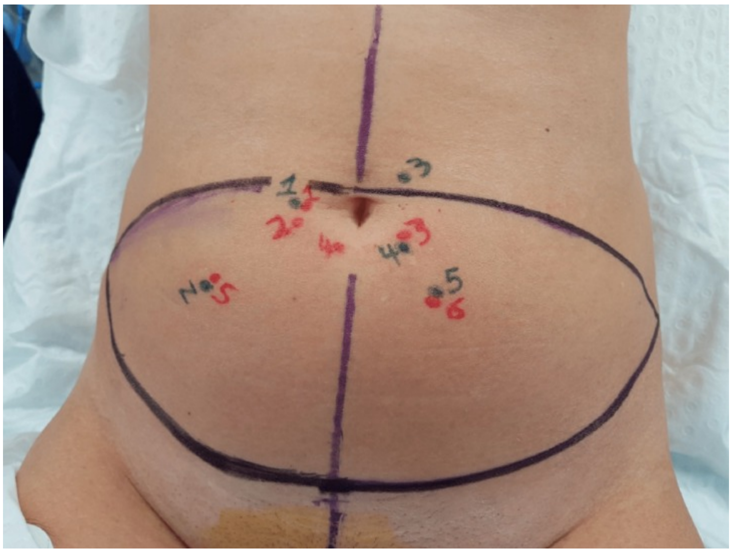


Figure 4.2: Patient's abdomen after the tracing process [15].

4.2 Co-design

To ensure that the project is able to meet professionals' expectations and needs, co-design sessions were held. These sessions were useful to obtain feedback on the pre-prototype developed, creating an iterative design process and allowing us to achieve the best outcome possible. These sessions also allow stakeholders to be part of the design process and participate during this important step of the project in an active way. The prototype developed for these sessions consisted on a visualization of what the AR systems will display, to ensure that the focus is on what is important to visualize and how to visualize all the vital information during surgery.

4.2.1 Methodology

The observation session and informal interviews, combined with the literature review approached on Chapter 3, allowed us to build our vision of what the solution should be. This vision was then transformed on a pre-prototype that was used during these sessions. To make sure that we were able to obtain the best information possible, a previously prepared script was made and used during all the sessions. Due to the COVID-19 pandemic, all sessions were conducted remotely using Zoom's platform. Three separate co-design sessions were conducted with the help of three surgeons and one nurse (75 percent male vs. 25 percent female), with specializations in distinct areas such as general surgery, surgical oncology, plastic surgery, and rehabilitation nursery. All participants have 8 or more years of experience in breast reconstruction surgery and 50 percent of them have experience in breast reconstruction using DIEPs.

4.2.2 Sessions and Results

An informal session was firstly held with one surgeon. During this session, the surgeon stated that the proposed redesign of the report would enhance its readability, while increasing the attractiveness of its graphical elements. It was also noted that a legend for the data table was missing, which could lead to a misrepresentation of the data. Regarding the prototype, some redesign suggestions were made such as:

- Adding a horizontal and vertical ruler to allow professionals to perform a quantitative analysis regarding the spatial data presented;
- Assign a color to each point to allow surgeons to understand which are the most important perforators within the data set.

The second session was conducted with two surgeons and produced similar results to those of the first session, with the proposed report redesign receiving compliments, but no further feedback being given. Regarding the prototype, it was stated that data obtained via the manual system should be removed from the visualization. Both surgeons have also agreed that the visualization should contain a color encoding that would allow professionals to understand the most important perforators instantaneously.

A third session was conducted with one nurse and the surgeon from the first (informal) session. Regarding the report, they stated that the glyph that encodes the location of each perforator should include, in each direction, the distance from the umbilicus, to allow professionals to analyze only the glyph and not the text presented on the left. The prototype received no further feedback beyond that of the first session.

After carefully analyzing all the feedback obtained, we reiterated the current pre-prototype to reflect the new changes.

5

Methodology

Contents

Based on the related work explored in this report, we built BREAST FLAPPAR, an ecosystem created to help healthcare professionals during breast reconstruction surgery using DIEPs. This system will display important information regarding perforators on the patient's abdomen, eliminating the time-consuming and tedious manual process, reducing surgery time and subjectivity associated with this process. A redesign of the report and the development of a data visualization for the OR screens was also made, not only to match the new information presented during the visualization of the AR systems, but also to add important new information and its encoding.

5.1 Overview

BREAST FLAPPAR is an ecosystem built to help surgeons and healthcare professionals involved in breast reconstruction surgeries using DIEPs. This work is composed by:

- Spatial AR system;
- Mobile-AR application;
- OST-AR system;
- Report and data visualization.

Even though our work mainly focuses on the systems listed above, other tasks were required to meet such goals. As we can observe on Fig. 5.1, the first step to develop such AR systems is to obtain and manipulate the data. This data is then transformed to obtain a 3D model that will then be used in the AR systems and in the report.

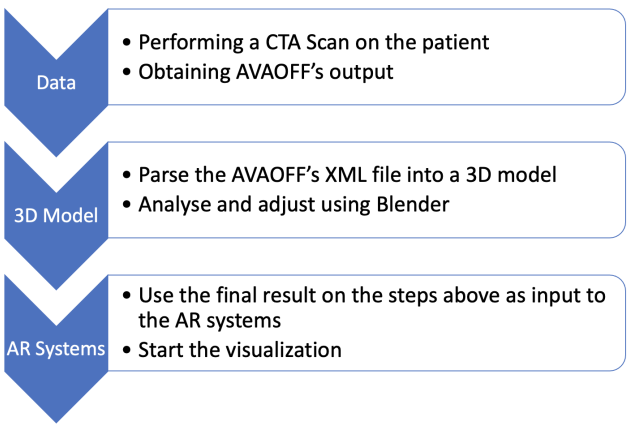


Figure 5.1: Flowchart representing the steps needed to achieve the final AR systems' visualization.

In the following sections, we will explain in detail all steps taken during the development of such topics that lead us to our final work.

5.1.1 Pipeline

Before moving on to the next sections that will explain BREAST FLAPPAR in detail, it is important understand our main goal - improve the current surgery model and create a new surgery pipeline. To do so, it is crucial to understand the differences between both the old and the new models in order to understand the context in which our systems will fit in, together with its importance to the surgery.

We started by analyzing the current process pipeline during and before the surgery in order to understand the key aspects of this process, as well as possible improvements that BREAST FLAPPAR can bring. While analyzing the left side of Fig.5.2, we understood that the first step included performing a CTA scan of the patient, sending imagery collected to the radiologist and to the automatic system AVAOFF. These two parties later analyze and annotate both the location and information for each perforator, while also providing some comments/observations that may be useful prior to the surgery. Information collected from the AVAOFF and the radiologist is then combined into a report that is sent to the team who will perform the surgery. Finally, professionals analyze the report prior to the surgery and use it in the first step of this surgery to annotate each perforator on top of the patient. This time-consuming task requires surgeons to go through each point in the report, marking its location using a ruler and a pen on the patient's abdomen. This task takes approximately 15 to 20 minutes for a trained team of professionals, resulting in longer surgery time and in a more exhausted team.

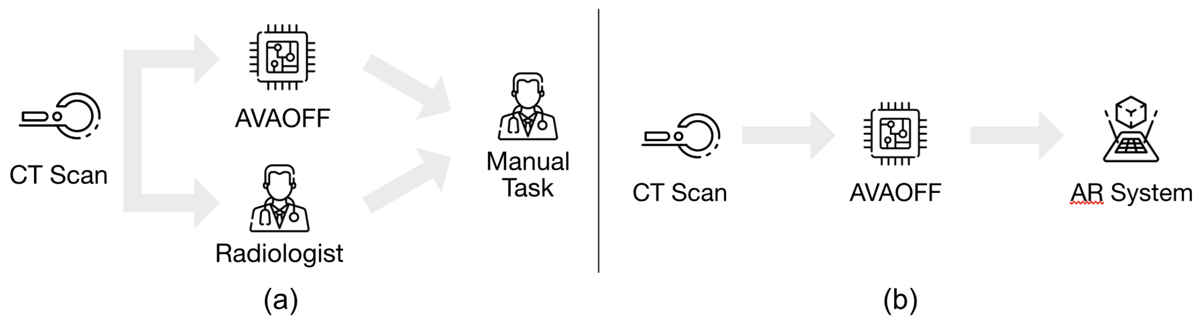


Figure 5.2: Representation of the current model's pipeline.

Our work tries to improve this pipeline while creating advanced systems that are able to migrate this surgery into the future of medicine. For that, we started by eliminating the need for the manual task associated with the radiologist and to use only the information collected by the automatic system (AVAOFF). This information will then be used in the creation of the report, matching the layout and data encodings of the proposed system, and will be delivered to the team in charge of the surgery and to the AR systems. These systems will be able to present relevant information to the team of surgeons in a matter of seconds, eliminating the need for the time-consuming manual annotation task performed by surgeons, and ultimately reducing surgery time. With these steps, we can achieve a semi-automatic pipeline that significantly reduces the time and number of tasks needed to perform the surgery when compared to the current model as demonstrated on the right side of Fig.5.2.

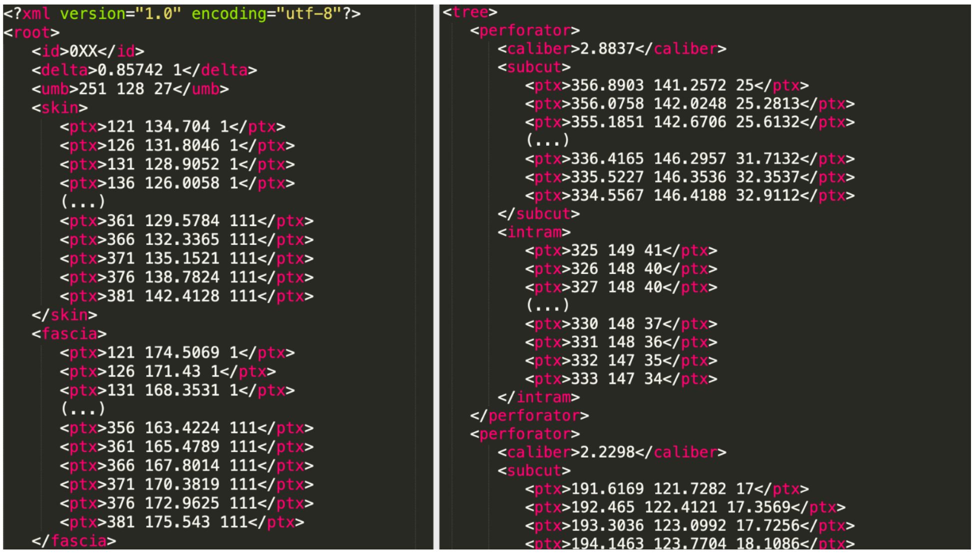
5.2 Data

As we can observe in Fig. 5.1, the first step on BREAST FLAPPAR's pipeline is Data. The first step in obtaining the data, which will allow us to generate the 3D model of the patient, is to obtain preoperative imagery to access the location and information regarding the patient's perforators. To do so, we perform a CTA scan on the patient. As explained in the first chapter of this work, performing a CTA scan is currently the gold standard for imagery when it comes to breast reconstruction surgery using DIEPs. A CTA scan consists of combining a regular CT scan with the injection of a contrast material. The special dye used in this test identifies blood vessels and tissues present on the lower abdomen [1, 24]. This allows us to obtain information about the perforators such as location, caliber, intramuscular course, and subcutaneous course.

After obtaining the information generated by the CTA scan, we can then use this data as input for the AVAOFF - an automatic system that analyzes the CTA scan's output and obtains crucial information regarding perforators. This system can fully eliminate the need for a radiologist team to perform the manual task of analyzing the CTA scan's results.

In Fig. 5.3 we can observe AVAOFF's output. The output is an Extensible Markup Language (XML) file that contains information regarding the patient's skin, fascia, umbilicus, and perforators. When it comes to the perforators, this file contains information such as caliber, intramuscular and subcutaneous course, as well as their location. This information is cleverly described within XML tags as we can observe in the image. Each entry of the file, inside the tags, corresponds to the location of a single point.

On the left side of this figure, we can observe the header of the output file, containing the patient's ID, and the location of the patient's umbilicus which allows us to translate the data and define the umbilicus as the center of our visualizations. The following tags (skin and fascia) allows us to trace the two anatomical elements represented within these tags in 3D. On the right side of the figure, we can observe the part of the XML file containing the information regarding the patient's perforators. This part starts by stating the caliber of each perforator and then defines a path for the subcutaneous and intramuscular course for each perforator. This information allows us to accurately trace a three-dimensional detailed model of the patient's anatomy.



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   <id>0XX</id>
   <delta>0.85742 1</delta>
   <umb>251 128 27</umb>
   <skin>
      <ptx>121 134.704 1</ptx>
      <ptx>126 131.8046 1</ptx>
      <ptx>131 128.9052 1</ptx>
      <ptx>136 126.0058 1</ptx>
      (...)
      <ptx>361 129.5784 111</ptx>
      <ptx>366 132.3365 111</ptx>
      <ptx>371 135.1521 111</ptx>
      <ptx>376 138.7824 111</ptx>
      <ptx>381 142.4128 111</ptx>
   </skin>
   <fascia>
      <ptx>121 174.5069 1</ptx>
      <ptx>126 171.43 1</ptx>
      <ptx>131 168.3531 1</ptx>
      (...)
      <ptx>356 163.4224 111</ptx>
      <ptx>361 165.4789 111</ptx>
      <ptx>366 167.8014 111</ptx>
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      <ptx>376 172.9625 111</ptx>
      <ptx>381 175.543 111</ptx>
   </fascia>
```

```xml
<tree>
   <perforator>
      <caliber>2.8837</caliber>
      <subcut>
         <ptx>356.8903 141.2572 25</ptx>
         <ptx>356.0758 142.0248 25.2813</ptx>
         <ptx>355.1851 142.6706 25.6132</ptx>
         (...)
         <ptx>336.4165 146.2957 31.7132</ptx>
         <ptx>335.5227 146.3536 32.3537</ptx>
         <ptx>334.5567 146.4188 32.9112</ptx>
      </subcut>
      <intram>
         <ptx>325 149 41</ptx>
         <ptx>326 148 40</ptx>
         <ptx>327 148 40</ptx>
         (...)
         <ptx>330 148 37</ptx>
         <ptx>331 148 36</ptx>
         <ptx>332 147 35</ptx>
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         <ptx>192.465 122.4121 17.3569</ptx>
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         <ptx>194.1463 123.7704 18.1086</ptx>
```

Figure 5.3: Example of a XML file containing the file tags and patient information.

5.3 3D Model

The second step of BREAST FLAPPAR's pipeline is to generate a 3D model. In the section above, we explained how we can obtain the XML file containing all the important information regarding the patient's anatomy for the surgery. In this section, we will explain in detail how we generate the 3D model that will be used as input for the AR systems.

5.3.1 Parser

The first step to obtain the 3D model is to convert our input information into 3D data. To achieve this, we developed a parser using the widely known python programming language, particularly python 3.7.5. To parse the XML file, we also used the xml.etree.ElementTree API. This parser starts by separating the data using the XML tags within the file, allowing the parser to generate specific meshes for each object. Each XML code line inside a tag is then converted into a point within a specific 3D mesh, which generates a complete 3D object (which represents a part of the patient's anatomy) when the parser reads the closing tag. To ensure that our output 3D file is widely accepted by 3D softwares and the community itself, we decided to use Wavefront .OBJ files. Besides the fact that these types of files are widely accepted and recognized, they are used specifically to define 3D geometries, while allowing users to describe an unlimited number of colors and geometries within the same file.

A python script was also created to define the umbilicus as the center of the model. The AVAOFF's XML output file defines the origin of the data as a point of the patient's anatomy that is not easy to detect using only the human eye. We decided to perform this translation in order to facilitate the calibration of the AR systems described in the next sections, but also to visualize and rotate the model effortlessly.

5.3.2 Blender

After the 3D model is created, it is important to analyze it. To do so, we have chosen Blender as our favored 3D graphics software, particularly Blender 2.91.2. Blender is a widely used 3D open-source software, which supports the most common operative systems currently in the market. Beyond its powerful capabilities regarding 3D manipulation, this software contains many options when it comes to import/-export. Since most of BREAST FLAPPAR's AR systems need different types of input data, we decided that Blender was the best platform to manipulate our 3D data after the output of the parser. In this application, we verify and analyze the model to ensure there are no errors in the model. Some manual adjustments are also made to increase the visualization quality. These adjustments mainly focus on increasing the perforator's radius and are made to ensure that regardless of the AR system used, the roughly 2mm wide perforators are visible to the human eye. Even though the colors are defined in the .OBJ file in Blender, it is also possible to change the colors of a specific mesh/object or even change its properties. This possibility allows our 3D model to adapt to each surgical team in case they have a specific request.

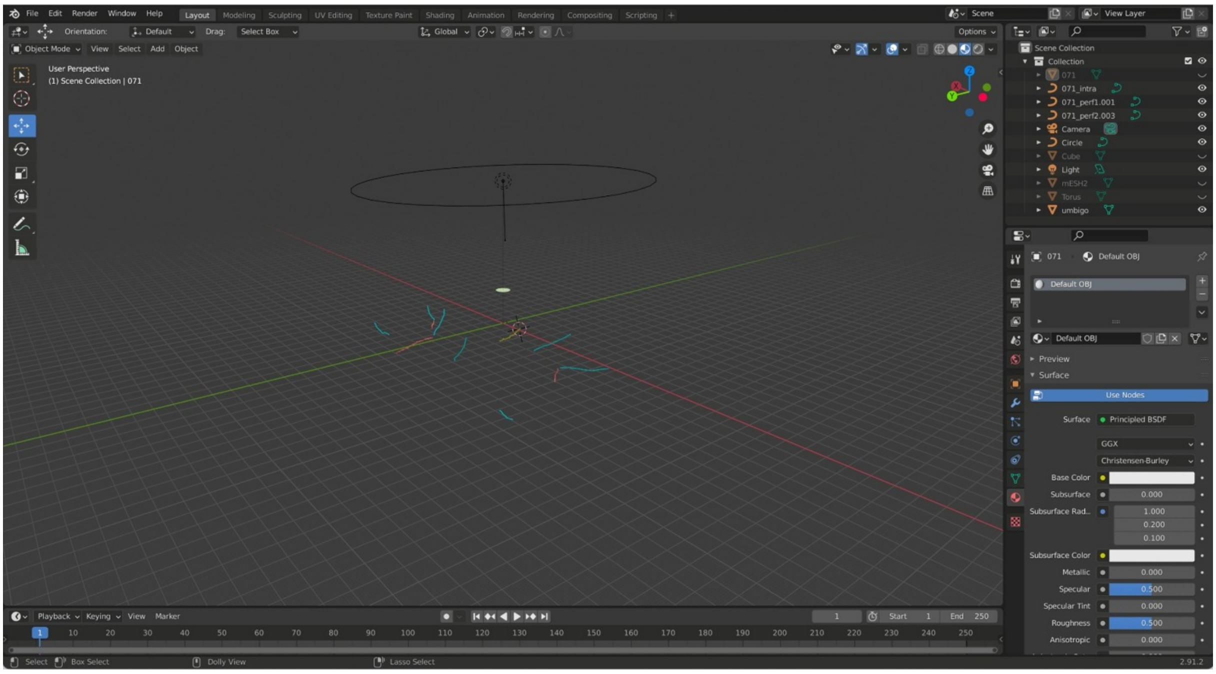


Figure 5.4: Blender dashboard during the 3D model's manual adjustments.

In Blender, some specific adjustments for each AR system were also made. When it comes to the OST-AR and the Mobile-AR system, a merger between our model and the patient's surface scan is needed. This process can also be done using Blender, which allows us to effortlessly align the two models (Fig. 5.5). For the SAR system, we first manipulate the lights to ensure that the model is effortlessly visible from the Z-axis. After making sure this visualization is optimized, we obtain a two-dimensional image from the Z-axis, perfectly aligned with the patient's umbilicus. In Fig. 5.4, we can observe Blender's dashboard during the final adjustments of the development of the SAR visualization. In the following sections, we will explain in detail how these processes are made using Blender and how these allow the model to adapt to each AR system's needs.

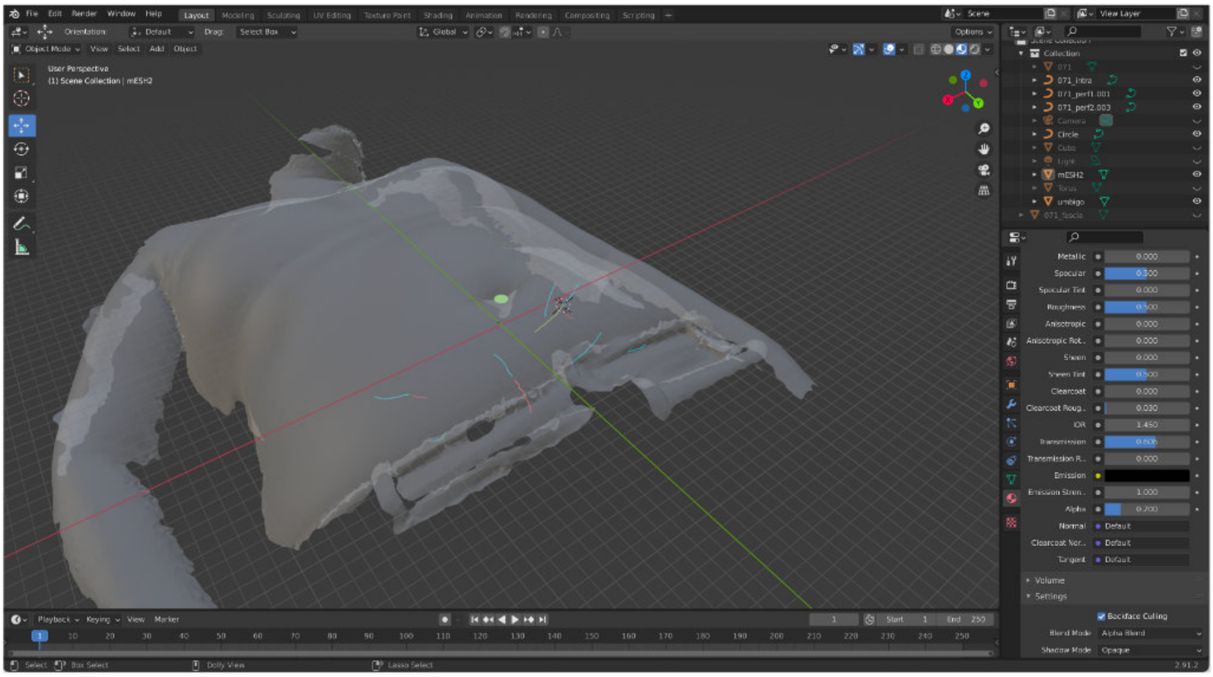


Figure 5.5: Blender dashboard with the 3D model merged with the surface scan.

5.3.3 Visualization & Data encoding

After completing the steps described above, the final 3D model is obtained, which will be used as input to all AR systems within BREAST FLAPPAR. This model contains a visualization composed of different elements, allowing healthcare professionals to analyze this information efficiently and effectively.

The visualization of the 3D model contains the following elements:

- Abdomen;
- Umbilicus;
- Perforators containing both the intramuscular and subcutaneous course.

The abdomen element in this visualization allows the users to visualize the external anatomy of the patient, and compare it with internal elements such as perforators. Furthermore, this element is also important for calibration purposes and for generating specific elements to a specific visualization (e.g. obtaining the silhouette lines for the SAR system's visualization).

The umbilicus allows users to locate this anatomy part, as well as the center of the visualization's coordinate system. This element is also crucial when it comes to the calibration of the AR systems as it represents the center of the visualization and is an easy-finding anatomy element in the patient.

Finally, the most important elements within this visualization are the perforators. These elements contain the location of the perforators, caliber, and the intramuscular and subcutaneous courses. To instantaneously separate these elements and identify the most important perforators to the surgery, the respective data was smartly encoded according to Table 5.1.

Table 5.1: Color assignment for each perforator and course.

Color	Caliber	Placement	Course
Blue	> 2mm	Below umbilical line	Subcutaneous
Yellow	≤ 2mm	Below or Above umbilical line	Subcutaneous
Red	-	-	Intramuscular

As we can observe in Table 5.1, the color encoding allows professionals to understand the most important perforators, identified with the color blue, which are the ones with a caliber greater than 2mm and that are placed below the umbilicus line. The perforators which do not fulfill the requirements are identified with the color yellow. Finally, the color red is used to identify the intramuscular course, allowing users to analyze the courses of each perforator.

5.4 SAR System

5.4.1 Overview

The first AR system within BREAST FLAPPAR that we will explore in this work is the SAR system. The SAR system developed is a revolutionary system made to be used inside the OR during a breast reconstruction procedure. By projecting a well-thought visualization on top of the patient's abdomen, the surgical team is able to obtain an enhanced visualization containing information regarding the patient's anatomy, particularly the patient's perforators.

By directly comparing the three AR systems within BREAST FLAPPAR, it is clear that the SAR system contains some clear advantages when it comes to visualization accessibility. Instead of limiting the visualization to the person who is holding or manipulating the specific device, with the SAR system, the surgical team, and any other individual present in the OR will be able to visualize the information displayed on the patient's abdomen. We believe this feature also increases communication between the team members present in the surgery since it ensures that everyone is accessing the same information simultaneously.

This system projects a previously captured image of the 3D model previously described which simulates a three-dimensional visualization obtained from above, more specifically directly above the umbilicus, which represents the origin of our coordinate system. When it comes to hardware, this system only requires a projector and an input source.

5.4.2 Calibration

During the development of BREAST FLAPPAR, we aimed at creating simple yet powerful systems that always focus on the user. When it comes to calibration, this goal also applies since we have aimed at creating a simple, intuitive, and fast calibration process that does not interfere with the surgery. Following these ideas, the SAR system contains simple calibration process. The visualization projected by the system contains two key elements to the calibration process. These elements are:

- A circle representing the umbilicus;
- Two curved lines representing the patient's silhouette.

To calibrate, the user simply needs to position the circle projected on top of the patient's umbilicus and align the curved lines with the patient's silhouette. By doing this, the system ensures that both the positioning and the depth of the projection are perfectly aligned with the patient. These elements allow professionals to intuitively understand how to align the visualization with the patient's body, but also to re-align during surgery if needed.

5.4.3 Visualization

The basis for the SAR system's visualization is the 3D model described above. In order to translate a three-dimensional visualization into a two-dimensional image that the projector is able to receive as input, a two-dimensional image is captured directly from the 3D model of the patient's anatomy. To obtain this image, we use Blender. This software allows us to insert a camera in the 3D model, specifically an orthographic camera, and define its position. In this particular case, we defined the camera's position as perfectly aligned with the center of our coordinate system (the patient's umbilicus), directly from above.

After the camera is positioned and the appropriate lights are added to the model, the image can then be rendered by the software, and then exported into a .png with transparent background. In Fig. 5.6, we can observe an example of the image obtained after this process. The image obtained contains:

- Perforator's location and course, both intracutaneous and intramuscular;

- Location and representation of the umbilicus;
- Representation of the patient's silhouette;
- Small circles placed in each perforator to allow the surgeon to visualize where each element perforates the skin.

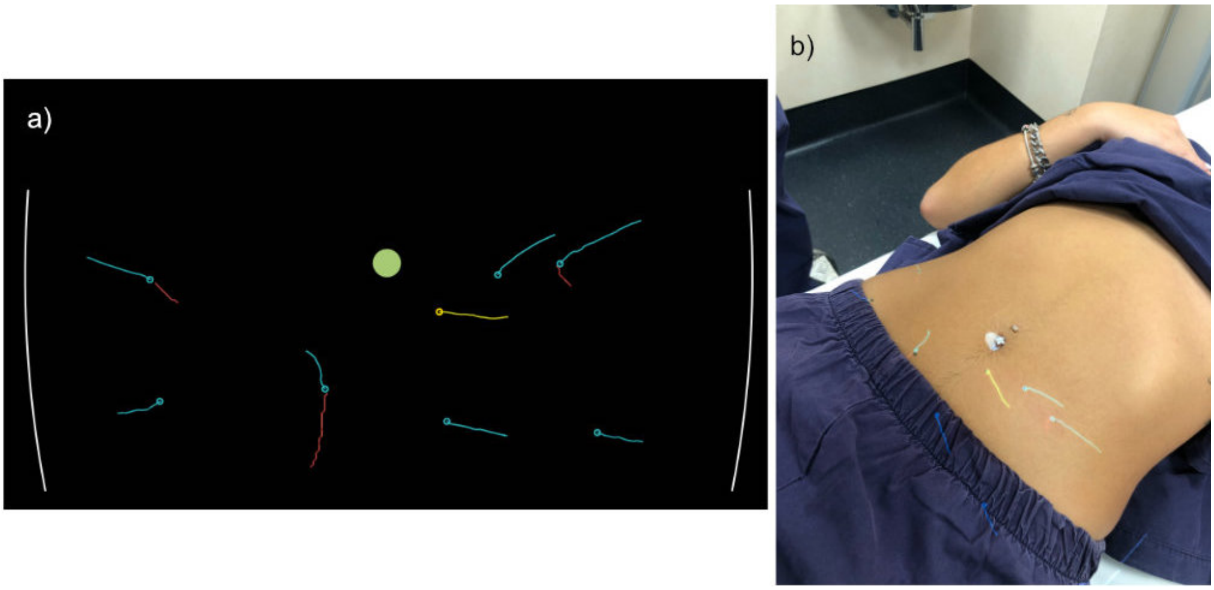


Figure 5.6: (a) SAR system's visualization; **(b)** System's projection on top of a simulated patient's abdomen.

5.4.4 Setup

By adding a projector in the OR, the system will be able to present the relevant information to the team of surgeons in a matter of seconds, eliminating the need for the time-consuming manual annotation task performed by surgeons and significantly reduce surgery time. With these steps, we can achieve a semi-automatic pipeline that significantly reduces the time and number of tasks needed to perform the surgery when compared to the current model. For our system, and during the user study explained in the next chapter, we used Philips PicoPix PPX3414 due to the high portability and high brightness that this device offers.

5.5 Mobile-AR Application

5.5.1 Overview

BREAST FLAPPAR's Mobile-AR system consists of an iOS app that allows healthcare professionals to analyze the patient's anatomy and important surgery information using only a smartphone, particularly, an iPhone. While comparing this app with the other AR systems within BREAST FLAPPAR, we are able to understand that some advantages arise from its use. These advantages are as follows:

- The system can be used not only in the OR but also during the preoperative process;
- No special hardware is needed, as it can be used with an everyday smartphone that you can carry in your pocket;
- An almost instantaneously calibration that can be made on top of any flat surface or even on top of the patient's abdomen during surgery.

The portability of such a system should be valued since we are allowing professionals to prepare for a complicated surgery without the need for a special room or advanced equipment. By using this system, the team is able to perform the preoperative process in an innovative way. They are able to simultaneously be in any comfortable place chosen by them and still possess all the equipment needed for this process. Furthermore, this system ensures that the team visualizes the same information as their peers, leading to an increase in communication between the team members.

In the next subsections, we will explore the details of this Mobile-AR application.

5.5.2 Calibration

The Mobile-AR app within BREAST FLAPPAR contains automatic calibration. To develop this feature within our Mobile-AR app, we used Apple's World Tracking feature [47]. This feature, just like any AR system, creates and tracks a correspondence between the real world and a virtual scene, allowing the user to visualize simultaneously both contents by simply using the output of the smartphone's camera. To ensure the best calibration possible, World Tracking also analyses the user surroundings using ray-casting, which in this particular case detects flat surfaces from the camera's output and calculates the surfaces' position and sizing. This also allows users to place and interact with virtual content in the visualized scene. It is also important to mention that once the user launches the app, the user will visualize on the smartphone's screen a message saying "Move iPhone to start", as well as an animation of an iPhone moving (Fig. 5.7). After a surface is found, this message will disappear, and the visualization will start automatically.

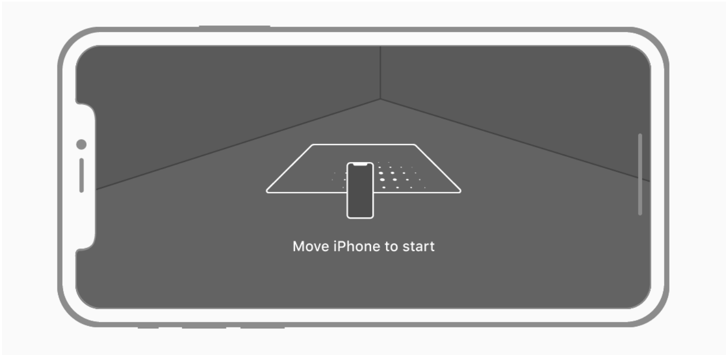


Figure 5.7: iPhone's screen visualization during the calibration process [16].

The result of this process allows healthcare professionals to calibrate this AR system by simply opening the app, moving the smartphone until a flat surface is detected by the algorithm, and the virtual scene will automatically merge with the real world scene within seconds. This feature available in our Mobile-AR system allows users to, in a matter of seconds, calibrate effortlessly the AR system, and focus on the analysis of the data visualized.

5.5.3 Visualization

The visualization present in this system is the result of a merging process between our 3D model, and a patient's surface scan. This model allows users to intuitively visualize the patient's anatomy and the most important information for a breast reconstruction surgery using DIEPs. Instead of representing the patient's 3D information in a two-dimensional way like the SAR system, the Mobile-AR system allows the visualization of the information in an immersive way.

This visualization (Fig. 5.8) contains two modes. In the first mode, the user is able to visualize the patient's stomach, as well as the perforators and umbilicus. To facilitate the analyses of the perforators, the user can switch to the second mode, which eliminates the patient's stomach and allows the user to analyze the most important information for the surgery - the perforators. To switch between the two modes, the user can simply tap on the 3D model using the smartphone's screen and the application will instantaneously switch to the other mode. This process is available after the calibration is completed and can be done as many times as the user desires.

5.5.4 Setup

As explained at the beginning of this section, this is the system that requires the least equipment or appropriate setup from all the three systems within BREAST FLAPPAR. In order to fully take advantage of the Mobile-AR app capabilities, the system requires:

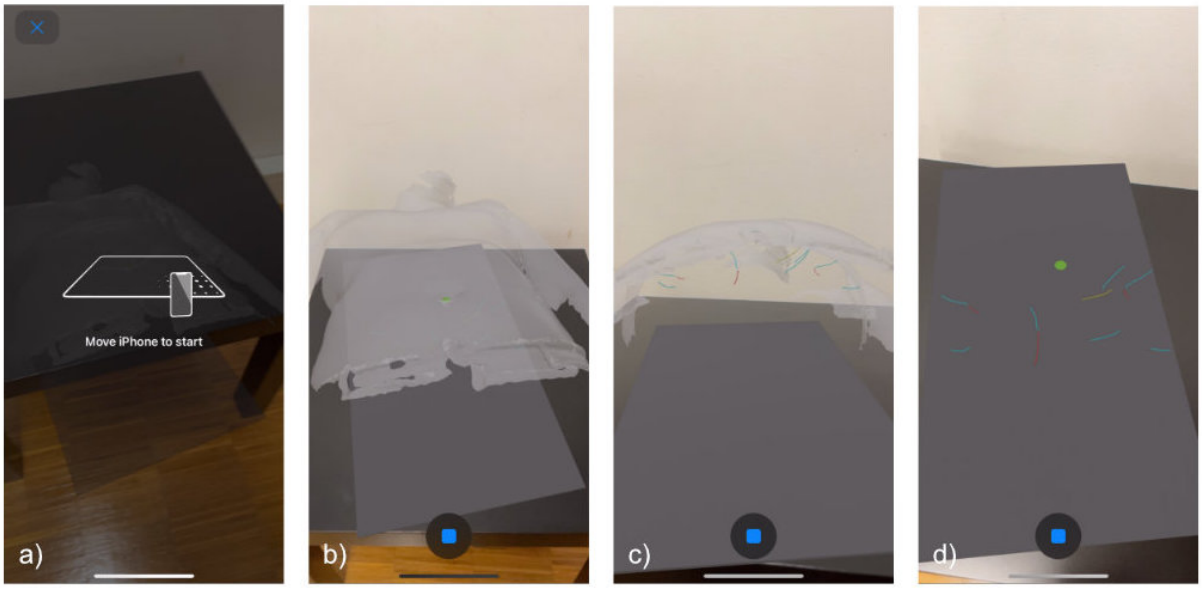


Figure 5.8: Visualization of the Mobile-AR system in: **(a)** Calibration process; **(b)**/**(c)** First mode - Surface scan + 3D model; **(d)** Second mode - Only 3D model

- An iPhone 6S (or more recent), or an iPad with back camera;
- iOS 11 (or more recent);
- A flat surface, or the patient's abdomen;
- A well-lit room.

Even though this system carries few and simple requirements, they are crucial to its proper functioning. It is also important to mention that in some cases where the requirements are not fulfilled, the system might present some erroneous behavior. If the real-world scene is not well lit, the user will be able to launch and use the application, but in some cases, some anchoring problems might arise, which leads to a harder and less pleasant data analysis. If the user has almost no light in the real-world scene, or if there are no flat surfaces with appropriate sizing for anchoring the virtual scene, the system might not complete the calibration process.

By having all four requirements, the user will be provided with a hassle-free experience from calibration to the end of the visualization. By launching the app, and by completing the automatic calibration system, the user will be able to take full advantage of this system's capabilities in a matter of seconds.

5.6 OST-AR System

5.6.1 Overview

The final AR system within BREAST FLAPPAR is the OST-AR system - an AR system made for surgeons to use during breast reconstruction surgery using DIEPs. Similarly to the other AR systems developed in this work, the visualization heavily relies on the 3D model explained above. To achieve the best possible outcome and for calibration enhancements, a 3D surface scan is also part of the data visualized in this system. Healthcare professionals use a 3D scanner to obtain a 3D surface scan of the patient's body during the pre-operative process, containing the patient's body between the neck and the hip line. This data is then merged into the already developed 3D model, allowing us to achieve a final 3D model (Fig. 5.9) containing detailed information about the patient's perforators, umbilicus, and a virtual body of the patient. It is also important to mention that the merging process between both models is made using Blender, which is currently one of the leading open-source tools when it comes to 3D computer graphics software.

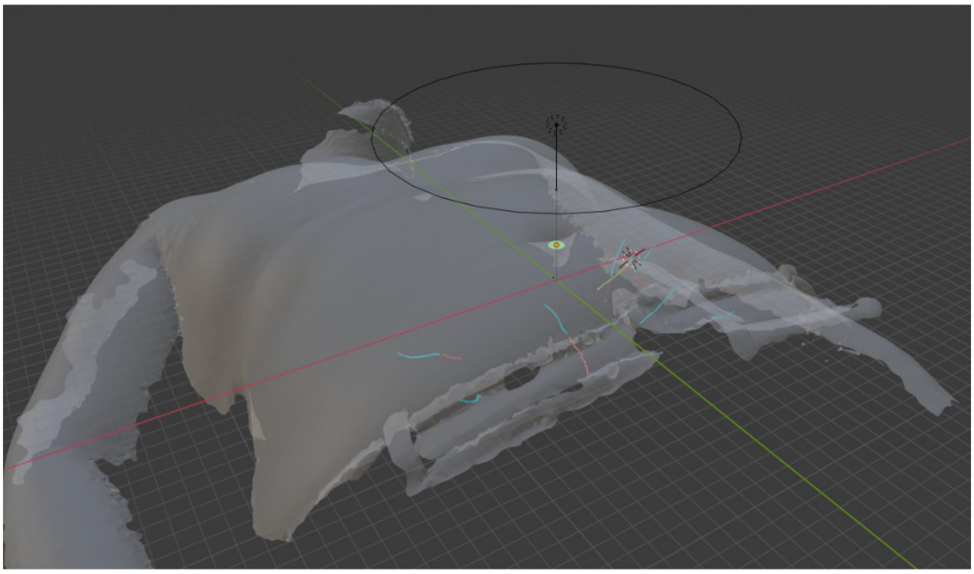


Figure 5.9: Result of the merging process between the 3D model and the surface scan, and example of the OST-AR system's visualization.

During surgery, this system should be used by the surgeon as it provides a hands-free visualization that does not interfere with the normal surgery processes and tasks. Furthermore, after the calibration process is completed, the surgeon will be able to visualize the information three-dimensionally anchored to the patient's body. This represents one major difference when compared to the SAR system. The SAR system allows the surgical team to visualize the information from above. The OST-AR system, besides allowing the surgeon to visualize the information from above, also allows three-dimensional visualization of the data, leading to an increase when it comes to accessibility of the information displayed. Regarding a direct comparison between the OST-AR system and the Mobile-AR app, some advantages also arise such as a hands-free environment, and a much bigger field of view, since the visualization is not restricted to the size of the smartphone's screen.

In the next subsections, further details of this system will be explained, as well as the importance of the 3D surface scan during the calibration process.

5.6.2 Calibration

The OST-AR system, similarly to the other systems within BREAST FLAPPAR, contains a simple calibration process. When the program is launched on your smartphone, the final 3D model of the patient will instantaneously appear. After this model appears, the user needs to align the model with the patient, which should be done by aligning the virtual body displayed in the headset, with the patient's real body. To move the model, the surgeon can manipulate its position and rotation using the touchscreen on the smartphone. After the alignment between the model and the patient is completed, the model will be anchored in that position throughout the surgery. The final step in this process is to place the smartphone inside the headset and the visualization will appear instantaneously. It is also important to mention that the position of the patient during surgery and the collection of the 3D surface scan's data is the same, which assures a perfect alignment between both during surgery.

5.6.3 Visualization

The OST-AR system provides the user with a complete three-dimensional visualization of the 3D model merged with the surface scan, while being a hands-free device. Just like the SAR and Mobile-AR systems, this visualization allows healthcare professionals to visualize and obtain information regarding the patient's perforators, such as location, caliber, intramuscular course, and others, but also the location of the umbilicus, all in a fast and intuitive way, providing an effective and efficient analysis of the visualized data. Furthermore, this system also allows the users to visualize the output of the 3D surface scan. This allows professionals to visualize a virtual representation of a specific part of the patient's body, three-dimensionally, particularly between the neck and hip line.

5.6.4 Setup

For the OST-AR system, we decided to use the Aryzon original headset - an affordable option that removes the price barrier when it comes to the adoption of such a system within medicine. The competitors of Aryzon are mainly Microsoft's HoloLens and Magicleap, both carrying a significantly higher price tag, which increases the difficulty of adoption of an OST-AR system within medicine. Furthermore,

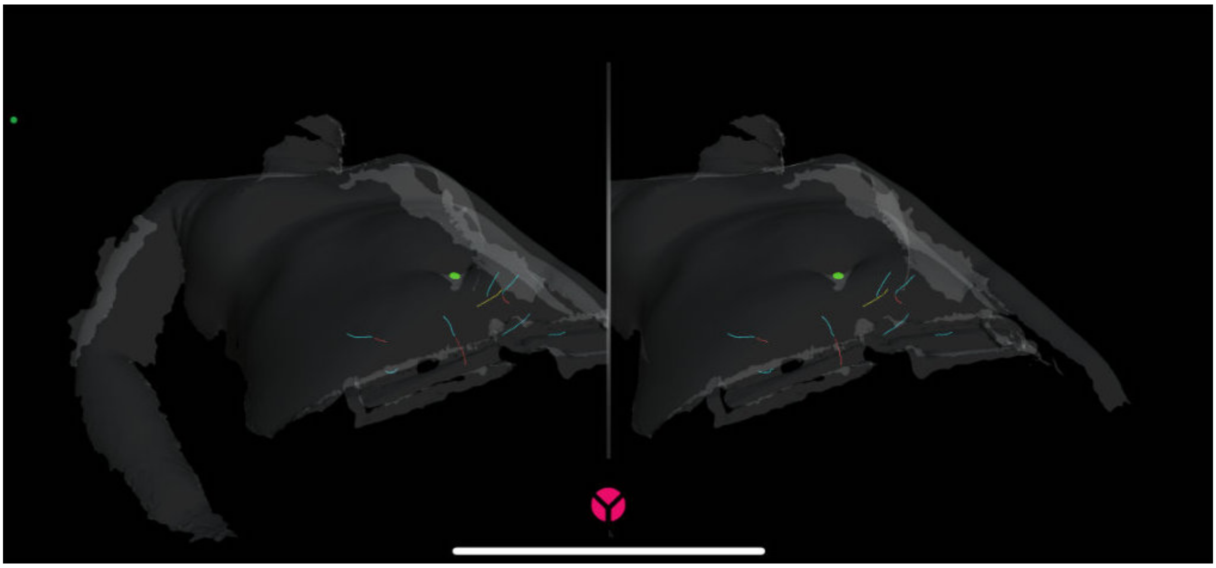


Figure 5.10: Smartphone's visualization after being placed inside the Aryzon's HMD.

this headset is small, light-weighted and comfortable, allowing the users to wear it for long periods of time. Since this system was developed to be used during surgery, and both the visualization and the surgery will take place on the patient's abdomen, it would not be possible to use AR targets to anchor the scene. Fortunately, this system gives the user the possibility to calibrate the system using a marker-less calibration process using the Aryzon AR studio app. Lastly, this system also requires a smartphone running iOS or Android. Aryzon's application is made for iOS 11.0 or higher and Android 7.0 or higher, supporting a wide range of smartphones in the market.

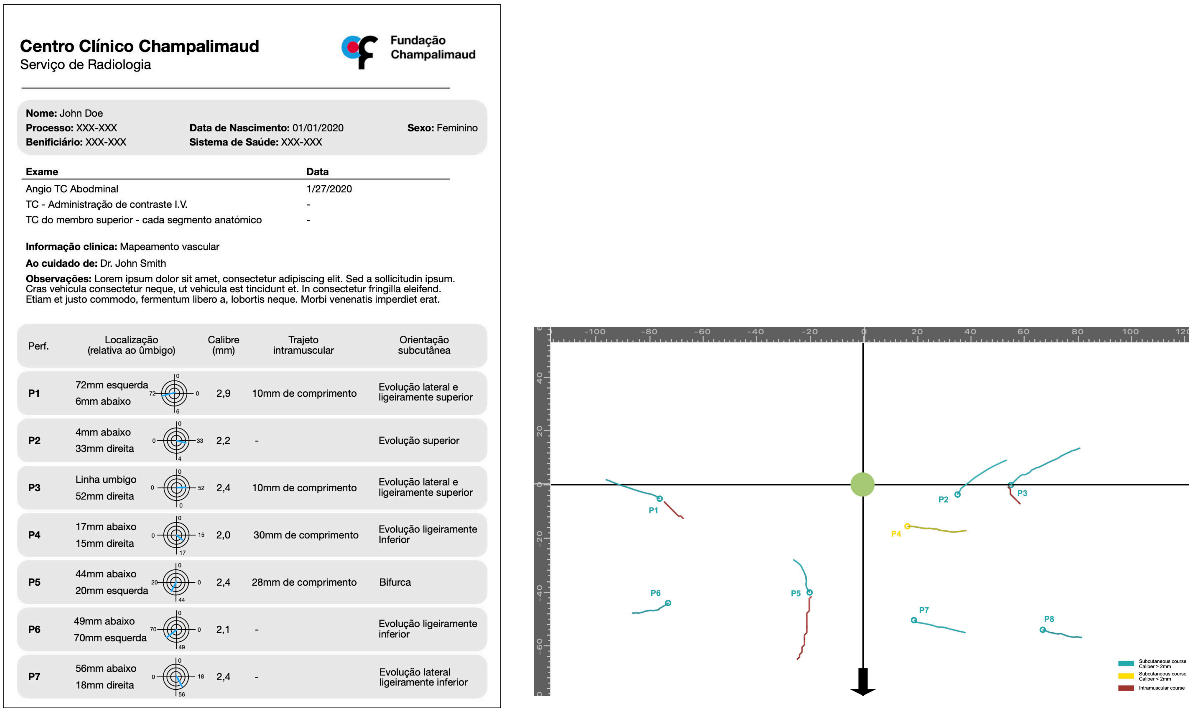
The combination of these specific characteristics led us to choose this device as the basis for our OST-AR system. The technological advancements present in this relatively small device allowed us to develop our system and achieve positive results.

5.7 Report & Data Visualization

5.7.1 Report

To ensure an alignment between the report used in the preoperative and intraoperative processes with the new AR systems, we created a new version of the report that makes it more efficient to analyze and extract information, as well as add new information visualized in the AR systems, creating a seamless interpretation experience between both. On our report (Fig. 5.11) we started by eliminating all the information collected from manual tasks, since our goal is to create a semi-automatic experience with these systems. Data is encoded using the most appropriate tool within the information visualization spectrum to enhance the effectiveness of the professionals' analysis.

The first iteration of this process consists of redesigning the data table with the location and information of the points (perforators), with special focus on increasing the separation between each line of the table to enhance readability. Following the same logic applied while developing the data table, light grey background containers and horizontal lines were added throughout the report to separate different sections. For spatial data, in particular points' location, we developed a small glyph in the table that will provide professionals with a glimpse of the location at each point. We aimed at increasing the understanding of the spatial data represented in the table while enhancing the search for the most important perforators to use during surgery. Finally, a representation of the system's visualization in a 1:1 scale was added in the last page, allowing professionals to analyze the information prior to the system's calibration.



Centro Clínico Champalimaud
Serviço de Radiologia

Fundação Champalimaud

Nome: John Doe
Processo: XXX-XXX **Data de Nascimento:** 01/01/2020 **Sexo:** Feminino
Benificiário: XXX-XXX **Sistema de Saúde:** XXX-XXX

Exame	Data
Angio TC Abodminal	1/27/2020
TC - Administração de contraste I.V.	-
TC do membro superior - cada segmento anatómico	-

Informação clinica: Mapeamento vascular
Ao cuidado de: Dr. John Smith
Observações: Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed a sollicitudin ipsum. Cras vehicula consectetur neque, ut vehicula est tincidunt et. In consectetur fringilla eleifend. Etiam et justo commodo, fermentum libero a, lobortis neque. Morbi venenatis imperdiet erat.

Perf.	Localização (relativa ao úmbigo)	Calibre (mm)	Trajeto intramuscular	Orientação subcutânea
P1	72mm esquerda 6mm abaixo	2,9	10mm de comprimento	Evolução lateral e ligeiramente superior
P2	4mm abaixo 33mm direita	2,2	-	Evolução superior
P3	Linha umbigo 52mm direita	2,4	10mm de comprimento	Evolução lateral e ligeiramente superior
P4	17mm abaixo 15mm direita	2,0	30mm de comprimento	Evolução ligeiramente Inferior
P5	44mm abaixo 20mm esquerda	2,4	28mm de comprimento	Bifurca
P6	49mm abaixo 70mm esquerda	2,1	-	Evolução ligeiramente inferior
P7	56mm abaixo 18mm direita	2,4	-	Evolução lateral ligeiramente inferior

Figure 5.11: Final report prototype.

5.7.2 Data Visualization

As explained above, we strongly believe that the OR's screens should display information tailor-made for these screens, instead of displaying an A4 PDF file or a smartphone photo. By optimizing such displays, professionals would be able to obtain information about the surgery more quickly and accurately than before. Furthermore, we also believe that such visualization would increase communication between professionals and would assure that all the professionals analyze this information which is crucial to the surgery.

Following these ideas, we decided to create a data visualization especially tailor-made for these screens. To achieve this, instead of starting with a blank page, we use the report as a basis for this visualization to ensure the coherence between both the report and the screens' visualization. All the data used and steps followed for the report were also used/made while developing this visualization. With this, healthcare professionals are able to visualize simultaneously both the report and the screens effortlessly, since all the graphical elements and data encodings are the same.

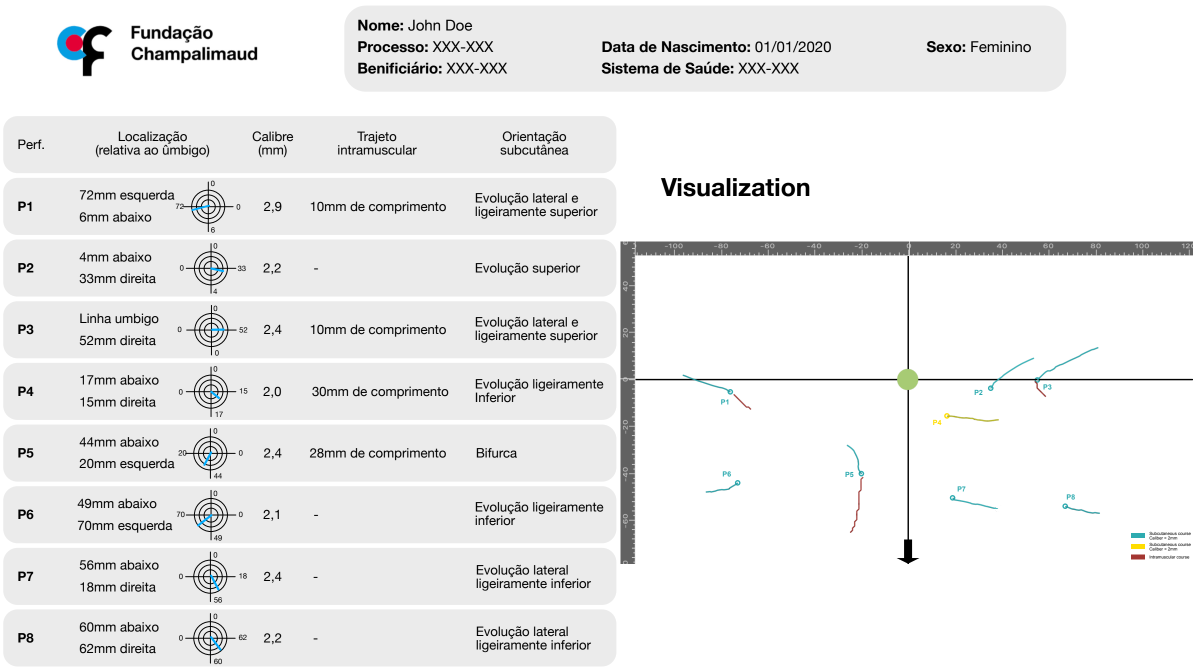


Figure 5.12: Final prototype for the data visualization displayed in the OR screens.

This visualization is composed by:

- A header containing the patient's information;
- A data table containing the perforators (rows) and the perforators' specific information (columns);
- A data glyph in each row of the data table, that allows visualizing the broad localization of each perforator in an abstract way;
- The visualization in two dimensions of what the AR systems will display, in particular, the SAR system.

In Fig. 5.12 we can observe the final result of this iterative process. As we can see, all information and data encodings present in the report are also displayed in this visualization. Furthermore, by comparing both elements, we can see the graphical similarities between them and how easy it is to analyze information using both visualizations simultaneously.

6

Results & Discussion

Contents

6.1 Overview

After the development of BREAST FLAPPAR, we decided to conduct a user study to understand if the proposed ecosystem can enhance the pre-operative and intraoperative space. In this study, the main goal is to verify how helpful our work is regarding breast reconstruction surgery using DIEPs. This study is separated into two different phases, with the first one focusing on the pre-operative elements of our ecosystem, i.e. the report re-design and the Mobile-AR system, and was conducted during a pre-operative process using real patient's data. In this phase, we asked the users to perform some normal activities of this process using the elements within BREAST FLAPPAR developed for this purpose. After the users concluded this process, they were asked to fill in a satisfaction questionnaire, as well as answering open questions regarding their experience during a semi-structured interview. The second phase focuses on the surgery, where the remaining elements of our work were tested, namely the visualization developed for the OR screens, the SAR system, and the OST-AR system. This phase was conducted during a simulated surgery with the same data used in the pre-operative study phase. Similar to the initial phase, we asked participants to perform specific tasks, and after the conclusion of these tasks, they were asked to fill in a satisfaction questionnaire and answer some open questions during a semi-structured interview as well. In this study, we mainly focused on gathering qualitative data given that, in some elements, it is not possible to obtain the accuracy and precision values to conduct a significant quantitative study. Furthermore, since the participants in this study are surgeons with a vast experience in this area, the number of participants was low and not enough to perform a significant statistical analysis.

To ensure the quality of our study, a pilot study was conducted where the same protocol was used and took place in a simulated office and OR for each phase of the study. This pilot study was conducted with a male plastic surgeon with 22 years of experience in breast reconstruction surgery and a female nurse with 2 years of experience with breast reconstruction surgery. In the next sections, we will further explain this study, detailing how both phases were conducted and analyzing the results.

6.2 Participants

This study was conducted with 7 specialists with high experience when it comes to this surgery, being 71,4% male and 28,6% female. The participants have backgrounds in general surgery and plastic surgery, with a range of years between 5 and 29 years in their expertise. All of the participants have experience with breast reconstruction surgery, with, on average, 13 years of experience, having participated in over twenty surgeries. Regarding breast reconstruction using DIEPs all the participants have experience in this type of surgery, having on average eight and half years of experience, where 71,4% has participated in over twenty surgeries, and 28,6% on less than ten surgeries of this kind. Regarding the users' experience with AR, 28,6% have experience with Mobile-AR, 42,9% with OST-AR, and 28,6% with SAR. The rest of the participants do not have experience with AR. Furthermore, 2 users (28,6%) have experience with OST-AR in pre-operative processes, and 1 participant (14,3%) has experience with OST-AR during an intraoperative process. The remaining participants do not have experience with AR in pre-operative or intraoperative processes.

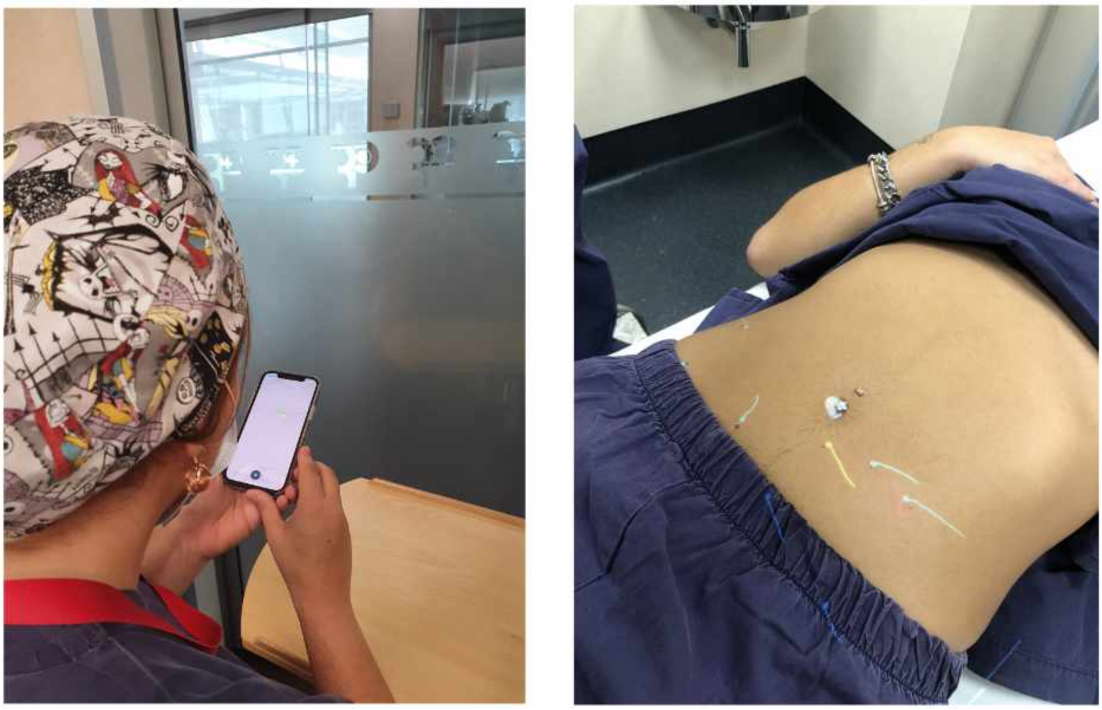


Figure 6.1: Participants performing tasks using the Mobile-AR system and the SAR system during our user study.

6.3 Phase one - Pre-operative

6.3.1 Apparatus

The first phase of this study was conducted in an office in Fundação Champalimaud. The setup of this study contains the old and new report, a smartphone running BREAST FLAPPAR's Mobile-AR app, and a flat surface to anchor the AR scene.

6.3.2 Tasks

In this particular phase of our study, we asked participants to independently complete two different tasks. By doing so, we assured that we obtained the best feedback possible and guaranteed that there were no bias in the feedback received. The first task consisted of identifying the most important perforator(s) to the surgery using both reports. The participants were randomly assigned a report to analyze on a first step, later changing the reports between them. This task allowed the users to directly compare both reports with the same data, and understand the differences within the new re-designed report. The second task consisted of identifying the most important perforators using our Mobile-AR system. Surgeons usually complete the pre-operative process without the aid of a three-dimensional visualization. In this particular task, they were asked to do this using only an enhanced visualization developed for this particular purpose.

Interpretation and usage errors during both these tasks were recorded to verify the viability of the elements tested in this phase.

6.3.3 Procedure

Prior to the execution of this study, a protocol was prepared represented in Fig. 6.2.

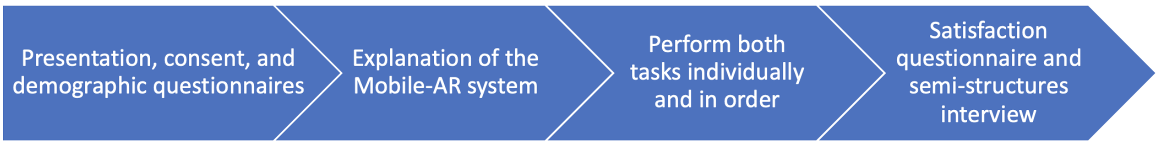


Figure 6.2: Representation of the protocol used on the first phase of our user study

The session started with a presentation of the objectives and purpose of our work and study conducted. After this information, we asked our participants to fill our informed consent form as well as our demographic questionnaire form, which can be consulted on Appendix A. Before performing the required tasks, a brief explanation of how to use and calibrate the Mobile-AR system was made. A random distribution of the reports was also made to assure the quality of the feedback. After completing these steps, the participants were asked to complete both tasks individually and in order, i.e. task one followed by task two. During the completion of these tasks, all comments and observations made by the users were registered. When the participants finished both of the tasks requested, we asked them to fill a Satisfaction questionnaire (Appendix B) regarding both elements tested in this phase. The questions present in the form were separated into two sections - one for the report and one for the Mobile-AR - and can be visualized in Table 6.1 and 6.2. To answer these questions, a 6-level Likert scale was used, allowing us to effectively compare and combine qualitative data gathered with techniques such as participant observation sessions, and semi-structured interviews [48].

Lastly, a semi-structured interview with each of the participants was conducted, allowing us to obtain further feedback from the participants. During the interviews, the responses to the questions made and

Table 6.1: Questions used to evaluate the Report in the satisfaction questionnaire

Regarding the Report prototype presented, I considered that...
It contains the most important information for the surgery and its preparation
It allows to identify the necessary information quickly
It is useful to analyze this information as a complement to the AR systems
It is easy to analyze the data
It is useful to the pre-operative process
It is useful to the surgery
It is useful to increase communication between the team members

Table 6.2: Questions used to evaluate the Mobile-AR system in the satisfaction questionnaire

Regarding the Mobile-AR system prototype presented, I considered that...
It contains the most important anatomical elements for the surgery and its preparation
It allows users to identify anatomical elements
It is useful when analyzing the anatomy particularly the perforators
It is easy to use
It is easy to learn how to use the system
It is useful to the pre-operative process
It is useful to increase communication between the team members

represented in Table 6.3 were recorded.

Table 6.3: Open questions used during the semi-structured interview (Phase 1)

Report
In your opinion what are the positive and negative aspects of the new report?
In this report, what is the most important information for the surgery or pre-operative process?
Do you consider that the new re-design helps during the information analysis within the report?
What difficulties did you have during the report's data analysis?
Given the tasks performed, what would you change in the report?
Mobile-AR
In your opinion, does BREAST FLAPPAR's pre-operative system complement the pre-operative process?
What features did you like the most within this AR system for the pre-operative process? Please explain.
What features did you like the least in this AR system for the pre-operative process? Please explain.
What difficulties have you felt while using this system?
Do you think it is possible to use this type of technologies during pre-operative processes?
If yes, how? If no, what barriers do you see?
What would you change in this system to increase the quality of the pre-operative process?

6.4 Phase two - Surgery

6.4.1 Apparatus

The second phase of this study was conducted in a simulated OR in Fundação Champalimaud and can be visualized in Fig. 6.3. To assure the conditions were as similar as possible to those of an OR, we used a nursing room containing some of the elements present in an OR, and added others such as a screen. The lighting conditions in the room used were also similar to those of an OR. The setup of this study is composed by screens displaying the visualization made for this purpose: an Aryzon HMD with a smartphone running BREAST FLAPPAR's OST-AR system and a projector displaying the developed SAR system.

Figure 6.3: Simulated OR used in the user study.

6.4.2 Tasks

In the second phase, similarly to the first, we asked participants to perform two tasks individually. The two tasks created to test the remaining elements of BREAST FLAPPAR represent real tasks that doctors need to perform during this type of surgery. We started by randomly assigning the order of the tasks, i.e. deciding if the participant will start with the SAR or the OST-AR system. Since both tasks are very similar, this random allocation was used to ensure the quality of the feedback and metrics obtained. In the first task, each participant was asked to perform the tracing process of the points visualized in the SAR system. In the second task, the user was asked to perform the same process, this time using the OST-AR system. In both tasks, during the tracing process, the participants could and should have used

Figure 6.4: Participant using the OST-AR system to perform a task during the user study.

the visualization displayed in the OR's screens. Interpretation and usage errors during both these tasks were recorded to verify the viability of the elements tested. Furthermore, the time the participants took to perform both tasks was also recorded.

6.4.3 Procedure

Figure 6.5: Representation of the protocol used on the first phase of our user study

For this phase, a different protocol was prepared, starting with a brief explanation on the elements we were testing as well as the goal of these elements within our work and the study. This protocol is represented in Fig. 6.5. Since the participants had already filled out the informed consent and demographic questionnaires in the first phase, they were not asked to fill these forms again. Prior to the beginning of the tasks, a simple explanation about controls and calibration of both systems was made. The participants were then asked to perform both of tasks in order, and after this process was completed, they were asked to fill a satisfaction questionnaire (Table 6.4 and 6.5) regarding the elements tested in both of these tasks, using a 6-level Likert scale.

Table 6.4: Questions used to evaluate the Data Visualization in the satisfaction questionnaire

Regarding the Data Visualization prototype presented, I considered that...
It contains the most important information needed for the surgery
It allows to identify the necessary information quickly
It is useful to use this information as a complement to the AR systems
It is easy to analyze the data
It is useful to the surgery
It is useful to increase communication between the team members

Table 6.5: Questions used to evaluate the SAR and OST-AR systems in the satisfaction questionnaire

Regarding the SAR/OST-AR system prototype presented, I considered that...
It contains the most important anatomical elements for the surgery
It allows to identify anatomical elements
It is useful when analyzing the anatomy particularly the perforators
It is easy to use
It is easy to learn how to use the system
It is useful to the surgery
It is useful to increase communication between the team members

Finally, each participant took part in a semi-structured interview, allowing us to obtain further feedback and comments. The questions used during this interview are represented in Table 6.6

Table 6.6: Open questions used during the semi-structured interview (Phase 2)

Data visualization
In your opinion, what are the positive and negative aspects of this visualization? In this visualization, what is the most important information for the surgery or pre-operative process? Do you consider that this visualization complements the intraoperative space and is helpful during surgery? What difficulties did you have during the visualization's data analysis? Given the tasks performed, what would you change in the visualization?
SAR + OST-AR
In your opinion, does BREAST FLAPPAR's intraoperative systems complements the surgery space? What features did you like the most within these AR systems? Please explain. What features did you like the least in these AR systems? Please explain. What difficulties did you have while using these systems? Do you think it is possible to use this type of technologies during surgery? If yes, how? If no, what barriers do you see? What would you change in these systems to increase the quality of the surgery? In your opinion, from the 3 AR systems, which one is the most important? Why?

6.5 Results

6.5.1 Phase 1

As explained before, in the first phase of this study, we evaluated the elements created with the purpose of helping users during the pre-operative process within BREAST FLAPPAR. These elements are the report and the Mobile-AR system, which were tested with satisfaction questionnaires and a semi-structured interview. In the next sections, the results and further details of these elements will be described.

6.5.1.A Satisfaction Questionnaires

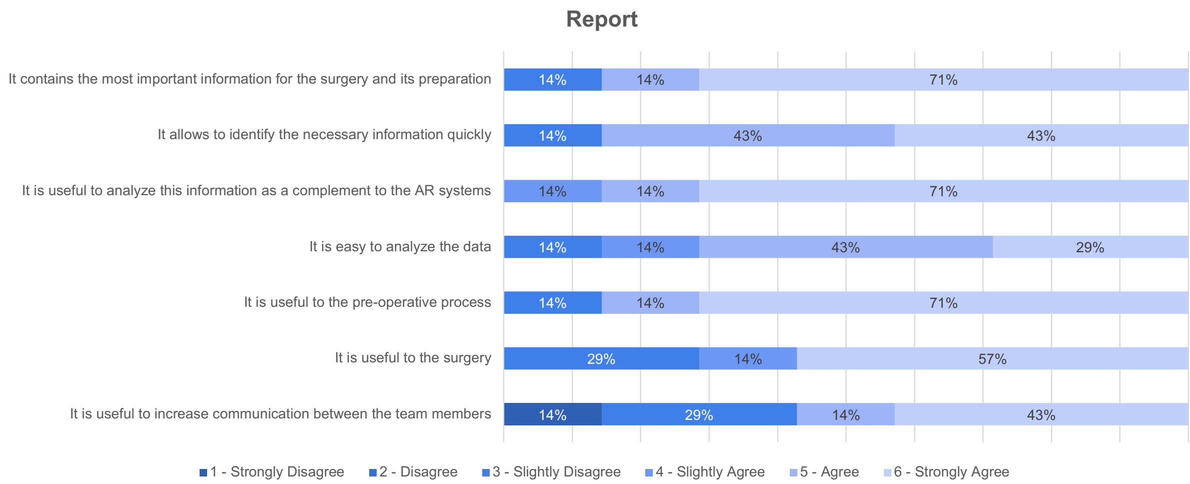


Figure 6.6: Stacked bar chart containing the answers (in percentage) for each statement presented in the report section of the pre-operative satisfaction questionnaire.

By analyzing Fig. 6.6 we can understand that the vast majority of our participants, more concretely 81.63%, answered the questions with a score of 4 and higher, meaning that they slightly agree, agree, or strongly agree with the statements presented. By analyzing both the questions presented (Table 6.1) and the participants' answers, we can infer that the new report is useful when it comes to presenting and identifying the most important information to the pre-operative and intraoperative process. Furthermore, this report also provides an easy-to-understand analysis, while also improving communication between team members. Amongst all the questions, this last one produced the most contrary opinions, with 42,8% of the participants not agreeing that the report increases the communication between team members. On the other hand, all the participants slightly agreed, agreed, or strongly agreed that this report is useful for analysing the information as a complement to the AR systems.

Regarding the Mobile-AR system, similar positive feedback was obtained with 87.76% of positive answers, meaning the participants had slightly agreed, agreed, or strongly agreed with the statements

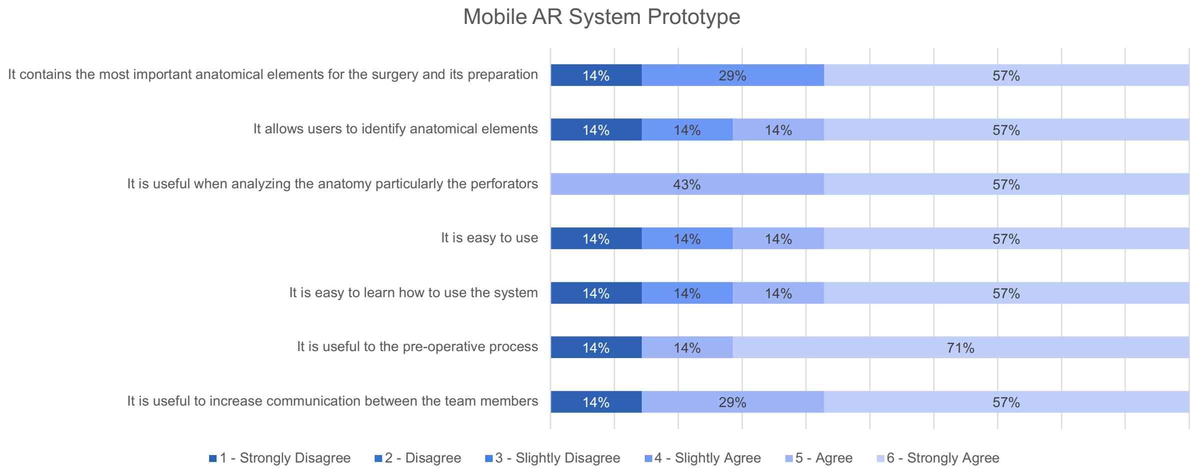


Figure 6.7: Stacked bar chart containing the answers (in percentage) for each statement presented in the Mobile-AR section of the pre-operative satisfaction questionnaire.

presented, as seen in Fig. 6.7. These answers allow us to infer that BREAST FLAPPAR's pre-operative AR system presents and allows users to identify the most important anatomical elements. Furthermore, the participants also stated that the system is useful, easy to use, quick to learn, and that it helps improving communication between team members. It is also important to mention that all the participants agreed or strongly agreed that this system is useful to analyze the patient's anatomy.

6.5.1.B Semi-Structured Interview

During the semi-structured interview, we asked participants to answer the questions in Table 6.3, allowing us to obtain feedback regarding their experience using the elements developed. The first element approached in this interview was the report. Participants stated that the new re-design is helpful mainly due to the addition of graphical elements and visual encodings. These additional elements helped participants performing the tasks quicker and more efficiently. They believed that this new re-design will help them during the pre-operative process and some participants stated that it can also be helpful during surgery. Some participants suggested some modifications regarding the data glyph presented in each row of the data table, such as changing the line to a single point and increasing the size to improve its readability. Furthermore, for the report's page containing a representation of the perforator's location, it was mentioned that it should contain the representation of the patient's silhouette, a graphical element representing the patient's head or pubis, and labels for each point in this representation.

The last topic approached in this interview was the Mobile-AR system. This system received strong compliments for how easy and helpful it is to calibrate and visualize the represented data. The possibility to visualize advanced vascular structures within seconds with just a smartphone, as well as the reduction of the time spent during the pre-operative process, represent some of the feedback obtained. Following these ideas, the participants also stated that they did not feel any difficulties using the system and that they believed this system complements, helps, and should be used during the pre-operative processes. Two participants also suggested a change in the system, particularly the addition of the patient's fascia into the 3D model visualized.

6.5.2 Phase 2

During the second phase of this study, we evaluated the elements within BREAST FLAPPAR created to aid users during the intraoperative process. These elements are the data visualization, the SAR system, and the OST-AR system, which were tested using a satisfaction questionnaire and during a semi-structured interview. In the next sections, the results and further details of these elements will be provided.

6.5.2.A Satisfaction Questionnaires

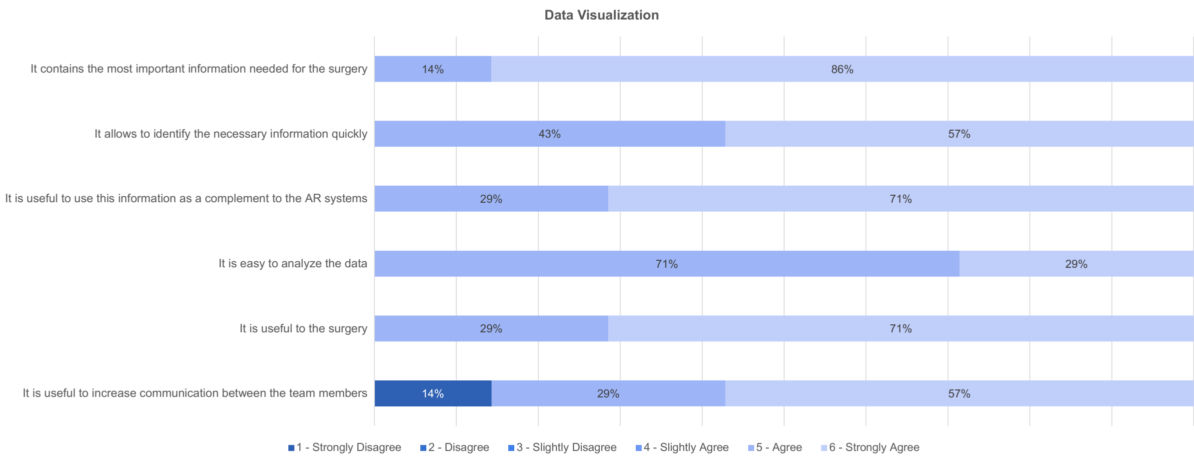


Figure 6.8: Stacked bar chart containing the answers (in percentage) for each statement presented in the data visualization section of the intraoperative satisfaction questionnaire.

The first element evaluated in our satisfaction questionnaire was the data visualization created for the OR screens. As we can observe in Fig. 5.12, the participants answered with agree, or strongly agree to every statement presented in Table 6.4, with the exception of one participant who did not agree with the last statement. These results translate into 97.62% of positive answers and allow us to conclude that this visualization is useful when it comes to representing and identifying the most important information during the intraoperative process. Furthermore, this visualization also provides an easy understanding analysis while improving the communication between team members. By comparing this element with the report, the visualization scored higher in the satisfaction questionnaire.

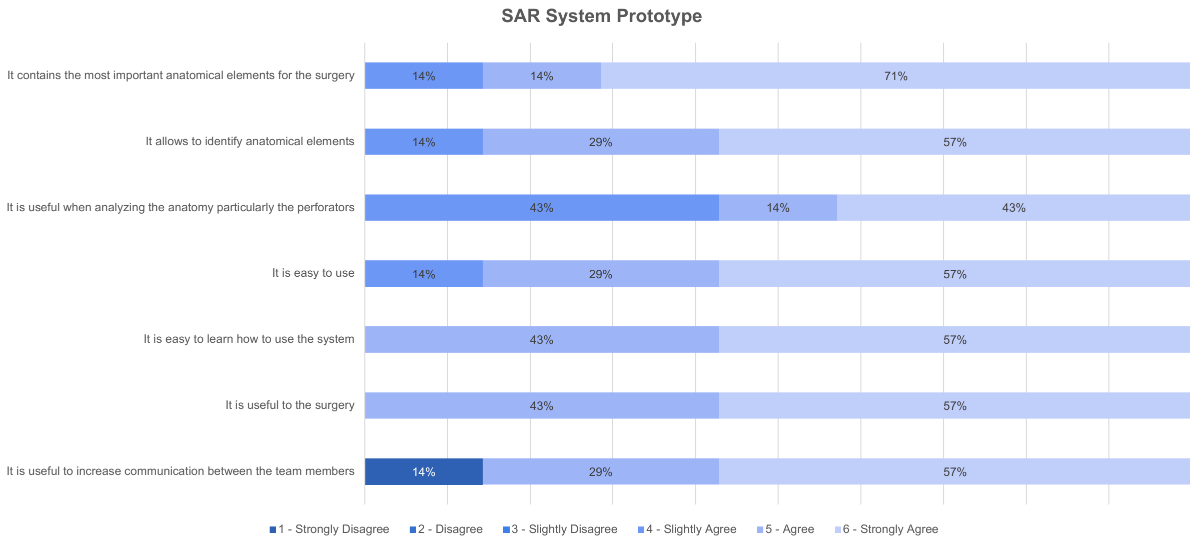


Figure 6.9: Stacked bar chart containing the answers (in percentage) for each statement presented in the SAR section of the intraoperative satisfaction questionnaire.

Regarding the SAR system, similar positive results were obtained (Fig. 6.9, with 97.96% of the participants answered with a 4 or higher, meaning the vast majority of participants slightly agreed, agreed, or strongly agreed with all the statements presented (Table 6.5). These strong results lead to the conclusion that the SAR system presents and allows users to identify the most important anatomical elements while being useful, easy to use, quick to learn, and improving the communication between the elements of the intraoperative team. It is also important to mention that this was the element within BREAST FLAPPAR that scored higher in the satisfaction questionnaires, especially when compared to the remaining AR systems.

The final element approached in our satisfaction questionnaire was the OST-AR system. This system scored the lowest among the elements tested, with 75.71% of positive results overall. Nonetheless, the results (Fig. 6.10) were mostly positive since the majority of the participants agreed with the statements presented. Regarding the usefulness of the system, even though it was a divisive statement, 57% of the participants answered with a 4 (slightly agree) or higher. 100% of the participants stated that this visualization contains the most important information, and 86% of the participants believe this system is ease to use and learn.

6.5.2.B Semi-Structured Interview

During the semi-structured interview, we asked participants to answer the questions mentioned in Table 6.6. These questions allowed us to obtain feedback and comments regarding their experience using

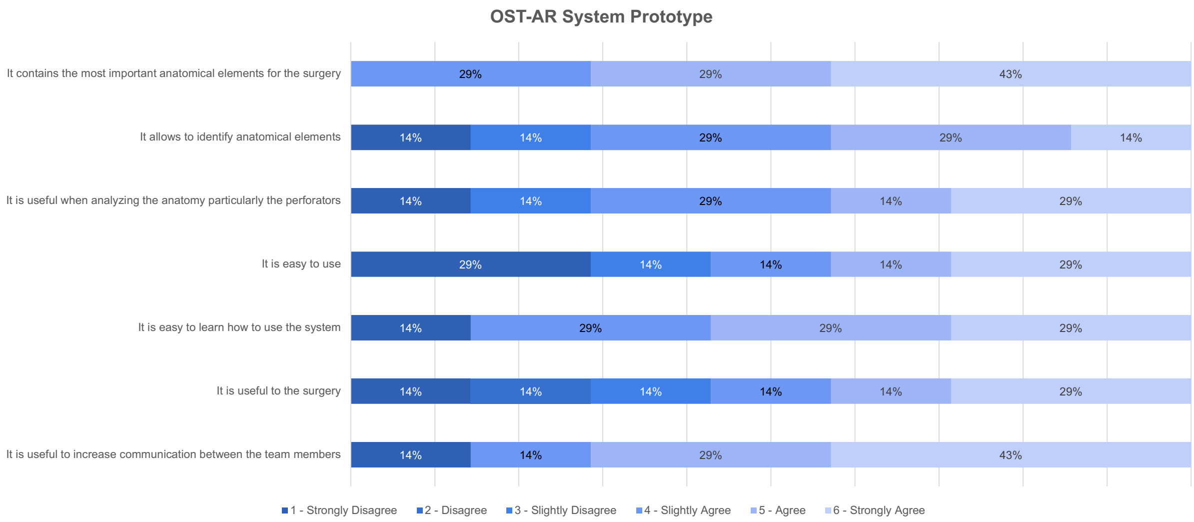


Figure 6.10: Stacked bar chart containing the answers (in percentage) for each statement presented in the OST-AR section of the intraoperative satisfaction questionnaire.

the elements developed. The questions created to obtain feedback regarding the data visualization allowed us to obtain similar conclusions to the ones stated in the previous section. The participants stated that the visualization is useful to the surgery and presents important information to this process. Similarly to the report, the participants also stated that the added graphical elements increase the quality and effectiveness of the analysis of the information presented. Regarding changes, some participants suggested a change in the data glyph to represent the location of the perforator with a single point, and not a line. A participant also suggested adding to the same visualization, (or create a new one for a second screen) images of the 3D model for the users to visualize this information three-dimensionally.

When it comes to the SAR system, very positive feedback was obtained, similarly to the results stated in the section above. The participants stated that the system provides the user with a quick calibration and easy-to-understand interface, allowing a fast and simple tracing process. It was also stated this system complements the intraoperative space, and can and should be part of this process. Some changes were also suggested, particularly to place the projector in the OR ceiling to increase the visualization's stability.

Regarding the OST-AR system, some participants experienced some problems while using the OST-AR system. The negative feedback for this system was mainly regarding the need to re-calibrate the system and some visualization issues such as a continuous flickering in the visualization. The participants stated that these problems should be fixed. Regarding positive feedback, it was stated that the visualization contains important information, as well as an intuitive and easy to analyze interface. Also, it was mentioned that the system provides the users with a hands-free visualization, which is an important feature. Beyond these issues, the participants considered this system an interesting visualization and were able to perform the tracing process.

Finally, the participants were also asked to explain what system they liked the most, and in what scenario. The vast majority of the participants answered with the SAR system for the intraoperative process and the Mobile-AR system for the pre-operative process. Some participants only mentioned the SAR system in this question.

6.6 Discussion

To validate the elements within BREAST FLAPPAR's ecosystem, we conducted a user study with 7 surgeons highly specialized in breast reconstruction surgery using DIEPs. To understand how helpful each element is for the pre-operative or intraoperative process, we asked the participants to perform different tasks using the elements within our ecosystem, followed by two satisfaction questionnaires and two semi-structured interviews. As explained in detail in sections 6.5.1.A and 6.5.2.A, all the elements achieve positive results for every statement presented during the satisfaction questionnaires, where 88.14% of the answers were positive. By analyzing sections 6.5.1.B and 6.5.2.B, we can understand that participants provided us with mainly positive feedback and comments. Further improvements were also mentioned, mainly regarding the addition of graphical elements such as a legend for each point in the report and data visualization, or the patient's fascia in the Mobile-AR system. These suggestions are important and were immediately implemented in the systems to increase the quality of the interface presented. The new version of the report and data visualization now contains more graphical elements suggested, such as the legend for each point, and the Mobile-AR system now also includes the patient's fascia to allow professionals to analyse the separation between the intramuscular and subcutaneous tissue.

As stated before, the participants found some issues related to the calibration process and visualization while performing the task related to the OST-AR system. In some cases, the system needed to be re-calibrated if the user moved, leading to the need to re-calibrate the system more than once in certain cases. It was also difficult to align the virtual scene with the real scene for some users, making this process harder than needed - we believe that the calibration issues found during this procedure arose from the OR lights and could be fixed later on. Regarding the problems found in the visualization, some participants mentioned some flickering in the virtual scene, and a few experienced a duplication of the virtual scene. Even with these issues, the participants believe that this system is helpful to the surgery and represents a good way to visualize the patient's anatomy to obtain insights during the surgery.

These results allow us to conclude that the elements within BREAST FLAPPAR's ecosystem are useful and should be added to the current pre-operative and intraoperative processes.

During the tasks performed by the participants, no usage errors were found, although two participants struggled to understand the data glyph present in the report and data visualization, asking for help to understand this particular data encoding element. Furthermore, in the report, some participants struggled to understand the orientation of the graphical element.

Regarding the impact on surgery time, during our user tests, the participants took, on average, 12 seconds for calibration and 47 seconds for the tracing process using the SAR system. With the OST-AR system, the participants spent on average 3 minutes in the calibration and 1 minute in the tracing process. Without using one of BREAST FLAPPAR's AR systems, this process usually lasts between 15 to 20 minutes - this means that the SAR system allows for a reduction in time spent in this process of 93.3% to 95.0%, while the OST-AR system allows for a reduction of 73.3% to 80.0%.

The vast majority of the participants found the SAR system to be the most helpful amongst the AR systems. By comparing the average time spent in calibration and tracing processes between the SAR and OST-AR systems, we can state that the SAR system is the fastest choice for this task.

7

Conclusion

Contents

Our work intends to verify if an AR ecosystem can complement and enhance the current model of performing a breast reconstruction surgery using DIEPs, mainly when it comes to improving the manual tracing process and reducing surgery time. BREAST FLAPPAR's ecosystem is composed by three AR systems - a SAR system which only requires a conventional inexpensive projector, an OST-AR system using Aryzon's HMD, and a Mobile-AR app made for iOS devices. All three systems receive as input the same data - a previously developed 3D model made from the output of the patient's CTA scan. This model allows the system to display important information regarding the patient's anatomy to the user, such as the location of the umbilicus, the abdomen, and the perforators, particularly their location, caliber, and intramuscular and subcutaneous course. Beyond these AR systems, and to complement the pre-operative and intraoperative space, a re-design of the medical report used for this surgery was made, together with a data visualization for the OR screens. Both these elements ensure the use of the same data encodings and design elements on all interfaces, creating a seamless experience when using all the elements within the BREAST FLAPPAR's ecosystem.

The design process of BREAST FLAPPAR was always user-focused. To ensure that our work fulfills the needs of healthcare professionals who will use these systems, we conducted an observation session of a breast reconstruction surgery to better understand their needs and the environment, which combined with our literature review allowed us to define our initial ideas on how the prototype should be. After gathering this information, we conducted co-design sessions creating an iterative design process always with the help of our users, to reach the best possible solution to their needs. In these sessions, we received feedback on our prototype as well as important suggestions that directly influenced the final product. A user study was conducted during a simulated pre-operative and intraoperative process with a real patient's data to directly evaluate our ecosystem in a closest as possible real-life scenario. These tests were conducted with 7 specialists, who were asked to perform specific tasks and then asked to fill questionnaires, and that also participated in a semi-structured interview, providing us with feedback and comments and allowing us to evaluate our work. The results stated in the previous chapter allowed us to understand that our AR systems are helpful to this surgery, and can also validate our hypothesis since these indicate that our ecosystem decreases surgery time and increases user satisfaction. Furthermore, it was also stated that BREAST FLAPPAR, through well-tough interfaces and data-encodings, increases the efficiency and communication between the members of the team, verifying our last hypothesis.

To conclude, after performing an analysis on the current market needs and by taking into consideration the results from the user study, we strongly believe that BREAST FLAPPAR is a next-generation system, ready to overcome challenges that medicine might face over the next decades.

7.1 Future Work

Even though our work achieved remarkable results, there is still a margin for improvement. The results gathered in our study represent only one patient. With patients with different anatomies, other scenarios might arise using these systems, meaning that further studies should be conducted. Furthermore, more participant data should be gathered in order to do a significantly statistical analysis of the results. It is also important to mention that with more participants and more surgeries, it would be possible to conduct a quantitative study, mainly measuring the error margins of the AR systems.

Regarding our SAR system, further improvements should be made especially when it comes to stability. Since our system is a handheld device, some stability and perspective issues might arise if the user does not manipulate the device properly. This limitation might be mitigated with the use of a wall-mounted projector place directly above the patient during the surgery. When it comes to our Mobile-AR system, the first limitation arises from being an iOS-only application. Since iOS users in Europe represent 32 percent of the smartphone market [49], this application should also be available to other operating systems, mainly Android. This system also contains limitations when it comes to low-lighting conditions, particularly calibration and visualization issues that should be improved. For the OST-AR system, further research should be conducted to improve the problems users found during our study. Other technologies such as the Microsoft HoloLens should also be considered and directly compared with the Aryzon. A study to understand if AR markers improve the stability of the visualization should also be conducted.

This work was developed focusing on breast reconstruction surgery using DIEPs. We believe that these systems can be applied to other medical procedures such as other breast reconstructive surgeries, other reconstructive flap-based surgeries, and even other types of medical procedures where it is helpful to visualize a virtual scene containing the patient's anatomy on top of the patient.

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A

Consent & Demographic forms

Formulário de consentimento informado

Título – Desenvolvimento de um ecossistema de realidade aumentada para a cirurgia de reconstrução mamária usando o DIEP flap.
Investigadores – João Amaral Lopes, 5º Ano Mestrado em Engenharia Informática e de Computadores, Instituto Superior Técnico
Investigador Principal – Prof. Doutor Daniel Simões Lopes
Orientadores – Prof. Doutor Daniel Simões Lopes, Dr. David Pinto

* Required

Caro participante,

Estamos a conduzir um estudo que consiste no desenvolvimento um ecossistema de realidade aumentade para ser usado preparação e durante a cirurgia, particularmente, numa cirurgia de reconstrução mamária usando o DIEP flap.
Para tal, necessitamos da sua contribuição!

Para participar neste estudo, irá colaborar num teste, em que lhe será apresentado o protótipo das ferramentas que estão a ser desenvolvida, lhe serão pedidas várias tarefas e serão feitos registos das observações feitas. No início da sessão, ser-lh ão feitas várias questões, de cariz demográfico, para inclusão no estudo. Ao longo do teste, serão propostas várias tarefas no final de cada tarefa, ser-lhe-á pedido para preencher um questionário de satisfação. No final da sessão ser-lhe-á pedido para preencher o questionário de satisfação geral e será conduzida uma pequena entrevista. Se assim o permitir, serão feit registos de vídeo, áudio e imagem ao longo da sessão, de forma a obter dados mais específicos que ajudem à análise dos resultados.

Toda a informação obtida, incluindo fotografias, vídeo e áudio, será tratada de forma confidencial, não podendo ser revelad qualquer pessoa, no entanto, pode ser usada para análise estatística, ou com fins científicos.
Comprometemo-nos a guardar os dados durante 5 anos. Após este período, toda a informação será eliminada. Caso deseje poderá pedir a remoção dos dados em qualquer altura. A sua autorização para participar no programa é voluntária, podend se assim o desejar, negar qualquer consentimento em qualquer momento do estudo.

Para participar nesta experiência, pedimos-lhe que preencha o consentimento presente neste questionário, concordando co as frases escritas abaixo.

Obrigado pela sua colaboração!

1. ID Participante *

____

2. Li e compreendi o significado deste estudo. Tive a oportunidade de colocar questões, caso necessário, e recolher as respectivas respostas. *

Check all that apply.

- [ ] Concordo

3. Compreendo que a participação neste estudo é voluntária e que posso desistir a qualquer momento, sem apresentar qualquer explicação. Caso tal aconteça, não serei alvo de qualquer penalização e os dados relativos à minha experiência serão removidos e destruíd *

Check all that apply.

- [ ] Concordo

4. Autorizo a recolha de informação durante a sessão na forma de: *

Check all that apply.

- [ ] Áudio
- [ ] Vídeo
- [ ] Fotografias

5. Autorizo o uso dos dados recolhidos durante a sessão. *

Check all that apply.

- [ ] Concordo

6. Autorizo o processamento dos dados experimentais no âmbito deste projecto para fins de análise, investigação e disseminação de resultados em publicações científicas ou conferências na área do projecto, pelos investigadores deste projecto. *

Check all that apply.

- [ ] Concordo

7. Compreendi que os dados recolhidos neste estudo serão utilizados como mencionado anteriormente. *

Check all that apply.

- [ ] Concordo

8. Compreendi que em qualquer altura poderei ter acesso aos meus dados pessoais recolhid neste estudo, bastando para o efeito contactar o investigador principal do projeto através email: daniel.lopes@inesc-id.pt. *

Check all that apply.

- [ ] Concordo

9. De acordo com o descrito acima, autorizo a minha participação neste estudo e aceito as suas condições. *

Check all that apply.

- [ ] Concordo

Sessão de Co-Design - Questionário informação demográfica dos participantes

Esta informação será tratada de forma confidencial, não podendo ser revelada a qualquer pessoa, no entanto, pode ser usada para análise estatística, ou com fins científicos. Comprometemo-nos a guarda[r] os dados durante 5 anos. Após este período, toda a informação será eliminada. Caso deseje, poderá pedir a remoção dos dados em qualquer altura.

* Required

1. ID Participante

____

2. Género *

Mark only one oval.

- ◯ Masculino
- ◯ Feminino
- ◯ Outro

3. Especialidade *

____

4. Anos de experiência na especialidade *

____

5. Tem experiência em cirurgias de reconstrução mamária? *

Mark only one oval.

- Sim
- Não

6. Se sim, quantos anos de experiência tem em cirurgias de reconstrução mamária?

____

7. Se sim, aproximadamente em quantas cirurgias de reconstrução mamária já participou

Mark only one oval.

- 1 - 10
- 11 - 20
- > 20

8. Tem experiência em cirurgias de reconstrução mamária utilizando DIEPs? *

Mark only one oval.

- Sim
- Não

9. Se sim, quantos anos de experiência tem em cirurgias de reconstrução mamária utilizando DIEPs?

____

10. Se sim, aproximadamente em quantas cirurgias de reconstrução mamária utilizando DIEP já participou

Mark only one oval.

- ◯ 1 - 10
- ◯ 11 - 20
- ◯ > 20

11. Tem experiência com tecnologias de realidade aumentada? *

Check all that apply.

- [ ] Sim, utilizando um smartphone (Mobile-AR)
- [ ] Sim, utilizando headsets (OST-AR, ex. Hololens)
- [ ] Sim, utilizando mecanismos de projeção (SAR)
- [ ] Sim, utilizando outras tecnologias
- [ ] Não

12. Tem experiência com tecnologias de realidade aumentada em ambiente cirúrgico? *

Check all that apply.

- [ ] Sim, utilizando um smartphone (Mobile-AR)
- [ ] Sim, utilizando headsets (OST-AR, ex. Hololens)
- [ ] Sim, utilizando mecanismos de projeção (SAR)
- [ ] Sim, utilizando outras tecnologias
- [ ] Não

13. Tem experiência com tecnologias de realidade aumentada em ambiente de preparação cirúrgica? *

Check all that apply.

- [ ] Sim, utilizando um smartphone (Mobile-AR)
- [ ] Sim, utilizando headsets (OST-AR, ex. Hololens)
- [ ] Sim, utilizando mecanismos de projeção (SAR)
- [ ] Sim, utilizando outras tecnologias
- [ ] Não

B

User study - Satisfaction Questionnaires

Questionário de satisfação final

* Required

1. ID Participante *

Relatório

2. De um modo geral, relativamente ao protótipo do relatório apresentado, considera que... *

Mark only one oval per row.

	1 - Discordo totalmente	2	3	4	5	6 - Concordo totalment
contêm a informação mais importante para a cirurgia e a preparação da mesma.						
permite identificar a informação necessária rapidamente.						
é útil a possibilidade de analisar esta informação como complemento aos sistemas de AR.						
é fácil de efetuar a leitura dos dados.						
é útil para a preparação da cirurgia.						
é util para a cirurgia.						
é útil para o aumento da comunicação entre a equipa.						

Mobile-AR (Preparação cirurgia)

3. De um modo geral, relativamente ao protótipo do sistema de Mobile-AR apresentado, considera que... *

Mark only one oval per row.

	1 - Discordo totalmente	2	3	4	5	6 - Concordo totalment
contêm os elementos anatómicos mais importantes para a preparação da cirurgia e a sua preparação	⬭	⬭	⬭	⬭	⬭	⬭
permite identificar os marcos anatómicos.	⬭	⬭	⬭	⬭	⬭	⬭
é útil a possibilidade de ver a anatomia interna (perfurantes).	⬭	⬭	⬭	⬭	⬭	⬭
é fácil de usar.	⬭	⬭	⬭	⬭	⬭	⬭
é de aprendizagem rápida.	⬭	⬭	⬭	⬭	⬭	⬭
é útil para a preparação da cirurgia.	⬭	⬭	⬭	⬭	⬭	⬭
é útil para o aumento da comunicação entre a equipa.	⬭	⬭	⬭	⬭	⬭	⬭

Questionário de satisfação final

* Required

1. ID Participante *

Visualização ecrãs

2. De um modo geral, relativamente ao protótipo da visualização criada para os ecrãs do bloc operatório, considera que... *

Mark only one oval per row.

	1 - Discordo totalmente	2	3	4	5	6 - Concordo totalment
contêm a informação mais importante para a cirurgia.						
permite identificar a informação necessária rapidamente.						
é útil a possibilidade de analisar esta informação como complemento aos sistemas de AR.						
é fácil de efetuar a leitura dos dados.						
é util para a cirurgia.						
é útil para o aumento da comunicação entre a equipa.						

SAR

3. De um modo geral, relativamente ao protótipo de realidade aumentada para uma cirurgia c reconstrução mamária utilizando DIEPs (BREAST FLAPPAR SAR), considera que... *

Mark only one oval per row.

	1 - Discordo totalmente	2	3	4	5	6 - Concordo totalment
contêm os elementos anatómicos mais importantes para a cirurgia	◯	◯	◯	◯	◯	◯
permite identificar os marcos anatómicos.	◯	◯	◯	◯	◯	◯
é útil a possibilidade de ver a anatomia interna (perfurantes).	◯	◯	◯	◯	◯	◯
é fácil de usar.	◯	◯	◯	◯	◯	◯
é de aprendizagem rápida.	◯	◯	◯	◯	◯	◯
é útil para a cirurgia.	◯	◯	◯	◯	◯	◯
é útil para o aumento da comunicação entre a equipa.	◯	◯	◯	◯	◯	◯

OST-AR

4. De um modo geral, relativamente ao protótipo de realidade aumentada para uma cirurgia c reconstrução mamária utilizando DIEPs (BREAST FLAPPAR OST-AR), considera que... *

Mark only one oval per row.

	1 - Discordo totalmente	2	3	4	5	6 - Concordo totalment
contêm os elementos anatómicos mais importantes para a cirurgia						
permite identificar os marcos anatómicos.						
é útil a possibilidade de ver a anatomia interna (perfurantes).						
é fácil de usar.						
é de aprendizagem rápida.						
é útil para a cirurgia.						
é útil para o aumento da comunicação entre a equipa.						