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FINAL REPORT

Disposable medical products used in the OR at the University Medical Center Utrecht –

Defining barriers and circular strategies

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ABSTRACT

Introduction & Aim of the research project: The healthcare sector is responsible for high resource consumption, and disposable medical products in particular are characterized by being resource-intensive and generating large amounts of waste after use. The University Medical Center Utrecht (UMCU) has formulated ambitious targets to reduce the hospital's impact and to increase the circular use of products and materials. The main aim of this six-month research project was to investigate the barriers to circularity of disposable medical products used in the operating room (OR) at UMCU and to explore possibilities for an alternative, innovative and more circular use of some of those. Therefore, this study was initiated to both accelerate the transition to circularity at UMCU and to create knowledge and facilitate future research in this relevant sector.

Methodology: To investigate the barriers to circularity for disposable medical products at UMCU, a roundtable discussion was organized with UMCU internal staff working at different departments. This discussion focused on five different disposable products, namely diathermy pencil, trocar, blood pressure cuff, finger pulse oximeter and surgical table sheet. In addition, semi-structured interviews with five employees working in three different departments (procurements, sterilization and infection prevention) were conducted to extend and validate the findings of the roundtable discussion. To gain an initial understanding of the external barriers that may influence the circularity of disposables, four semi-structured interviews with suppliers of the respective products were carried out.

Results: The roundtable discussion and the interviews led to the identification of various barriers present at the organizational (UMCU) and supplier levels. The barriers could be categorized into six overarching groups namely technological and informational, organizational, behavioral, financial, legal and market barriers. Depending on the disposable medical product different barriers to circularity were present. The barriers were used to develop several circular strategies for the respective medical products to provide UMCU with opportunities to increase the circularity of these products. Finally, the integration of all findings has strengthened the formulation of hospital-level recommendations as well as the development of future research directions.

Conclusion: This research has shown that there are a variety of barriers to circularity for disposable medical products and that these depend on the characteristics of each product group. Some barriers are within the power of hospitals to be changed, while others require intervention, engagement, and collaboration at the system level. The willingness of stakeholders and medical professionals to participate in this transition was observed throughout the study. In terms of developing circular alternatives for disposable medical products, this study highlighted the diversity of strategies that can be employed. Future research should aim to validate the findings of this study in, e.g. living labs and conduct a system-level analysis focusing on the specification and interaction of barriers and development of solutions to successfully overcome them.

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1. INTRODUCTION

The healthcare sector is growing rapidly on a global level reinforced, inter alia, by an increasing number of people getting access to medical services as well as aging populations that are in need of these services for a longer period of time (Yeganeh, 2019). However, at the same time, this sector is dependent on a high amount of materials, water and energy. A study by Pichler, Jaccard, Weisz and Weisz (2019) showed that the OECD countries, including China and India, in sum are contributing with their healthcare services approximately 4,4% to global carbon dioxide emissions. On a national level, the Netherlands is among those countries in which the healthcare sector has the highest share of carbon dioxide emissions in comparison to the other countries. In 2019, the Dutch healthcare sector contributed 7% to total national carbon emissions (Gupta Strategist, 2019).

Within the healthcare sector, more specifically hospitals are responsible for large consumption of resources. One of the factors besides the direct use of energy and water is the use of materials and products resulting in the production of large amounts of waste (Capolongo et al., 2015). This conversion of materials to waste also contributes to carbon dioxide emissions caused by waste incineration. When examining the generation of waste within the different parts of a hospital, especially operating rooms (ORs) stand out. The amount of OR waste differs between countries. McGain et al. (2015) found out that in Australia around 10% of hospital waste is generated in the operating rooms, whereas Tieszen and Gruenberg (1992) estimated it to be between 20-30% in the United States. This is caused, among other aspects, by the high and increased use of medical disposable products in the OR (Blough & Kaylee, 2021). These are products that are intended to be used only once. Disposable medical products range from simple and relatively cheap products such as syringes, gloves, medical masks, or medical draping to complex and more expensive products, such as disposable surgical staplers. Circular alternatives are often available on the market, such as redesigned products, reusable products, recyclable products or even the refuse of products, meaning choosing not to use a specific product anymore, is sometimes an option. But predominately disposables are used.

The reliance and trend towards disposables in hospitals have been increasing in the last decade and reasons for this are, among others, infection control, convenience and cost savings (Kane et al., 2018; Voudrias, 2018). Interestingly, there have been studies comparing the costs of disposables and reusables for selected products (blood pressure cuff, laryngoscopes and anesthetic drug trays). The authors found evidence that in the long-term the use of reusables can be cheaper than using disposables (Sanchez, Eckelman & Sherman, 2020; McGain et al., 2010; Sherman, Raibley & Eckelman, 2018).

In terms of sustainability, the high usage of disposables in the last decade contributed to an increasing waste production in hospitals. To counteract this high amount of waste, circular strategies are needed to minimize the spillage of products and

materials and to keep these as long as possible in the usage cycle while considering potential infection risks and logistical and financial barriers.

Green Deal on Sustainable Healthcare

To address the high impact of the healthcare sector in the Netherlands, in 2018 the Green Deal on Sustainable Healthcare was formulated by the government together with healthcare institutions and companies (Ministry of Health, Welfare and Sport, n.d.). The different parties formulated and agreed upon various targets to reduce the sector's impact. The four main goals are the following Ministry of Health, Welfare and Sport, n.d.):

- A 49% reduction in carbon emissions by 2030
- Socially and environmentally responsible procurement (Circular procurement)
- Fewer pharmaceutical residues in drinking water
- A healthy environment for care workers and patients

Since its formulation, the Green Deal on Sustainable Healthcare has been signed by over 200 parties that commit to actively contributing to the achievement of the abovementioned goals. The reliance and great use of disposable medical products is one challenge that needs to be addressed to achieve those goals.

The University Medical Center Utrecht (UMCU) has also committed itself to the Green Deal on Sustainable Healthcare. Therefore, it has formulated targets for the hospital that are in line with this deal, such as aiming at reducing its carbon emissions, using 50% less primary raw materials until 2030 and becoming fully circular by 2050 (UMC Utrecht, n.d.). More concretely, the hospital stresses to choose where possible, products that are made from sustainable, renewable or secondary raw materials and products that can be repaired, reused or recycled (UMC Utrecht, 2022). Additionally, UMCU specifically aims to make disposables more sustainable (UMC Utrecht, 2022). However, also at UMCU predominantly disposable medical products are used in the OR which reinforced the need to investigate the reasons behind the dominance of disposables and to develop strategies for a circular use of specific products.

2. AIM OF THE RESEARCH PROJECT

This study was funded by the Alliance of Eindhoven University of Technology, Wageningen University & Research, Utrecht University and University Medical Centre Utrecht from November 2021 until March 2022. These four parties, which are complementary in knowledge, joined forces to tackle societal challenges and lead transitions in different areas, namely energy, sustainability, health and food. One specific subtopic the alliance is working on is called 'Circular Hospital' and is addressing the sustainability challenges the healthcare sector is facing and aims to develop circular solutions to overcome those. From March 2022 until May 2022 the Utrecht University hub Towards a Circular Economy and Society granted funding to extend this research project for two months.

For this specific research, the aim was to investigate the disposable medical products used in the OR at UMCU and to explore possibilities for an alternative, innovative and more circular use of some of those. This work was conducted as a foundation for further research in this area. To achieve the overarching research aim, the following objectives were formulated:

- Development of an overview of potential disposable medical products used in the OR at UMCU that may be used circularly
- Identification of barriers to circularity for selected products
- Development of circular strategies and recommendations at the product- and hospital-level
- Formulation of future research directions and acquisition opportunities on circular health

Generally, this research was initiated to build knowledge around the topic of medical disposables and to function as a starting point for further research, draw attention to this topic on product-, hospital-, and system-level and steer innovation towards more circular medical products. Additionally, this study could facilitate long-term research on a mission-level with a focus on investigating the innovation system of disposable medical products in the Netherlands. This is especially important and interesting since the Dutch Green Deal mission on Sustainable Healthcare was formulated. For the achievement of the set targets, it is crucial to investigate the actors, markets and activities involved in this mission-oriented innovation system and this research contributes with first recommendations and direction for future research.

To structure the research and its findings it was organized around three levels, namely product-level, hospital-level and alliance-level. This report addresses these three

levels as follows: After explaining the methodological approach in Chapter 3, Chapter 4 specifically provides findings for the product-level and the supplier level. In Chapter 5 recommendations are given at hospital-level and lastly in Chapter 6 conclusions are drawn and future research directions are formulated that are important at the alliance-level.

3. METHODOLOGY

To achieve the research objectives an exploratory, qualitative research design was chosen. An overview of the different stages of the research project is roughly outlined in Figure 1.

First, to gain an overview of the state of the art of the literature addressing disposable medical products used in the OR, scientific literature, webinars and blog articles were scanned and prioritized. Additionally, the stakeholders involved in the topic of circularity in the healthcare sector throughout the Netherlands were mapped to understand the involvement of different parties in this topic and their focal points. Meetings with different stakeholders such as a member of the Green OR,

Figure 1: Outline of the research project's main steps per month

researchers from Wageningen University, medical staff working at UMCU and an employee of the Rijkswaterstaat were held to exchange research ideas, expertise and establish contact for future research.

Data collection

The first goal was *to gain an overview of what types of disposable medical products are used in the OR* in order to make a considered selection on a couple of products that were more extensively analyzed within this research. To do so, the procurement data from UMCU summarizing the disposable products used in the OR were examined. Additionally, medical professionals from different specialties working in the OR were asked by filling out a brief survey to name five different disposable products which they deemed important to be investigated. This estimation was based on the disposables' high frequency of usage, material composition or perceived high environmental impact. In total, the survey was filled out by six different medical specialties as well as an estimation by the OR logistic department. More than 30 disposable medical products were named. This overview of different products was then discussed in several meetings with medical professionals, who use these products in their daily work as well as an environmental expert from the hospital to make a selection on those disposables that should be further analyzed. In detail, the five chosen disposable medical products for this research are:

- Diathermy pencil
- Trocar
- Blood pressure cuff
- Finger pulse oximeter
- Surgical table sheet

To achieve the second goal - *the identification of barriers to circularity per disposable product* – on the 15th of February 2022 a roundtable discussion with UMCU internal staff was carried out online (see Appendix A for an outline and the discussion questions of the roundtable). In this roundtable discussion not only medical staff who use the selected product in their daily work was included, but also other employees from departments that were relevant for this research, namely logistics, infection prevention/ sterilization, waste management and sustainability. Unfortunately, the procurement department which is also essential in terms of circularity due to their responsibility for selecting and purchasing medical products, could not be present. In total, 14 people working at UMCU joined the roundtable discussion.

In this roundtable, the pre-selected five different disposable products – Diathermy pencil, trocars, blood pressure cuff, finger pulse oximeter and surgical table sheets – were discussed in breakout sessions aiming to understand the functionality/usage of the specific product, the development of it over the last years (for example, if it has changed from being reusable to disposable), and to identify barriers and solutions for circularity. To do so, multiple questions guiding the discussion were prepared beforehand. In each breakout room the discussions were moderated by one person from the research team and also a note-taker was assigned. After each product was discussed in the breakout sessions, the findings were summarized and presented to the whole group by one participant from each breakout session to inform the others about the most important conclusions. Additionally, other participants had the possibility to add to the findings by sharing their insights.

The extension of the research project allowed us to validate and extend the data that was collected through the roundtable discussion by conducting additional four interviews with five UMCU employees working in the procurement, sterilization and infection prevention departments. These departments were recognized as being crucial when discussing the circularity of medical disposables. Therefore, in-depth interviews with each department were deemed important to get a holistic understanding of the present barriers towards circularity at UMCU. The interviews were semi-structured and guided by an interview guide that was slightly adapted to the respective department (see Appendix B and C). First, questions were raised to understand the tasks of the department and the role of circularity within the specific department better. Then, more specific questions directed to examine the disposable medical products used at UMCU and potential barriers to more circular strategies were asked. Lastly, recommendations for improvements were discussed.

Besides the additional interviews with UMCU internal departments, the extension of this research allowed us to conduct interviews with the suppliers of the respective products. To do so, six suppliers

from which UMCU purchases the investigated products were contacted and four of them agreed to participate in an interview. Again, these interviews were semi-structured and guided by an interview guide (see Appendix D). First, the interviewees were asked to describe their daily tasks as well as the role of circularity and/or sustainability in their daily work and within the company in general. Afterwards, several questions aimed at investigating the company's position towards medical disposables and reusables were raised including questions intended to examine the barriers to more circular alternatives of disposables. If possible, questions regarding the specific investigated products were included in the interview. However, this was not always feasible since it depended on the level of expertise the interviewees had about the specific products.

Data analysis

The results of the roundtable discussion and additional interviews were used as the main source of information for this report. Based on the analysis of the roundtable discussion recommendations for each identified barrier per product were formulated. The complementary interviews with three UMCU departments were used to validate and extend the findings of the roundtable discussion and also provided additional insights by focusing on medical disposable products in general and their overarching barriers to circularity. Moreover, the interviews with the suppliers were analyzed concentrating on their perception of barriers to the circularity of the medical disposable products they offer.

Afterwards, circular strategies per investigated product were developed addressing different circularity levels and recommendations were articulated to achieve the third goal - *Development of circular strategies and recommendations at the product- and hospital-level* - of this research. To do so, the circular strategies developed by Potting, Hekkert, Worrell and Hanemaaijer (2017) were applied. The different strategies per product were discussed within the research team while taking the identified barriers into account. This resulted in the formulation of multiple possible circular strategies for each of the products.

Lastly, to address the fourth research objective, *future research directions* that were identified throughout this study (among others in meetings with UMCU, in the roundtable discussion, in meetings with the alliance, talks with medical professionals, etc.) were summarized to highlight the importance of the societal challenges that the Green Deal of Sustainable Healthcare is addressing and provide opportunities for the alliance and other research institutes to continue investigating this topic.

4. RESULTS

In the following, the research results are presented starting with a general overview of the products that were identified by the survey with the medical professionals from UMCU. Afterwards, the selected five products are briefly introduced. Then, the barriers to circularity are presented and categorized into different levels. As can be seen in Figure 2, barriers to circularity at the product-level (5 investigated disposables & general insights about medical disposables) are outlined including recommendations on how to overcome these barriers. These findings are part of the organizational level (UMCU). Afterwards, the barriers to circularity that were identified through the interviews with four suppliers are presented, comprising the 'Supplier' level. Lastly, different circular strategies for each investigated product are described, aiming to facilitate the circular use of the selected products.

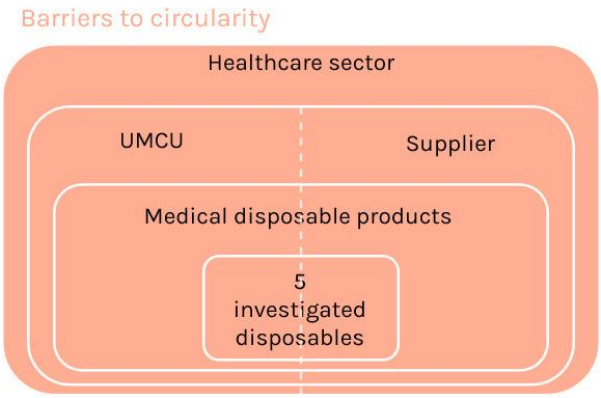


Figure 2: Barriers to circularity divided in levels of investigation

General insights

The survey distributed among various surgical medical specialties was filled out by six different specialties, namely urology, ophthalmology, trauma surgery, anesthesiology, gastrointestinal surgery and vascular surgery. Additionally, data was provided by the OR logistic department. An overview of the answers can be found in Appendix E.

The findings show that some disposable medical products that were pointed out in the survey are only used for specific surgeries (such as loops and coagulation balls for transurethral resection); however, other products are worked with across multiple medical specialties (such as diathermy pencil, forceps, etc.). Moreover, some of the products that were

highlighted as important to investigate due to being disposable and having a high environmental impact by being disposed after one use are products that are used for every procedure under anesthesia such as disposable blood pressure cuffs, masks for

ventilation or finger pulse oximeters. Additionally, the personal protective equipment (PPE) of the medical staff such as different types of OR jackets, OR caps was pointed out as potential products for further analysis. Also interesting to point out is draping as a disposable medical product since it is used (in different ways) for every surgical procedure.

In general, it is important to highlight the variety of disposable medical products that was mentioned in the survey. Also at UMCU disposables are adopted having multiple functions, different degrees of complexity and value. Some products like the Endo GIA which is a surgical stapler have a high value and complexity, whereas others such as disposable kidney trays or forceps are relatively cheap and simple products. Hence, these findings underline the high reliance on disposables in the ORs and demonstrate that not only specific product groups are used in a disposable way but that these types of products are widely spread among medical products in general.

The selection of those products for further investigation in this study was done together with medical professionals discussing what products have a large impact in terms of frequency of usage, material composition and if these are products used by multiple medical specialties.

Introduction to the selected disposable products

1. Diathermy pencil

The first selected product is the diathermy pencil. This is an electrosurgical pencil used to, among other things, cut a patient's skin by applying an electric current. The disposable version used at UMCU contains the pencil including a needle as well as a cord with integrated smoke evacuation so that the device can be plugged into another machine that provides power and suction (see Figure 3). Since there is evidence that the smoke that is released by using electrosurgical pencils can be harmful to humans, smoke evacuation is an important function to be integrated.

Figure 3: Disposable diathermy pencil

Since this product is an essential device used in many different surgeries from various medical specialties, it was interesting to investigate since the positive impact of changing towards a more circular use of this product may be quite large within UMCU.

2. Trocar

A trocar, a surgical instrument used during laparoscopic and other minimally invasive surgeries, is the second disposable medical product that was selected (see Figure 4). It provides access into the abdomen and acts as a portal through which other instruments can be inserted.

Figure 4: Disposable trocar

In terms of circularity, trocars are an important product to analyze since all laparoscopic or other minimally invasive surgeries require this instrument, and around 3-4 trocars are used per procedure. Therefore, the introduction of an alternative, more circular usage of this product is advised.

3. Blood pressure cuff

The third selected disposable medical product is a blood pressure cuff used in the OR to monitor the blood pressure of the patient during the surgery. As illustrated in Figure 5, the disposable version contains the cuff itself and also a small tube that connects the cuff to the monitoring machine. This blood pressure cuff is used for every surgery performed at UMCU and hence the creation of waste of this product is quite extensive.

Figure 5: Disposable blood pressure cuff

4. Finger pulse oximeter

The finger pulse oximeter is the fourth selected disposable product and is used in the OR to measure the oxygen saturation of the patient during the surgery. For every surgery, at least one finger pulse oximeter is used, and as pointed out during the roundtable discussion, often also two are used in case the first one does not work properly right away. The disposable version comprises a small 'bandage' including the sensor that is being attached to the patient's finger as well as a cable that allows the product to be connected to the monitoring machine (see Figure 6).

Figure 6: Disposable finger pulse oximeter

5. Surgical table sheet

Lastly, surgical table sheets were chosen as the fifth disposable product. These are put on the surgery table to absorb human fluids during the procedure and also provide comfort for the patient. There are two different disposable versions used at UMCU.

The first one is made from different types of materials such as a combination of synthetics and paper (see Figure 7). Besides the mentioned absorbency and comfort for the patient, it offers additional features such as being waterproof on the backside as well as providing stability. This type of

sheet is used for surgeries that are characterized by a long duration and are often linked to a high loss of fluids.

Figure 7: Disposable surgical table sheet type 1

The second one is a thinner sheet protecting the surgical table from fluids by having a plastic layer. However, the absorption volume is low and it breaks more easily; hence, it is not as stable compared to the first one. This type of sheet has been reintroduced to the OR complex for specific medical specialties.

Barriers to circularity and recommendations at the product- and organizational-level

The analysis of the roundtable discussion and the additional interviews revealed various barriers to circularity for the selected products and also for medical disposables in general. In the following, first, some general insights are given, followed by a detailed description of the different identified barrier categories. For each barrier recommendations at the product-level are given, intended to overcome this barrier and to take a step towards a more circular and innovative product solution.

In general, the barriers could be grouped into six different main categories, namely technological and informational barriers, organizational barriers, behavioral barriers and financial barriers, legal barriers and market barriers. The main categories each encompass various, specific barriers. Depending on the disposable medical product different barriers to circularity are present. Moreover, some barriers were expressed but not linked to one of the investigated products and were therefore linked to the category 'Applicable to various disposable medical products', as can be seen in Table 1.

Interestingly, for the diathermy pencil and the trocars mainly technological and informational barriers could be identified. This could be due to the higher degree of contamination (directly getting in touch with human fluids) of these products and, hence, the importance of sterilization to ensure safe usage when working with, for example, reusable products. This requirement coupled with the higher complexity in terms of the design of the products that affects the easiness of sterilization contribute to the observed technological barriers that might hinder a more circular use. On the other hand, for the other three products, namely the blood pressure cuff, finger pulse oximeter and surgical table sheets, the majority of the identified barriers could be assigned to the overarching category of organizational barriers. Possible financial barriers to circularity were only mentioned regarding three of the five products (blood pressure cuff, finger pulse oximeter and OR table sheet).

In the following, each barrier category is explained and recommendations are given. A detailed overview of each product's barriers and recommendations can be found in Appendix F.

Table 1: Overview of identified barriers to circularity per disposable product at the UMCU level

Type of barrier	Applicable to various disposable medical products	Diathermy pencil	Trocars	Blood pressure cuff	Finger pulse oximeter	Surgical table sheet
Technological and informational	Issues related to sterilizing and cleaning a product (due to design, material, technical features, etc.)					
	Lack of knowledge about circularity connected to infection prevention & sterilization					Lack of knowledge about best alternatives (in terms of sustainability and medical procedures)
	Reusables: Potential health risk for medical staff or patient					
	Technical features and quality of disposables sometimes better than reusables					
	Difficulties to check quality and functionality of reusables					
Organizational	Convenience & Practicality					
				Cleaning: Responsibility & workload		
	Uniformity and standardization of preparation, cleaning and sterilization procedures and policies			Uniformity and standardization of preparation, cleaning and sterilization procedures and policies		
	Logistics: Reusables require more complex logistics			Logistics: Fear of running out of products		Logistics: Reusables require more complex logistics
	Hospital structure/way of operating slows down change					
	Missing workforce, time and distribution of responsibilities					
	Hospital has limited purchasing power					
Behavioral	Personal preference towards disposables					
		Negative incident with reusable product				
Financial	Focus on saving costs hinders adoption of circular alternatives and favors disposables			High initial investment of reusables		
Legal	Instructions for Use (IFU)					
	Suppliers often do not fulfill their post-market surveillance duty					
Market	Limited number of sustainable suppliers					
	Money-driven mindset throughout the market hinders circular innovations					

1. Technological and informational barriers

As mentioned above, the presence of the various barriers differs depending on the disposable product.

Concerning technological and informational barriers, it is noteworthy that one barrier was expressed similarly for four of the five products and also for disposable medical products in general, namely *issues related to sterilizing and cleaning a product*. It was mentioned that e.g. due to the complexity of the product (diathermy pencil and trocars) a reusable version might be difficult to sterilize for the internal sterilization department. Additionally, also the cleaning process itself or the design of a product was pointed out as hindering factors for the finger pulse oximeter and blood pressure cuff. These findings were reinforced when discussing reusables in general with employees working at UMCU's sterilization department. It was stressed that although it is possible to change a lot of disposables back to reusables, there are also disposables where it will not be possible because some small or hallow instruments are too difficult to clean and if not sterilized correctly can pose a high risk for patients.

To overcome part of this barrier, it is recommended to assess the market to see if new reusable products are available and if so, how easy they are to clean. Therefore, it is important to involve the producer of the specific reusable product, and the UMCU sterilization department to test the sterilization/ cleaning process and communicate, if necessary, problems directly to the producer to allow them to improve the product. Additionally, since, for example, reusable blood pressure cuffs are used in different departments at UMCU and also alternatives for the other products are used in other hospitals, this barrier should be easy to overcome by discussing the disinfection with other departments at UMCU that use reusable products, or (if needed) with other hospitals.

Moreover, it was pointed out that the *reusable version* of two products (diathermy pencil and trocars) *might pose a risk for medical staff or patients.* Additionally, a potential higher infection risk was also pointed out when discussing disposable medical products in general. Concerning the diathermy pencil, a smoke evacuation is an important function since breathing in the smoke that is occurring during surgery can be harmful to humans. However, the last reusable version used at UMCU did not have this functionality. Regarding the trocars, it was pointed out that the last reusable product had a very sharp and pointy tip that could pose a safety risk for the patient compared to the disposable ones that are used at the moment at UMCU.

Therefore, it is recommended to involve producers and discuss these product features with them, so that they have the possibility to innovate and design reusable products addressing these two challenges.

Another technological barrier is addressing the *technical features and quality of disposables*. During the interviews, it was mentioned that sometimes the specific characteristics or the quality of disposables is better than of reusables. More specifically, for the diathermy pencil as well as the trocars it was stressed that the disposable version fulfills the technical requirements better than the last reusable versions. It seems like either innovation was happening mostly on the side of the disposable products, or that the participants are not aware of the recent developments of the reusable versions. Since there are reusable alternatives on the market and used in other hospitals, to overcome this barrier it is recommended to reach out to the producers and let medical staff try these to test if they fulfill the requirements. If medical professionals are not satisfied with the reusable alternatives, it might be an idea to further communicate the missing/ lacking technical features to the producer to stimulate innovation and improvements of the product.

Connected to the previous point, it was also highlighted that in general for some reusables it is difficult for staff to *check the quality and functionality* of reusable products. For some products, certain technical features are crucial for their successful use and these features could wear out during the cleaning and sterilization processes. Therefore, it is important to regularly perform checks of reusable instruments by qualified staff. This contributes to correct usage and the safety of the patient.

Lastly, the interviews with infection prevention and sterilization departments revealed *a lack of knowledge about the application of circularity strategies in their professions*. It was highlighted that there is not enough information present about the potential health risks of reusing specific products and that many questions still need to be answered. Moreover, regarding the cleaning procedures of reusables, it was pointed out that often it is not clear whether a product needs to be sterilized or only disinfected.

More specifically, concerning the surgical table sheets, an informational barrier to circularity was observed. The roundtable discussion demonstrated a *lack of knowledge* about different alternatives. More specifically, the participants were aware of some more circular alternatives to the current use of surgical mats, however, they did not have enough knowledge to assess which the best choices are in terms of circularity and sustainability. To understand the environmental impact of different surgical sheets, conducting Life Cycle Assessments might be a useful tool.

Moreover, medical staff stressed that employees preparing the OR do not have the knowledge to decide which surgical sheet is appropriate for the respective surgery in terms of absorption of fluids. This could hinder a more circular approach if multiple versions are used. To overcome this barrier, it is advised to discuss with medical staff the requirements for different procedures to understand the level of absorption that is needed and, hence, the level of thickness of a surgical sheet.

2. Organizational barriers

An organizational barrier that was mentioned regarding medical disposables in general and also the investigated disposables refers to *the convenience and practicality* of disposable products. Mostly, disposables are very easy to use and this also applies to the selected products of this study. This is a relevant and interesting barrier that is also likely to be present for other disposable medical products beyond this research. There may be several reasons for this: one being that product innovation was mainly happening on the side of disposables which led to disposable products being adapted to the needs of the users. At the same time, reusables might have not been relevant products to innovate further since the majority of customers continuously bought disposables.

However, it is important to stress that for many disposable products reusable alternatives exist, so it is recommended to test these to evaluate whether they fulfill the requirements in terms of convenience and practicality. These insights could then be discussed with the producer. More specifically, the information on how potential unpractical product characteristics could be improved could provide them with the opportunity to innovate on the reusables. However, although the inconvenience can be minimized by product optimization, often reusables may still be more inconvenient. Single-use materials are designed to be convenient for the user. Therefore, lastly, it is also essential to compare the benefits of using a circular product to the losses of neglecting the previously chosen disposable one. It could be that the benefits might outweigh smaller losses regarding the convenience of the product.

Another organizational barrier that was present when discussing the blood pressure cuff and finger pulse oximeter, is the *responsibility and workload of cleaning reusable products.* It was highlighted that the cleaning process when using reusable blood pressure cuffs or finger pulse oximeters might pose a barrier since it is up to discuss who should be responsible for disinfecting them as well as the additional workload that is connected to it. Since other departments at UMCU already use, for example, reusable blood pressure cuffs and also in other hospitals in the Netherlands it is common practice to use these, it is advisable to reach out to them to learn from their experiences. Engagement with other departments within UMCU is further recommended to get their support to implement the same system of blood pressure cuffs and finger pulse oximeters throughout the whole hospital.

This is also useful to overcome another organizational barrier mentioned, namely that different types of connectors of the blood pressure cuffs are used throughout

UMCU which can make it difficult to implement alternative systems favoring circularity. Therefore, also to overcome this barrier, engagement with other departments is needed to implement one system at UMCU that leads to patients using ideally only one reusable blood pressure cuff throughout their stay in the hospital.

Another barrier that could emerge when needing to clean reusable medical products is the *standardization of the OR preparation, cleaning and sterilization procedures and policies.* During the interviews with the sterilization department, it was mentioned that specific CSA practices are too stringent and might hinder the adoption of reusables. For example, the standard that everything that leaves the CSA department will be sterile even though some of the products might not need to be sterilized for usage requires unnecessary financial, natural, and human and resources.

Additionally, the overarching barrier was also highlighted when discussing the blood pressure cuffs, the finger pulse oximeters and the surgical table sheets. Regarding the cleaning, it was stressed that the disinfecting/ sterilizing of reusable products should align with the common producers present at UMCU. To do so, it is useful to map the "way" of reusables to understand if and how the cleaning of the product might deviate from standard procedures. Additionally, it is advised to review the current cleaning and OR preparation procedures in such a way that the use of reusables is encouraged and not seen as a problem or additional workload.

Logistical aspects form another organizational barrier. Reusables challenge the traditional way of operating also in the logistical functioning of a hospital. Generally, it was highlighted during the interviews *reusables require more complex logistics.* For example, concerning the blood pressure cuff and the finger pulse oximeter, the *fear of running out of products when relying on reusables* was specifically pointed out. Always when deciding to work with reusables, it is essential to calculate the number of needed products for the OR complex and also include in the calculation some additional spare products.

More specifically the logistical challenge of *reusables requiring more complex logistics* was mentioned when discussing the surgical table sheets. To prepare the logistics for the increasing use of reusables, it is proposed to again map the "way" of a, for example, reusable surgical table sheet to understand what logistical requirements need to be fulfilled and to review procedures to favor the use of reusables in general.

Another general organizational barrier to circularity that is applicable for various medical disposables refers to the *hospital's structure and way of operating which may slow down change* also concerning circularity. For example, the thinking in hospital divisions and not as an entire hospital makes the implementation of certain changes difficult. Additionally, sometimes crucial departments, such as the procurement department are not involved in the process of changing from reusables to disposable products. Moreover, it was emphasized that some hospital policies have been favoring the usage of disposables. This aspect is closely connected to the third organizational

barrier about uniformity and standardization of procedures and policies.

Another barrier linked to the hospital's way of operating refers to the short-term thinking in terms of purchasing medical products. During the interviews, it was stressed that the procurement department is involved too late in the purchasing process. More specifically, it needs time to look ahead and assess which contracts are ending next and then do the research about which circular alternatives exist on the market that could replace a certain product. Additionally, it takes time to engage with suppliers and give them the chance to innovate and make a circular proposition. However, the current way of operating is characterized by planning on a short-term basis.

Additionally, since the different medical divisions could choose the suppliers they wanted to work with, UMCU is working with around 150 vendors at the moment. This high number contributes to several issues the hospital is dealing with such as complicating the hospital structure and the work of the procurement department, making the implementation of changes more difficult and reducing the negotiation power of the hospital.

The last organizational barrier that was specifically observed by UMCU's procurement department is that the *hospital has limited purchasing power.* It was pointed out that when discussing medical products with suppliers, they do not start directly with innovations or changes if only UMCU as a hospital asks for them. This may hinder and slow down the transition to circular medical products.

3. Behavioral barriers

Behavioral barriers to circularity were expressed regarding medical disposables in general and more specifically when discussing the diathermy pencil.

First, it was pointed out that medical staff might have *a personal preference towards disposables* since disposables have become the standard product to be used over the last decade. Second, more specifically concerning the diathermy pencil, a *negative incident with a reusable*, alternative product (a surgeon burnt his hand when using it) further affected the trust in reusables and preference for disposables. Therefore when changing to reusables it is important that medical staff is introduced to the new product and that the opportunity is given to test it and get familiar with it. It might be an idea to ask a couple of surgeons from different specialties to test multiple products to gather feedback and then, also based on the experience of the surgeons, make a decision on which new product will be implemented. At the same time, it might be beneficial to highlight the additional benefits of using it, namely reduction of waste, less use of raw materials, etc., while directly connecting the decision to the hospital's circularity goals.

4. Financial barriers

In general, it was pointed out by different UMCU departments that the *hospital's focus on saving costs may* favor the purchase of disposables and hinder the adoption of circular and/ or sustainable alternatives to disposable medical products.

More specifically, for three products – blood pressure cuff, finger pulse oximeter and surgical table sheet – it was emphasized, that switching to reusables requires *high initial investments*. Reusables might be more expensive at the beginning, however, it is likely that already after a couple of years they will become cheaper than disposables. Evidence for this cost reduction can be found in the study conducted by Sanchez, Eckelman and Sherman (2020). They assessed reusable and disposable blood pressure cuffs focusing on comparing the environmental and economic impact of these. They found out that if patients use the same blood pressure cuff throughout their stay, "reusable cuffs are more economical" (p. 1). Therefore, it is advisable when adopting reusable blood pressure cuffs to assign one cuff for each patient throughout the whole patient's stay.

In general, it is recommended to make detailed calculations and include a long-term perspective to emphasize the financial benefits of adoption reusables.

5. Legal barriers

A legal barrier to circularity that was underlined during the interviews with UMCU's infection prevention and sterilization department refers to the *Instructions for Use* (IFU) of medical products. The IFU is part of the Medical Device Regulation (MDR) and comprises among other aspects a description of the intended use and purpose of the respective product. The interviewees stated that sometimes the intended use of a product is formulated quite rigid, more specifically, when referring to the number of cycles a product can be used. Sometimes the number of cycles a medical product can be used is reduced to one per patient, even though, more usage cycles may be possible without significantly increasing the risk of infections. This may hinder the adoption of more circular strategies such as the 'Reuse' of medical products.

Closely linked to the challenges related to the IFU is another barrier that refers to *suppliers not fulfilling their post-market surveillance duty*. The post-market surveillance is also regulated in the MDR and, among other things, obliges manufacturers to monitor the usage and performance of their products. However, an interviewee stressed that often suppliers do not comply with this obligation. This may be a barrier to circularity since post-market surveillance is also an opportunity to improve the product and its instructions for use. The interviewee elaborated by stating that if, for example, a hospital uses a product for more cycles than stated in the IFU after the hospital has assessed that there is no additional risk for the patient, the manufacturers of this product might need to update their IFU including the new information. This could then contribute to a product being used more circularly by, for example, reusing it for more than one patient.

6. Market barriers

When discussing the circularity of medical products during the interviews with different UMCU departments two market-related barriers emerged. First, it was stated that in the healthcare sector there is only *a limited number of suppliers that are engaged in sustainability* and offer sustainable alternatives to disposable medical products. This barrier can hamper hospitals in their sustainability ambitions, especially when the organization has a willingness to change but this change is slowed down by the limited availability of products on the market.

This barrier is directly linked to the second one which refers to the *short-term money-driven mindset dominating the healthcare sector* which focuses on investments in medical disposables and hinders circular innovations. The present paradigm and change of business models of companies offering disposable medical products instead of reusables led to companies being most profitable by selling disposables.

Barriers to circularity at the supplier level

The extension of this research project allowed us to conduct interviews with the suppliers of the selected products to investigate the barriers to circularity from their point of view. As mentioned in the methodology chapter, it was not always possible to receive specific information for each product instead barriers to circularity for disposable medical products, in general, were expressed.

Overall, barriers regarding each overarching barrier category could be identified, as can be seen in Table 2. Compared to the findings from UMCU, the suppliers also touched upon several technological and information barriers which are very similar to those mentioned by UMCU internal staff.

In the following, the barriers will be explained in detail. However, if the barriers match the ones from the previous chapter, they will only be mentioned briefly. If possible, specific information for the investigated products is given, if none of the products is mentioned the information refers to disposable medical products in general.

1. Technological and informational barriers:

Also when discussing circular alternatives to disposables with the suppliers, *issues related to sterilizing and cleaning a product* were expressed. The interviews validated and extended the findings from the roundtable and beyond the information that was given during the first part of this research, the suppliers also pointed out that specifically hollow and small instruments (e.g. trocars) are difficult to be sterilized. Furthermore, these small instruments are at risk of being damaged in standardized CSA processes.

The second and third technological barriers, that are given in Table 2, namely the *potential infection risks of reusables* and *the sometimes better quality of disposables*, were also perceived as barriers by the suppliers as well as by UMCU staff. Concerning the latter, it is noteworthy to add that one interviewee pointed out that the quality and characteristics of disposable products make these products sometimes the best versions since they are designed and intended to be used only once.

Another technological barrier that was highlighted and not expressed before was that *recycling certain disposables may be difficult.* As an example, the surgical table sheets were stated. More specifically, the combination of different materials (in this case a type of plastic and paper) makes it not possible to recycle surgical table sheets how they are designed at the moment with existing technologies.

Lastly, also when discussing the topic of circularity and sustainability with the suppliers, a *lack of knowledge about the best alternatives to disposables products in terms of sustainability* was observable. This corresponds with the findings from UMCU and it becomes evident that there is expertise missing in the field.

2. Organizational barriers (Hospitals):

One organizational barrier was expressed by multiple suppliers and it refers to the *lacking willingness to change within hospitals.* The suppliers experienced that hospitals often seem to not want to change

the way they are operating. More specifically, when discussing medical disposables, hospitals frequently do not want to start using a different product because they are satisfied with the disposable product they are using at the moment. Generally, it was emphasized that the healthcare sector can be very slow and characterized by conventional thinking when adapting to new ideas and changes.

3. Behavioral barriers:

Two behavioral barriers emerged when discussing disposable medical products and circularity with the suppliers.

The first one, which was pointed out by two suppliers refers to *reusables might being perceived as less hygienic* compared to disposables. The change to using disposable medical products instead of reusable ones has become dominant in the last decades and might have also affected the personal perception about reusing products. Since the standard has shifted to throw products away after one use, washing, disinfecting and/ or sterilizing might not be recognized as hygienic as the use of disposables.

The second behavioral barrier is linked to the prerequisite of *careful sorting of medical products when using reusables.* One supplier specified that for reusables medical staff or cleaning companies must sort the products correctly. They elaborated that there have been incidents with reusable surgical table sheets that have not been separated accurately from other products and then a patient was placed on a sheet that still had electrodes in it. Even though this might have been an exception, it is important to highlight the fact that reusing medical products comes along with the requirement of sorting these products correctly.

4. Financial barriers:

When discussing the financial barriers with the suppliers, it became apparent that they also frequently stressed the *price of reusables as too high for hospitals* to adopt them on a larger scale. Additionally, also the sterilization of certain products, such as smaller trocars used in ophthalmology might be too expensive and require too much work.

Additionally, it was stated that when discussing reusables with hospitals, the suppliers experienced hospitals interested in purchasing more *sustainable* alternatives, however, preferably to the same price as the disposables. The interviewees emphasized that this is at the moment too difficult to realize and not profitable for them.

Finally, one interviewee stated that for some products, such as surgical table sheets, *product innovation might not be profitable* since the product group is too small and the disposable product is too cheaply available on the market.

5. Legal barriers:

Concerning legal barriers, the *Medical Device Regulation (MDR)* that is applicable for one year was stated as a barrier. More specifically, one supplier expressed that the company strived to change the packaging of a certain product to bio-degradable packaging. However, they stated that that was not possible due to the MDR. Another supplier indicated that the MDR includes a lot more requirements and that these make it more difficult to bring a new product to the market due to long

review times. More precisely they pointed out that it will take years before products will be implemented in the market. This may also be a barrier for products that are focused on adopting circular strategies since it slows down the process of bringing a product to the market.

6. Market

As the last barrier, a market barrier was mentioned by one supplier, namely that the *Dutch sales market may be too small for innovation*. The supplier indicated that for the company the Dutch sales market does not play a significant role and is not really interesting. This may hinder some suppliers' willingness to change also in terms of circularity, especially, if the Netherlands is the only market for the supplier that moving in a different direction from other sales markets.

Table 2: Overview of identified barriers of disposable medical products to circularity at the supplier level

Type of barrier	Potential barriers expressed by suppliers that may be applicable for various medical disposables
Technological and informational	Issues related to sterilizing and cleaning a product (due to design, material, technical features, CSA processes etc.)
	Reusables: Potential infection risk fror patients
	Quality of disposables sometimes better than reusables
	Recycling of certain disposables is difficult
	Lack of knowledge about best alternatives (in terms of sustainability)
Organizational (Hospitals)	Lacking willingness to change within hospitals
Behavioral	Perception that reusables are less hygienic
	Reusables sometimes require careful sorting from medical staff
Financial	Price and sterilization of reusables too high for hospitals
	Sustainability vs. higher costs
	Product innovation not profitable for some products
Legal	Medical Device Regulation very strict for introduction of innovative products
Market	Dutch sales market is too small for innovation

Circular strategies at the product-level

Using the results from the roundtable discussion and meetings with UMCU staff different circular strategies could be developed for the chosen disposable medical products. These strategies were created by applying the proposed framework of Potting, Hekkert, Worrell and Hanemaaijer (2017), as illustrated in Table 3.

The authors summarized several strategies aiming to increase circularity in the production chain. The Table underlines the importance of prioritizing the strategies by adding a number to each one. Some R-strategies contribute to a higher extent to circularity (strategies with a low R-number) while others add to circularity only to a smaller extent (strategies with a high R-number).

At the end of this Chapter, in Table 4, an overview of the different developed circular strategies linked to each product is given. As can be seen in Table 3, some R-strategies, such as recycling, did not play a significant role when developing the circular strategies for the selected products, but these might still be relevant for other disposable medical products.

Table 3: Circular strategies prioritized by R-number

Circular Economy	Strategies		
↑	Smarter product use and manufacture	R0 Refuse	Make product redundant by abandoning its function or by offering the same function with a radically different product
		R1 Rethink	Make product use more intensive: Sharing or multi-functionality
		R2 Reduce	Increase efficiency in product manufacture or use by consuming fewer natural resources or materials
	Extend lifespan of product and its parts	R3 Re-use	Re-use by another consumer of discarded product which is still in good condition and fulfills its original function
		R4 Repair	Repair and maintenance of defective product so it can be used with its original function
		R5 Refurbish	Restore an old product and bring it up to date
		R6 Remanufacture	Use parts of discarded product in a new product with the same function
		R7 Repurpose	Use discarded product or its parts in a new product with a different function
	Useful application of materials	R8 Recycle	Process materials to obtain the same (high grade) or lower (low grade) quality
Linear Economy		R9 Recover	Incineration of materials with energy recovery

Note. Adapted from "Circular Economy: Measuring innovation in the production chain," by J. Potting, M. Hekkert, E. Worrell, A Hanemaaijer, 2017, p. 5 (https://www.pbl.nl/sites/default/files/downloads/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf)

In the following section, the five developed circular strategies (A-E) are explained, which are the following:

- Strategy A: Change to an entirely reusable product
- Strategy B: Change to using mainly a reusable product and use a disposable one under certain circumstances
- Strategy C: Change to using a modular product (combining reusable with disposable components)
- Strategy D: Change to using a reusable including a disposable cover
- Strategy E: Change to using a disposable, biobased product

Also, specifications for individual products are given and the role of innovation is touched upon since some strategies require more innovation than others.

Strategy A: Change to an entirely reusable product

R0: Refuse

R1: Rethink

R2: Reduce

R3: Reuse

In our opinion, all products can be exchanged by adopting different, reusable alternatives, which is the first proposed circular strategy. These alternatives would then need to be washed, disinfected and/or sterilized after each use (depending on the requirements of the respective product). As indicated by the different R-strategies that this approach applies, it is greatly contributing to a circular economy by reducing the amount of waste to be incinerated drastically and reusing materials as long as possible, and not disposing them after each use. Additionally, implementing reusables would contribute directly to the hospital's goal to become circular. Interestingly, regarding all products, reusable alternatives have been used at UMCU in the past; and reusable blood pressure cuffs are still used at other medical departments at UMCU at the moment.

For all products, alternative reusables still exist on the market and they should be tested to evaluate if they fulfill the technical and safety requirements. Generally, like already mentioned above, it is useful to discuss the desired product features directly with the producer, in case the available reusable is not sufficient, and communicate clearly the demand for an improved reusable product.

More specifically, for example, regarding the diathermy pencil, the smoke evacuation system is crucial for the safe use of the product. Reusable versions of the diathermy pencils are available on the market and also reusable smoke evacuation systems can be attached to either disposable or reusable diathermy pencils that do not have this integrated yet. Therefore, it is recommended to test these and assess if they fulfill the technical and safety requirements.

Regarding the blood pressure cuff and the finger pulse oximeter, both products are not only used in the OR but other departments at UMCU. Therefore, the reusable products could stay with the patient when being transferred to another department (if needed) and extend the positive impact of using reusable products to the whole hospital. Additionally, these

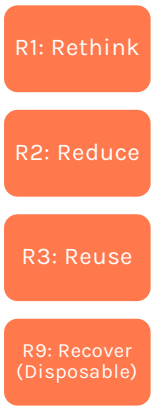
'personal' medical products reduce the cost of cleaning the reusable and, hence, make these products also economically favorable.

Also for the surgical table sheets, reusable alternatives exist, ranging from cotton sheets to sheets designed for different levels of required absorption of fluids during the procedure. Traditionally, cotton sheets were used to place on the OR table and were reused after washing these after each surgery.

chosen due to ill-defined usage criteria or confusion. To prevent this strategy from being misused, it requires a classification of the reusable and disposable products concerning the medical procedure. Instead of using one product that fits all surgeries, an educated person or procedure is necessary to select the proper product.

If adopted effectively, this strategy can reduce the amount of waste from surgical sheets and could be an intermediate step before moving entirely to reusables.

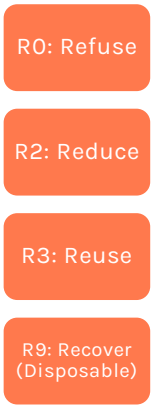
Strategy B: Change to using mainly a reusable product and use a disposable one under certain circumstances



The second strategy also strives to use mainly reusable products, except for using disposable products under specific circumstances. This approach addresses the same R-strategies as the first one, except for R9 (Recover) for handling the disposable product.

Even though this strategy can be applied to all of the selected products, we chose to only propose it for the surgical table sheets. This is because for this product it seems to be most appropriate to only use disposables when the surgery demands it, namely when the procedure requires a high absorption rate of fluids. This requirement clearly defines when to use a disposable product and if this condition is not given, the standard is to use reusables. However, it is important to stress that the use of disposables should be indeed the exception and that disposables are not

Strategy C: Change to using a modular product (combining reusable with disposable components)



Further combining reusable and disposable components comprise the third circular strategy. This strategy follows the idea to design a product in a modular way so that the main part of it (for example, in the case of the diathermy pencil the wire and the pencil itself) can be reused by cleaning it and another part (for example, the blade) can be detached and disposed after each use. Besides the diathermy pencil, this strategy might be also applicable for trocars and the finger pulse oximeter.

It is important to note that this strategy might entail an innovative rethinking of the current product to develop a product that can be used in a modular way in case no modular alternatives are available yet. Therefore, it might be very useful to collaborate with the products' producers and to communicate the needs directly to

the producers, so that they have the opportunity to innovate and create a product that fulfills the needs.

Regarding the trocars, participants from the roundtable discussion have expressed that a supplier has already presented trocars to UMCU that are made of reusable and disposable components. Also in the past reusable versions of this product have been used, however, the disposable trocars that were invented had improved technical features, so these instruments were adopted by UMCU. The conversations with the medical staff showed that the disposable trocar functions very well and that it solved challenges that were arising from the use of reusable trocars. Hence, innovation mainly occurred on the side of the disposable product. The new reusable versions presented to UMCU could be tested to evaluate if they fulfill the technical requirements of trocars and could be potentially introduced to the OR at UMCU again.

This strategy, even when not focusing on using an entirely reusable product, would still positively reduce the amount of waste and could accelerate innovation on the side of reusables.

Strategy D: Change to using a reusable including a disposable cover

R3: Reuse

R8: Recycle (Disposable)

R9: Recover (Disposable)

The fourth strategy combines the use of reusables with applying a disposable cover and is suggested for the blood pressure cuff, finger pulse oximeter and surgical table sheets.

When, for example, using a reusable blood pressure cuff, a disposable cover could be placed on the cuff or the arm of the patient to prevent direct contact with the skin. The product itself could be reused multiple times while the cover would be disposed after each patient. Disinfecting the product after each use might then be unnecessary and, hence, tackle the perceived barrier of additional workload and responsibility of the cleaning of reusables.

This strategy could also be adopted for the finger pulse oximeter and the surgical table sheets. However, for the finger pulse oximeter, it is under question if the reusable product can still function properly when a cover is placed on the finger or the product itself. This would need to be tested and evaluated.

The reduction in the amount of waste would not be as great compared to the first strategy. However, there might be a possibility to recycle the covers if separated and disposed of correctly since the degree of contamination is low. Another idea could be to produce the cover from a material that is being wasted from another manufacturing process (by-product) to be less reliant on raw materials and close the circle of circularity.

Strategy E: Change to using a disposable, biobased product

R1: Rethink

R9: Recover (Disposable)

The last circular strategy is to change to using a disposable, biobased product when possible. This strategy could be adopted for the surgical table sheets. By using a biobased product, the dependence on finite raw materials decreases. The strategy

would become more circular by using a material that is wasted from another industrial or agricultural process. Then the waste from one production chain would become a resource for another, which is favorable when aiming to create a circular economy. The development of such a sheet might require cross-industry collaboration and innovation to identify waste streams that might be useful for the production of a surgical sheet.

It is important to highlight that although this strategy focuses on adopting biobased materials, the product itself is still a single-use, disposable product and, therefore, does not address many of the prioritized circular R-strategies.

Table 4: Overview of developed circular strategies per disposable medical product

	Strategy A: Change to entirely reusable product	Strategy B: Change to using mainly reusable product (disposable for exceptions)	Strategy C: Change to using a modular product (reusable + disposable component)	Strategy D: Change to reusable with a disposable cover	Strategy E: Change to disposable biobased product
	R0: Refuse R1: Rethink R2: Reduce R3: Reuse	R0: Refuse R2: Reduce R3: Reuse R9: Recover (Disposable)	R1: Rethink R2: Reduce R3: Reuse R9: Recover (Disposable)	R3: Reuse R8: Recycle (Disposable) R9: Recover (Disposable)	R1: Rethink R9: Recover
Diathermy pencil	✓		✓		
	Alternative products available on the market. Innovation might be required to integrate smoke evacuation		*Innovation required to design modular product*		
Trocars	✓		✓		
	Alternative product available on the market – Test technical features		*Alternative product available on the market – Test technical features*		
Blood pressure cuff	✓			✓	
	Alternative product available on the market and used by other department at UMCU			*Arm cover available on the market*	
Finger pulse oximeter	✓		✓	✓	
	Alternative product available on the market		*Innovation required to design modular product*	*Innovation required to assess if product still functions when using a cover*	
Surgical table sheet	✓	✓		✓	✓
	Different alternatives available on the market	*Implement standard to use reusable sheet unless a surgery requires high absorption of fluids*		*Use reusable sheet with thin disposable sheet for every procedure*	*Innovation: Is it possible to use biobased material that is by-product from another process and would get incinerated?*

5. GENERAL RECOMMENDATIONS TO THE HOSPITAL: UMCU

Based on the developed circular strategies and recommendations given at the product-level several general recommendations could be formulated at the hospital-level that enable the implementation of circular strategies at UMCU. Moreover, these recommendations support the hospital to achieve its goal to become fully circular by 2050. It is important to note that these strategies are not mutually exclusive and can be strengthened and complemented by further research on this topic. In the following, six recommendations at the hospital-level are presented.

1. Define clear governance, engagement and communication and information streams

The findings demonstrate that there is a lack of governance concerning the direction and steps UMCU strives to take towards achieving circularity, more specifically at the product-level. Also, a lack of information and knowledge about circular alternatives regarding the chosen products could be observed.

However, a clear direction, leadership, distribution of responsibilities and communication and information streams are vital for engaging others in the topic and implementing circular strategies successfully. To do so, the formulation of concrete steps that are needed on product- and hospital-level to achieve the overarching goal to become circular in 2050 is essential. These steps should include clear administration and specification on how these actions contribute to the overarching goal. This research forms a starting point to develop a stepwise procedure for the selected products to move towards circular alternatives. Additionally, it was stated by multiple interviewees that it is crucial to distribute clear responsibilities and also authority to initiate change in terms of circularity within the hospital. This can be achieved by policy rules, making professionals responsible for this, or, for example, establishing a sustainability group that is responsible for driving change and innovation within the organization.

Also equally important is the continuous, hospital-internal communication of the hospital's strategy. Spreading awareness about circularity throughout the hospital and making UMCU's ambitions tangible for its employees, can help to enable engagement in the topic and allows the workforce to translate circularity into their daily work. This engagement could be further facilitated by providing opportunities for employees to incorporate circularity into their personal growth objectives, for example, by offering courses and other educational possibilities on this topic.

Lastly, sharing good practices of circular alternatives within and outside the hospital is important to increase the reach of this type of information and allow other stakeholders to get involved.

2. Choose and use circular alternatives first

For UMCU to move continuously towards increasing circularity throughout the whole hospital, it is crucial that circular alternatives are chosen first and foremost. Align with the recommendations given by Mac Neill et al. (2020) this means, for example, reviewing current procurement policies to favor circular alternatives over disposables, and also restructuring the OR standardized procedures, such as the preparation and cleaning procedures, in such a way that circular alternatives can be more easily implemented and are preferred.

This could be facilitated by a hospital-wide policy such as '*Circular unless…*' or '*Comply or explain*'. Both strategies aim to primarily adopt circular products and approaches unless there is a legitimate explanation given why not to do so. This could further reduce the barrier '*Convenience and practicality'* that was expressed related to all investigated disposables, since choosing disposables would become more and more difficult if no valid reason can be given. Even though this restructuring requires organization-wide engagement and consent, it is especially recommended since UMCU has committed itself to use 50% less primary raw materials and becoming entirely circular by 2050 and this approach directly contributes to the achievement of these goals. Furthermore, this policy may also address one organizational barrier that refers to a hospital having difficulties changing due to resistance coming from the conventional way of operating in the healthcare sector.

Furthermore, in the case that disposables are perceived as indispensable for a medical procedure, it can be very insightful to hear the reasons for this need for disposables. In some cases, these reasons could also be used to communicate to the producers to encourage them to innovate in the area of reusables (see recommendation 6).

3. Get support from essential UMCU internal departments

As indicated, the above-mentioned strategy to favor circular strategies requires engagement from multiple departments, especially from procurement, sterilization, medical staff, logistics and waste management. Since circularity addresses various steps of a product's lifecycle, from its production until disposal, all departments whose working practices are involved in this product lifecycle need to participate during the process. Only then the circular strategies on product-level can be implemented successfully. Therefore, it is recommended get engage these departments early in the process and potentially assign 'Circular agents' in each one also addressing the lack of clear governance and responsibility.

More specifically, considering the proposed circular strategies at product-level, especially the sterilization department (CSA) is a fundamental department to be engaged since the strategies often adopted 'Reuse' as a possible circular solution. Therefore, it is recommended to professionalize and improve disinfecting and washing processes and capacities. Additionally, reparation and collection activities might enable the implementation of other R-strategies and make it is easier for different medical specializations to become circular.

4. Aim for the highest circularity level

It is important to note that the circular strategies explained in Chapter 4 vary in their impact and circularity level. As can be seen in Table 3 on page 24 strategies such as refuse, rethink and reduce are contributing to a greater extent to a circular way of operating than, for example, recycling. Some strategies might be easier to implement than others, but also the positive impact of more straightforward strategies might be limited. Therefore, whenever possible it is advised to adopt circular strategies that are higher on the list of circularity since those have a greater positive impact. To do so, an organization-wide policy that favors circular approaches (mentioned in recommendation number 2) could be very helpful. Generally, circularity should be a factor always being involved in the continuous search for medical and/or product improvements.

Furthermore, it is recommended to review current working practices and procedures having in mind the variety of circular strategies starting with 'Refuse'. During the interviews, the relevance of the first circular strategy 'Refuse' also became clear, which involves the question of whether all disposable products that are part of surgical procedures are actually used or are only used on very rare occasions. This underscores the importance of regularly evaluating the product selection for medical procedures so that medical disposables are not discarded even when they were not used.

Additionally, it is advised for the circular strategy 'Recycle' to strive to integrate the recycling of certain products into existing recycling processes instead of investing in the development of recycling technologies for specific medical products. Since cost-effective recycling requires high volumes of materials, focusing only on specific medical products for a certain recycling stream, might not result in the required volumes for recycling.

5. Share expertise and learn from other hospitals, networks, universities, etc.

This brief research showed that in the Netherlands multiple actors, such as hospitals or research institutes, are engaged in the topic of circularity in the healthcare system. Therefore, it is highly recommended to reach out to other hospitals to exchange experiences and learn from best (circular) practices. Since the final goal is to reduce the impact of the healthcare system on a national or even global level, we believe it is the best approach to share knowledge and establish cross-hospital research projects to accelerate the transition towards circularity and avoid repeating research.

Moreover, the interviews with UMCU departments as well as with the suppliers underlined the importance of hospitals collaborating to advocate jointly for circular medical products and to increase their negotiation power to stimulate product innovation in the market.

6. Engage with producers and suppliers

The findings highlight the current perception that reusables might be difficult to disinfect or sterilize.

Additionally, the opinion that the last reusables that were used did not have the technical features needed to satisfy medical requirements was observed. To steer innovation towards reusables and consequently improve their functionality and practicality, it is highly recommended to engage with producers of medical products that UMCU strives to use circularly. By formulating the needs from the work floor directly to producers, they recognize a demand for circular solutions and have the opportunity to react to those needs and hence start to innovate in this direction. The relevance of communicating the hospital's needs to the suppliers was specifically expressed by one of UMCU's suppliers as it is difficult for the company to understand their local needs. This engagement and exchange can greatly contribute to facilitating circular thinking in the healthcare sector and may also help to overcome the lack of information regarding available circular product solutions.

6. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

This research aimed to analyze different disposable medical products used in the OR at UMCU and explored possibilities for alternative, innovative and more circular uses of some of those.

The first three research objectives were answered in the previous chapters. First, five different disposable medical products – diathermy pencil, trocars, blood pressure cuff, finger pulse oximeter and surgical table sheets – were selected for this study. For these products, different types of barriers to circularity (technological and informational, organizational, behavioral and financial) were identified and recommendations on how to overcome these barriers at product-level were discussed. Additionally, general barriers to circularity that may be relevant for various medical disposables were summarized resulting in the formulation of two additional barrier categories, namely legal and market barriers. Furthermore, by interviewing four suppliers from UMCU barriers on the supplier level were identified and classified along the six overarching barrier categories. Afterwards, five different circular strategies addressing multiple R-strategies from 'Refuse' to 'Recover' were presented and specificities for each product were given. These findings led to the formulation of recommendations at the hospital-level on how to facilitate the transition towards circularity.

Before highlighting future research directions, some limitations of this study have to be pointed out. It is important to stress that the outlined barriers to circularity are most likely not all the barriers that are present for each product since not all relevant actors could be involved or were involved only to a small number (in the case of UMCU suppliers). Some of UMCU's external stakeholders, such as government-related actors were not included in this research. Moreover, the main focus was set on investigating only five different disposable medical products and therefore, additional barriers might be identified when analyzing other types of disposables.

Lastly, the fourth research objective, namely the formulation of future research directions that were identified throughout this study and are important to be addressed is described in the following. These research directions constitute the last level of this research, more specifically, the alliance-level. They are presented to further facilitate research on this topic based on the findings of this study. Four different main research directions were articulated and are presented in the following:

1. Further validation of the findings with additional stakeholders and product groups

Since the duration of this research was limited to six months, the aim was to gain an initial understanding of the barriers to circularity of selected medical products. Therefore, it is essential to further validate the findings in, for example, living labs to also address the limitations of this study.

Furthermore, it is important to investigate the barriers to circularity with UMCU

external stakeholder groups such as additional producers of disposable medical products, standardization organizations, healthcare insurances and central government-related actors. This would allow to get a more holistic understanding of the barriers to circularity and, hence, contribute to developing concrete solution pathways how to overcome these barriers.

Since disposable medical products encompass a variety of products differing, for example, in value, complexity and degree of contamination, it would be interesting to assess the barriers to circularity with additional products that differ from the ones selected for this study.

Lastly, it might be of added value to further validate the findings by including other hospitals in this research. This would allow examining what barriers to circularity for disposable medical products are present in their hospital environment, and what strategies for implementing circular solutions have been carried out successfully and what steps are taken in the future.

2. Analysis of the innovation system

The first research direction will also contribute to the second one, namely to analyze the innovation system of the transition to circular medical products instead of using disposables. This is desirable since the innovation system around circular medical products is quite complex including a range of different products and actors that are essential to engage with when moving towards a circular use of medical products and equipment. Understanding this system could be achieved by applying the mission-oriented innovation system approach developed by Hekkert, Janssen, Wesseling and Negro (2020). This approach is aiming to map various actors involved in the innovation system that contribute to achieving a mission targeting to solving a societal challenge. In this case, the specific mission is linked to the Green Deal and strives to adopt circular and socially responsible procurement strategies in the healthcare system.

Additionally, this approach could help to understand at a system-level the reasons why certain innovative and circular solutions, like reusables, are not implemented on a large scale and what is needed for these types of circular innovations to be successful. Understanding these barriers at a system-level is crucial to further develop interventions like national legislation, hospital policies, procurement strategies, circular design or other instruments to accelerate the transition to a circular healthcare system in the Netherlands. Furthermore, solution routes could be developed considering also other actors involved in the innovation system. Conducting these systematic analyses further allows to test and monitor the success of the implementation of these solution routes. Lastly, it enables sharing information to reduce the fragmentation of knowledge on this topic.

The outcomes of conducting research at the system-level could be used for the transition to a circular use of products and materials not only for the OR but might also be applicable for other parts of the hospital and other healthcare facilities.

3. Monitor success of the implementation of circular strategies

The circular strategies have so far only been developed and formulated in this research. One of the next steps is to put them into practice on the work floor. Also for research, it is insightful to monitor the implementation of these strategies and evaluate their success. Therefore, a longer study tracking the different steps during the implementation phase is needed and also to summarize the benefits and problems. This is especially useful for other hospitals that strive to move towards circularity but also for the same hospital to improve its strategy and evaluate its success.

4. Innovation procurement for medical disposable products

Lastly, academics could focus on assessing the importance and role of the innovation procurement approach for medical disposable products. This is especially interesting for medical products for which a circular alternative is not yet available or if this alternative does not fulfill the technical or safety requirements needed for the daily work. Innovation procurement might facilitate product innovation favoring circular solutions in the healthcare sector. Therefore, the engagement of hospitals and the communication of needs and challenges the hospital is facing to producers is essential. Researchers could monitor, facilitate and assess this process and its opportunities to contribute to a circular healthcare system.

In conclusion, these research directions are important areas to be investigated in the future and aim to accelerate the goals formulated in the Green Deal on Sustainable Healthcare. Moreover, this study provides the opportunity to further work on this topic by expanding the scope to other medical departments, hospitals and healthcare facilities.

To continue accelerating the research in this area, consortium building between UMCU and UU, the alliance circular hospital and other academic, private and societal parties as well as partners from the healthcare system is needed. Currently, future funding opportunities are assessed and by participating in the 2022-2023 NWA-ORC program which is part of the Dutch Research Agenda (NWA), we aim to further build the consortium and develop a systematic approach (see the link to the registered initiative on this topic: https://initiatieven.wetenschapsagenda.nl/en/initiatives/facilitating-transition-medical-disposables-circularity-operating-room).

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APPENDICES

Appendix A: Outline and discussion questions roundtable

Date: 15.02. 16:15-17:45

Aim of the roundtable:

- Understand usage of selected products in OR
- Collect potential barriers to more circular approaches of usage of these products
- Develop first strategies how to overcome specific barriers and create solutions

Outline:

Steps of the roundtable	Duration
1. Introduction to the project: Circular Hospitals a. UMCU b. Aim of the roundtable	5-10min *16:15-16:25*
2. Introduce product selection based on the small survey at UMCU	5min *16:25-16:30*
3. Explanation of questions/ structure of break-out rooms	5min *16:30-16:35*
4. Break-out rooms a. Functionality & Usage b. Experiences & Development c. Problems d. Solutions & Barriers	35-40min *16:35-17:15*
5. Summary of main findings & Discussion a. Each group presents its findings	20min *17:20- 17:40*
6. Conclusion a. Summary of the roundtable b. Outlook/ Next steps	Max. 5min *17:45*
	approx. 90min

Detailed steps of the roundtable:

1. Introduction to the project: Circular Hospitals (5-10min)
    a. UMCU
    b. Aim of the roundtable/ Why are we doing this?
- Mention Green Deal
- Stress motivation for medical staff to join the roundtable

2. Introduce product group selection based on the small survey at UMCU (5min)
- Stress that we include packaging of the products as well
    a. Diathermy pen & Trocars
    b. Finger pulse oximeter & Blood pressure cuff
    c. Surgical table sheets

3. Explanation of Questions for Break-out rooms (5min)
    - Explain division of break-out rooms per product
    - Will ask the same questions touching upon functionality, sustainability/ circularity of the product
    - Moderator will guide discussion and keep time in mind
    - Time: 35-40min
    - Afterwards, will come back together again and one person from each group will present the main findings

4. Break-out rooms: (35-40min)
    - Around 15-20min per product if two products will be discussed

    a. Functionality & Usage: (Ask specialists to introduce products)
        i. *How do you use this product, what is it used for and how is it disposed?*
            - *What is the degree of contamination?*
        ii. From first contact until disposal. *Guide us through the process of usage.* → Important to understand the ways/ pathways a product becomes obsolete

    b. Experiences & Development of this product over the years:
        i. *Have you been using this product more?*
        ii. *Has it always been disposable in the last 5-10 years? How has the product developed over the last 5-10 years?*
        iii. *What would happen if we would not use this product?*

    c. Problems/ Issues:
        i. *In terms of sustainability, do you think the way this product is used in the OR is an issue?*
        ii. *Yes, why? → Solution & Barriers (question d)*
            1. *In which step of the process do the problems appear?*
        iii. *No, why?*

    d. Solutions*:*
        i. *If you were to make this product more sustainable/circular (Connected to question d: for example use this product less, reuse, recycle, etc.) what aspects would you focus on?*
        ii. Barriers*: Why is it not used this way? What are potential barriers to a more circular use of this product?*
            - *In which part of the usage process do they appear?*

5. Summary of main findings & discussion (20min)
    - One/Two persons from each group will present the main findings
        - Short introduction to the product for the group
        - Name main barriers and possible solutions
    - Discuss similarities & differences between the products

6. Conclusion (5min)
    - Summary/ Recap of the roundtable
    - Outlooks/ Next steps
        - What we will do with this information
        - More partners within the Alliance to continue research
        - NWA-ORC proposal

Appendix B: Interview guide: Interview with infection prevention & CSA

General questions (20min)

1. Can you please briefly explain to us your daily tasks and work?
    a. How do you interact with other departments?
2. What process/ guidelines/ rules do you follow in your work?
3. How is success measured in your work?
4. What role does sustainability/ circularity play in your daily work?
    a. What steps/ goals are taken/set from UMCU, and your department specifically, concerning circularity and/or sustainability?
5. How does CSA/ infection prevention influence the purchase of medical products?

Product-specific questions & Barriers to circularity (30min)

6. What potential barriers to more circular strategies do you perceive for disposable medical products in general?
    a. Do you perceive different barriers for the selected products? *(Trocars, diathermy pencil, blood pressure cuff, finger pulse oximeter, surgical table sheet)*
    b. What barriers do you perceive when using, specifically more reusable medical products?

7. What would you need/ are you missing from the hospital to overcome these barriers?

8. Do you have any other comments or questions you would like to ask?

Appendix C: Interview guide: Interview with the procurement department

General questions (15min)

1. Can you please briefly explain to us your daily tasks and work?
2. What process/ guidelines/ rules do you follow when selecting the products to buy? (Quality, price, etc.)
    a. Who decides what product to order?
3. How is success measured in your work?
4. What role does sustainability/ circularity play in your daily work?
    a. What steps/ goals are taken/set from UMCU, and your department specifically, concerning circularity and/or sustainability?

Product-specific questions focusing on disposables (20min)

5. How are disposable medical products chosen?
    a. Are you aware of circular alternatives of the selected products?
        i. If so, why are disposables chosen when reusable alternatives exist?
6. Are you keeping track of sustainable innovations in the field of disposables?
7. How do you engage with suppliers? Do you engage with suppliers/ producers of these specific products to discuss circularity/ sustainability with them?

Barriers to circularity (20min)

8. What potential barriers to more circular procurement strategies do you perceive?
9. What could you in your daily work/ circle of influence do to change this?
10. What would you need/ are you missing from the hospital to overcome these barriers?

11. Do you have any other questions or comments concerning this topic?

Appendix D: Interview guide: Interviews with suppliers

General questions

1. Can you please give me a brief introduction of the company you work for and what your tasks/ position are?
2. What role does circularity/ sustainability play in your business and in your daily work?
    a. What goals are set by your company concerning circularity and/or sustainability?

Product-specific questions

3. Have you always offered this product only in a disposable way? Or do you also offer a circular alternative of this product?
    a. *If not*, why do you only offer this product in a disposable way?
    b. *If yes*, which one do you offer?
        i. Why did you decide to do so and what were your customers' reactions?
4. What steps are being taken by your company towards sustainability/ circularity specifically focusing on medical disposables?
5. What potential barriers to more circular alternatives of this product do you perceive?
6. What would you need/ are you missing (from the company) to overcome these barriers?

Engagement with customers & Innovation

7. How do your customers communicate their wishes in terms of circularity and/or sustainability to you and how do you react to these?

8. Do you have any other questions or comments concerning this topic?

Appendix E: Overview of disposable products highlighted as impactful by different medical specialties

Urology	Ophthalmo-logy	Trauma surgery	Anesthesio-logy	Gastrointes-tinal	Vascular surgery	OR Logistics department
JJ catheters & urethral catheters	Forceps	Diathermy pencil	Laryngoscope blades	Trocars	Diathermy pencil	Procedure trays
Loops and coagulation ball for transurethral resection	Surgical draping	Blue trays/bowls	Mask for ventilation	Laparoscopic suction/flush system	Harmonic device	OR isolation jacket
Instruments for Intuitive DaVinci surgical robot	Cassette for cataract surgery	Thorax drains SHE - Set	Finger pulse oximeter	Diathermy pencil	Endo GIA (Surgical stapler)	Blue, warm OR jacket
Draping for surgical robot	Irrigation/Aspiration Cannulas	Suture set SHE	Blood pressure cuffs	OR jackets	Suction device	Blanket 'Bair Hugger/ (Blanket to warm the patient)
Scott ring retractor	Syringes	Procedure set	Thermometer	Insufflation tube	Disposable magnetic mats	Kidney bowl
Surgical draping			OR caps			
(Non) sterile gloves			Surgical table sheets			
			Inco sheets			
			Kidney bowl			
			OR jackets			

Appendix F: Identified barriers and formulated recommendations at the product-level per selected disposable product

Diathermy pencil

Barriers	Recommendations
Technological and informational: Reusable products might be difficult to sterilize.	Involve producer of reusables and CSA department to test sterilizations at the location at UMCU and discuss the sterilization procedure.
Technological and informational: Health risk for medical professionals: Reusable pencil without smoke evacuation is a health risk for medical professionals due to breathing in the smoke.	- Involve producers and express this challenge to them so that they have the possibility to innovate and design a reusable product including smoke evacuation system. - Assess for which procedures it is necessary to have this smoke evacuation system (for all or a part of them)
Organizational: Convenience & Practicality: Disposable product is easy to use and convenient.	- Research if reusables are available on the market. If so, test them to evaluate the convenience and practicality of the reusable product. Discuss satisfaction/ problems with the producer to drive product innovation in favor of reusables. - Evaluate the benefits and losses of changing from disposables to a more circular product. (Environmental benefit might outweigh minor losses regarding convenience)
Behavioral: Personal preferences from medical staff towards disposables Negative incident with reusable product in the past (affects trust in reusable)	- Introduce a selected group of medical staff to multiple reusable versions for them to test them. Gather feedback and then decide which one to implement for the whole OR complex. - Highlight the benefits of using this product (Reduction of waste, less use of raw materials, etc.)

Trocars

Barriers	Recommendations
Technological and informational: The technical features and design of the disposables are better than the last reusable ones used at UMCU.	- New reusable trocars exist in the market. Possibility to try these to evaluate if they fulfill the technical requirements. - If they do not fulfill the requirements: Get in touch with producers and express the specific technical requirements to them to give them the possibility to innovate and improve their reusable product.
Technological and informational: Reusable products might be difficult to sterilize due to being hallow or sometimes small.	Involve producer of reusables and CSA department to test sterilizations at the location at UMCU and discuss the sterilization procedure.
Technological and informational: Possible health risk for patients when using reusables.	Involve producers and express this challenge to them so that they have the possibility to innovate and design a reusable product addressing the communicated needs.
Organizational: Convenience & Practicality: Disposable product is easy to use and fulfills technical requirements.	- Research if reusables are available on the market. If so, test them to evaluate the convenience and practicality of the reusable product. Discuss satisfaction/ problems with the producer to drive product innovation in favor of reusables. - Evaluate the benefits and losses of changing from disposables to a more circular product. (Environmental benefit might outweigh minor losses regarding convenience)

Blood pressure cuff

Barriers	Recommendations
Technological and informational: Cleaning might be a challenge due to the material.	Discuss with CSA, producer, other departments at UMCU and (if necessary) with other hospitals that use reusable BP cuffs how to best clean it.
Organizational: Cleaning of reusables: Responsibility & Workload	Reach out and learn from other departments (e.g. emergency room) and hospitals that use reusable BP cuffs. Engage with other departments to get their support to change the product within the whole hospital.
Organizational: Standardization of cleaning procedures. Cleaning of reusables should “fit” in these procedures.	Map the “way” of a reusable BP cuff to understand if and how the cleaning might deviate from standard procedures. Review cleaning procedures to favor also the use of reusables in general.
Organizational: Uniformity: Different types of connectors from the BP cuff are used throughout the hospital. Makes it difficult to change.	Check within UMCU which reusable BP cuffs, connectors and machines are used most and implement one system so that the patient can ideally use on BP cuff throughout the whole stay.
Organizational: Logistics: Fear of running out of products when changing to reusables.	Make calculations on how many products the OR complex would need and include additional spare cuffs.
Organizational: Convenience & Practicality: Disposable product is easy to use and convenient.	- Test reusable BP cuffs to evaluate their convenience and practicality. Discuss satisfaction/ problems with the producer to drive product innovation. - Evaluate the benefits and losses of changing from disposables to a more circular product. (Environmental benefit might outweigh minor losses regarding convenience)
Financial: High initial investment of reusables.	Make detailed calculations for the long-term. Reusables will be cheaper in the long-term.

Finger pulse oximeter

Barriers	Recommendations
Technological and informational: Cleaning might be a challenge due to how the reusable was designed in the past	Check what reusable alternatives are offered on the market. Discuss with CSA and producer how to best clean it.
Organizational: Cleaning of reusables: Responsibility & Workload	Reach out and learn from other departments and hospitals that use reusable finger pulse oximeters. Engage with other departments to get their support to change the product within the whole hospital.
Organizational: Standardization of cleaning procedures. Cleaning of reusables should “fit” in these procedures.	Map the “way” of a reusable finger pulse oximeter to understand if and how the cleaning might deviate from standard procedures. Review cleaning procedures to favor also the use of other reusables.
Organizational: Logistics: Fear of running out of products when changing to reusables.	Make calculations on how many products the OR complex would need and also include additional ones.
Organizational: Convenience & Practicality: Disposable product is easy to use and convenient.	- Test reusable finger pulse oximeter to evaluate the convenience and practicality. Discuss satisfaction/ problems with the producer to drive product innovation. - Evaluate the benefits and losses of changing from disposables to a more circular product. (Environmental benefit might outweigh minor losses regarding convenience)
Financial: High initial investment of reusables.	Make detailed calculations for the long-term. Reusables will be cheaper in the long-term.

Surgical table sheets

Barriers	Recommendations
Informational: Insufficient knowledge about the alternatives in terms of sustainability.	Conducting Life Cycle Analyses might indicate the environmental impact of the different alternatives.
Informational: Insufficient knowledge about what alternatives are the best for the different medical procedures in terms of absorption.	Discuss with medical staff for which procedures a more absorbent mat is needed. One standard mat could be used primarily with exceptions when a procedure requires a higher absorption of fluids.
Organizational: Uniformity & Standardization: Standardized procedure how to prepare an OR.	Map the "way" of an alternative, more circular use of OR mats to understand if and how the preparation and cleaning procedures might deviate from standard procedures. Review the procedures to favor the use of reusables.
Organizational: Logistics: Using reusable mats requires more complex logistics.	Map the "way" of reusable OR mats to understand what logistical challenges need to be overcome. Review procedures to favor also the use of other reusables. Have 1-2 alternatives depending on the procedure.
Organizational: Convenience & Practicality: Disposable product is easy to use and convenient.	- Research if reusables are available on the market. If so, test them to evaluate the convenience and practicality of the reusable product. Discuss satisfaction/ problems with the producer to drive product innovation in favor of reusables. - Evaluate the benefits and losses of changing from disposables to a more circular product. (Environmental benefit might outweigh minor losses regarding convenience)
Financial: High initial investment of reusables.	Make detailed calculations for the long-term. Reusables will be cheaper in the long-term.