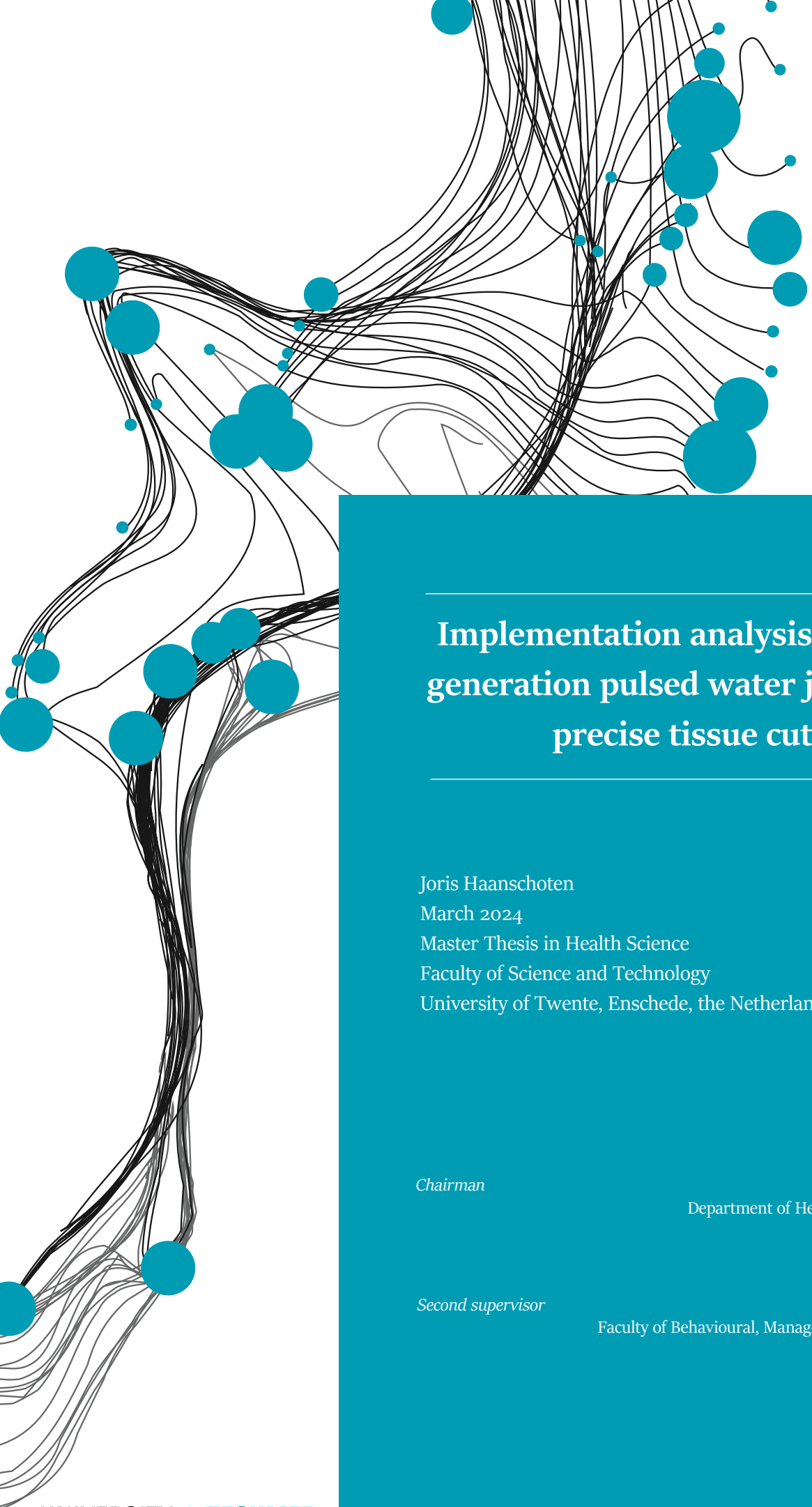

# Implementation analysis of a second generation pulsed water jet device for precise tissue cutting

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March 2024
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# Contents

## List of Tables



## List of Figures

# 1 Introduction

In today's society, with a growing demand for health care, health care innovations are key to establish a prosperous health care system for future generations. Effective translation from basic science to a standard care product requires tremendous effort, and many attempts fail to reach that goal [1]. For the development of medical devices, as less as 7-9% of medical devices that apply to the US Food and Drugs Administration each year reach their target of market approval [2]. This shows the immense complexity of medical device development due to the highly regulated aspects of the industry. More than other industries, medical device design is interdependent on existing health care systems, existing products and product users [3]. To reduce the clinical risks, business risk and regulatory risks for medical device developers as early as possible in the development process, an early implementation analysis or early health technology assessments now emerges as an evaluation method. These analyses aim to provide information on the potential benefits, risks, and costs of the technology, and to identify any potential issues that may need to be addressed before the technology can be introduced into clinical practice [4]. This typically involves a review of the available evidence on the technology, including the clinical need, involved stakeholders and any preclinical or clinical data that may have been collected. This information is used to estimate the likely impact of the technology on patients, healthcare providers, and the wider healthcare system, and to identify any potential challenges or barriers to its adoption. The results of an implementation analysis can be used to guide further development of the technology, to inform decisions about funding and reimbursement, and to support regulatory submissions. By conducting an implementation analysis, technology developers can make more informed design decisions, leading to a high quality final product.

One technology that is still under development and which could benefit from an early implementation analysis is that of surgical water jet cutting. This technology can be used in surgical procedures to precisely cut tissue using a high speed jet of water. Currently, the University of Twente is exploring the potentials of water jet surgery. A main benefit of water jet surgery is the promise that tissue selective cutting can be achieved. The water pressure directly relates to the cutting power of the water jet device [5]. By choosing the settings, it is possible to use the difference in mechanical properties of tissue to determine which tissue is dissected or not [6,7]. Therefore, it is hypothesised that the risk of complications could be greatly reduced for surgery around sensitive structures like nerves, blood vessels or brain tissue. Additionally, since water jet cutting is a cold machining technique, thermal damage to surrounding tissue can be avoided [8,9]. Also, the risks of toxic surgical fumes and fire hazards due to electrical shocks are eliminated [10]. The design of water jet applicators can be small, flexible, and easy to handle. Treatment of small anatomical sites could be made easier for surgeons compared to conventional rigid instruments, such as the scalpel, opening possibilities for use in laparoscopy [11]. Finally, because the cutting mechanism and tissue selectivity depend largely on the pressure used, a water jet cutting instrument can be versatile and could be applied during various surgical procedures. This could reduce the need for other equipment and thereby reduce costs [12]. Examples of applications that have already been investigated by other authors in either experimental setting, animal studies or clinical trials are: orthopedics [13, 14], liver surgery [9, 11, 15], gall bladder surgery [16, 17], lymph node resection [18], brain surgery [7, 19, 20], kidney surgery [21] and nerve preservation [6, 22]. In general, water jet dissection is applied in procedures that require extreme precision and benefit a reduced collateral tissue damage.

However, the advantages of water jet surgery have not yet been quantified for these applications, and neither have the advantages been outweighed to the disadvantages. Also, little information is known on the performance of water jet surgery compared to procedure specific competitors.

The Health Technology Implementation (HTI) group at the University of Twente has developed a pulsed water jet (PWJ) device for clinical use and has supervised multiple design cycles. By using a pulsed water jet, instead of a continuous water jet (CWJ), the researchers aim to improve the efficiency of the device, gain better control of the cutting depth and reduce water excess. Their latest report was set out to investigate the efficacy and feasibility of a second generation PWJ device for precise cutting of soft tissues [23]. This included development of a functioning prototype and verification experiments. The study reported that from the experimental results it can be concluded that the PWJ prototype operates within the theoretical framework and that the principle of PWJ technology is proven to be a viable option for use in soft tissue dissection. So, following after the research on surgical CWJs, proof of concept is being achieved. However, to prove the value and feasibility of the device, not only more experimental studies should be performed, but also the HTI group requires more information regarding the associated surgical procedures, additional requirements, implementation factors and medical device regulation. Up to this point in the development process, no external stakeholders were involved, while their input is critical. This report will describe an implementation analysis on the newly developed surgical PWJ device to identify stakeholders, and to provide an extensive overview of all relevant factors that can influence early development according to implementation theory.

# 2 Objective and research question

The main goal of this study is to summarise, evaluate and build new evidence on the surgical application of the PWJ device from the HTI group. Extra attention will be paid to identify stakeholders and to investigate how different stakeholders evaluate the clinical benefits of PWJ technology compared to traditional surgical techniques. Using their opinions, we hope to answer which surgical procedures would benefit the most from this new technology and should be the focus for further research. Although the device is still in an early state of development, an implementation analysis will benefit design decisions and help push the technology to a further level. This analysis should help stakeholders decide to further invest in this technology, eventually leading to its adoption in clinical practices.

The following research questions will be answered in this paper:

1. What are the main stakeholders in the development of a surgical pulsed water jet device and what is their role?
2. What are important requirements that have not been included in the development process yet?
3. What are the important strategic decisions that need to be made early in the development process?
4. Which surgical procedures should be the focus for future research and development in PWJ surgery?

# 3 Methods

A successful strategy to perform an implementation analysis is by applying aspects from one or more of the many technology implementation frameworks, choosing those that specifically tailor the needs and goals of your project [24, 25]. Well known and recent examples of implementation and innovation frameworks are the Med-Tech innovation guide [26], the Health-Tech Innovation Cycle [27], and the NASS implementation framework [28]. These frameworks will be used in this study to shape the structure of the report. By using the tools in the framework, and by performing some proposed development steps, this report will describe the project on the presented themes and milestones. In this way this report will try to answer the research questions stated above and will produce a complete overview of the technology including current status, future steps and important strategic decisions.

One of the innovation frameworks used in this study is the Health-Tech Innovation Cycle (see Figure 1), which provides a compact overview of ten phases that each health technology should go through during its development. Within these phases the device should be assessed on four domains, the clinical, market/business, regulatory and technology, with each domain bringing new deliverables in each phase. The first four phases of the cycle, which are the most relevant for the project at this stage, are elaborated in the table of Figure 1. This serves as a concise roadmap to evolve from a clinical need, to the first clinical trials. The complete cycle aims to accelerate the translation of research findings into tangible, impactful healthcare solutions [27] and the focus of this specific framework is on the reduction of four main risks. Clinical risks involve assessing whether the innovation will be accepted in workflows, leading to real improvements in outcomes and/or cost reduction. Business risk focuses on determining if there is a significant unmet need, with enough buyers willing to purchase the innovation at a sustainable price. The regulatory risk describes the capability to cope with all quality and safety requirements and the associated time and cost implications to complete regulatory processes. Technical Risk encompasses challenges related to the technology, including its protectability, functionality, and if it is future-proof compared to alternatives.

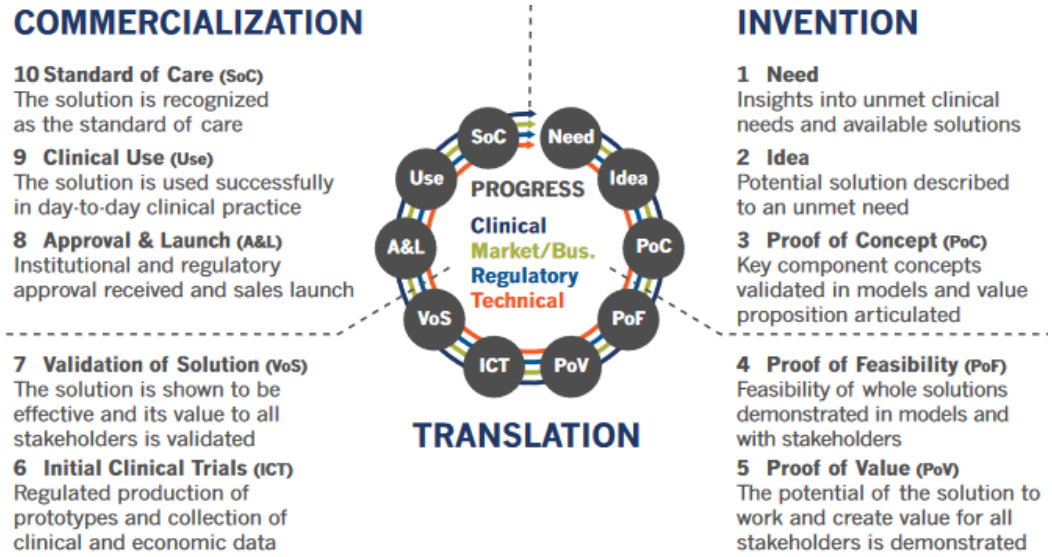


Figure 1: The Med-Tech innovation cycle [27]

The Med-Tech innovation guide has recently been developed as a much more extensive, step-by-step procedure for the innovation of medical technology. By combining the Health-Tech Innovation Cycle with other existing frameworks, it aims to streamline the development process by preventing interruptions as well as reducing the time to market approval [26]. The result is a framework, integrated in a web application, that is structured with much more themes, also including less pronounced themes such as sustainability, team formation, communication, and intellectual property (IP) rights. For each theme, the important milestones are described for the development phases: conceptualisation, concept validation, product development and product launch. The interactive web application, which is free to use, enables developers to use and share an entry level project management tool that integrates the Med-Tech framework as checklist. Functions for due dates, division of tasks, document inclusion and more are available as is illustrated in Figure 2. The Med-Tech framework also developed a way to validate the progress of your development by determining the clinical readiness level of your technology. This helps to prioritise next steps and understand the future perspective of the water jet surgery project. In this study a similar method will be used to evaluate the readiness of PWJ technology.

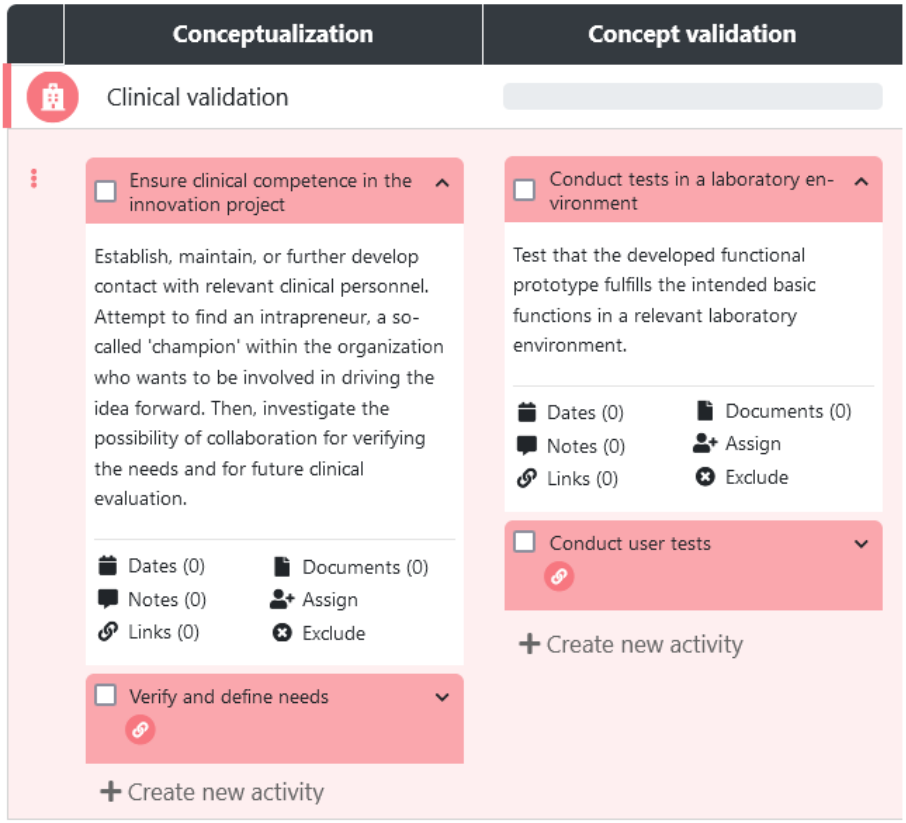


Figure 2: A Sample of the Med-Tech web application. In this sample, only the first two phases for the theme of clinical validation is shown. In total, the web application includes 4 phases for ten themes.

The last framework that will be used for this study is the NASSS health technology framework, which focusses more on implementation rather than innovation. For this framework, the authors specifically evaluated Nonadoption, Abandonment, and challenges in Scale-up, Spread, and Sustainability (NASSS) for new health care technologies [28]. Their model, which is included in Appendix C, provides a structured approach of identifying implementation barriers, starting small with the medical condition, and progressing via technology, value proposition, adopters, organisations to eventually the wider system. This process is an iterative process and should result in embedding and adaption over time. For this study, the added value of this model compared to the previous two lies within the extensive interview version of the framework, again see Appendix C. This version can be used as basis for a semi structured interview to identify implementation barriers and facilitators for stakeholders.

As displayed in Figure 3, to answer the research questions, this report will describe multiple research activities. The first is a systematic review set out to identify previous research and existing applications of water jet surgery. The second step will implement steps of the health technology frameworks, including: an evaluation of the clinical need for water jet surgery, a complete overview of the technology, a summary of all previously obtained preclinical data, and a stakeholder analysis leading to the identification of the most prominent stakeholders. Third, these stakeholders will be consulted for an expert interview modelled after the NASSS interview framework. All input will then be used to write a closing recommendation that will advocate to focus on one (or more) specific clinical treatments. Lastly, this study will describe the future steps with the highest priority, and highlight all important strategic choices that need to be made in the early development process.

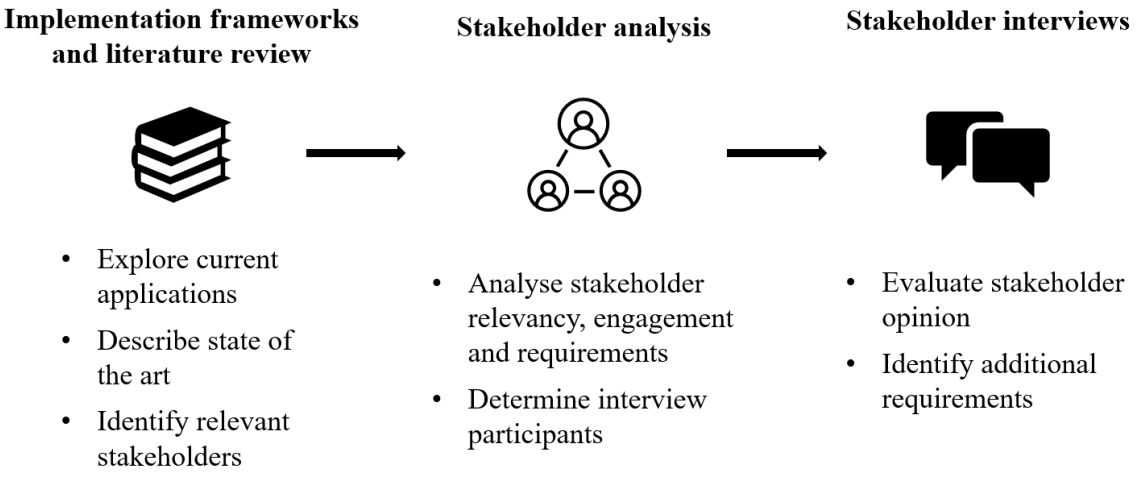


Figure 3: Order of research activities in this report.

# 4 Systematic review

One of the goals of this study is to investigate in how much of an improvement a PWJ device can be in different surgical procedures. By identifying the possible fields of application, PWJ technology development and design can be tailored to facilitate the correct scope from early on. As an initial exploration, a systematic review is performed to identify and classify the research that has already been done in the field of surgical water jets. In this way, we hope to gain more insight into the current state of the art and the clinical need for water jets. The knowledge gained this way can also help to define stakeholders and product requirements, and to identify market competitors. The systematic review was performed using the PRISMA guideline [29] and aimed to answer the following subquestions:

1. How can current experimental studies on surgical water jet technology be classified by medical field and procedure?
2. What are the main differences between the categories and how do they compare?
3. What competitor devices are mentioned in literature?

## 4.1 Sources of information

A wide search for relevant articles was performed using three digital databases: PubMed, Web of Science and Scopus. These libraries were chosen based on their relevance, reliability and importance, and they are among the most cited sources when it comes to topics surrounding soft tissue surgery [30].

## 4.2 Search criteria

For all three databases, the same search criteria was used. The search term was:

TITLE-ABS-KEY(Water AND Jet AND Dissection)

The search term was chosen to encompass all literature on water jets for medical use. The element "Jet" shifted the results towards the high pressure application of water, while the element "Dissection" was chosen instead of "Surgery" or "Cutting" as it best reflected the use of jets in a medical environment and specifically for the separation of tissues. Using the filter features that are available within the databases, the results were refined by excluding records that are older than the year 2000. Moreover, records that were not marked as article were also excluded. These were records marked as letters, comments, books or proceedings. The reason for this was that the goal of this systematic review was to identify experimental studies that use water jet technology to specifically address the medical application of water jet technology.

## 4.3 Study selection

The study selection process is illustrated in Figure 4. The initial query resulted in the amount of 611 entries combined from all three databases. After automated refinement by database filters, a total of 464 records were screened for duplicates by the author using Microsoft Excel. 233 Records were screened on title and abstract to remove records that did not describe actual clinical application of the technology (reviews, development studies, other water jets). A second analysis excluded records that did describe a similar

application, but with a different use or technology: not high pressure jets or jets for injection instead of dissection. Eventually, 165 studies were included for analysis. In this analysis, based on the full article, each study was classified per surgical field and per procedure of the water jet device. Also, it was noted if a study mentioned a brand or manufacturer of the device they were using.

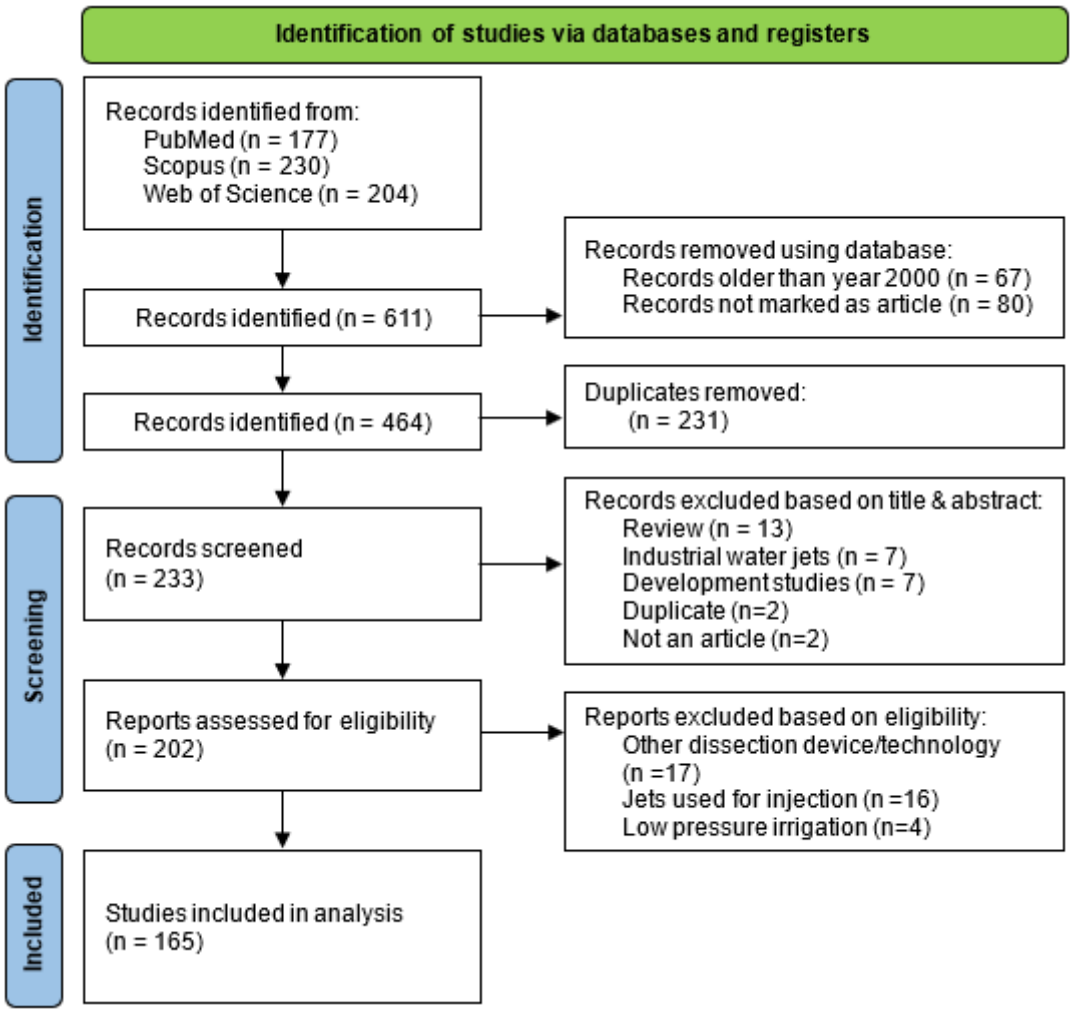


Figure 4: Flow chart of the selection process for the systematic review. From a total of 611 identified records, 166 studies were included in the analysis.

### 4.4 Results

In Figure 5 the included studies are classified per procedure type. Five classes were established based on the type of tissue or organ that was cut using a water jet device. It can be seen that more than half of the papers report use of water jet surgery for the dissection of soft tissue organs. In this group, mostly, the water jet dissector is used to cut between the natural separation of tissue layers of the parenchymal tissue, supportive tissue (stroma), nerves and blood vessels. Another large group is the dissection in the mucosa or submucosa layer of an organ. These tissues layers are particularly found in the gastrointestinal tract, but also in the urinary and respiratory tracts. The mucosa, which is a mucous membrane, comprises an epithelium layer, a layer of connective tissue, and a layer of smooth muscle. The submucosa is a tissue layer located just beneath the mucosa. It is primarily composed of connective tissue, blood vessels, lymphatic vessels, and nerves. Results for fatty tissue and skin are grouped because several examples in this group involve procedures in which water jet dissection is used to cut the fatty tissue layer of the skin. Harder tissues are the synovium, bone, bone cement and stone fragmentation.

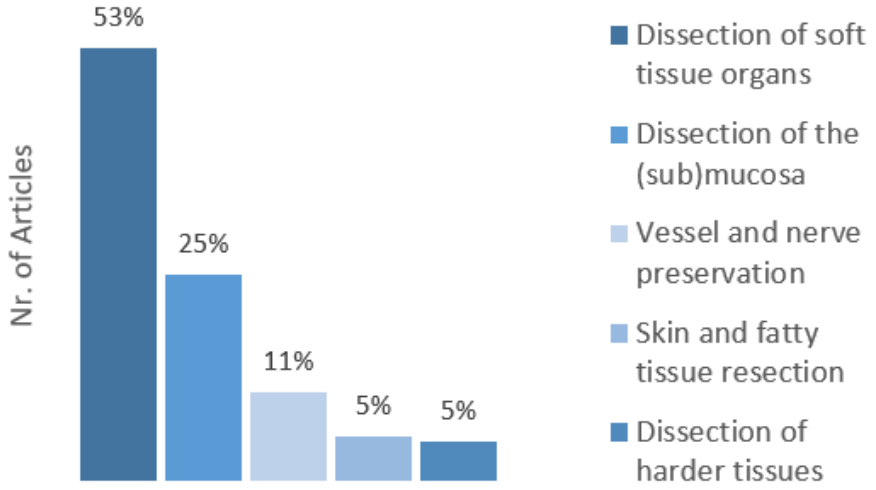


Figure 5: Classification of procedure types

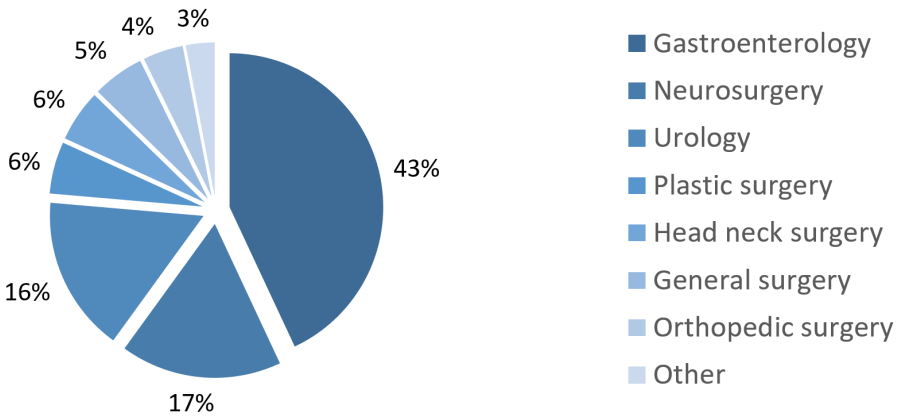


Figure 6: Classification of surgical specialties

Figure 6 provides an overview of the classification results for the different surgical specialities. The group of gastroenterology represents over 40% of the articles. To a complete overview of all the different treatments which were the investigated in one of the included articles, a word cloud was made. The size of the words represent the number of articles that reported the treatment as their main topic. From Figures 5, 6, and 7 it is notable that the research on water jet dissection is very diverse and no common consensus on the best application exists. This confirms the need for an implementation analysis and serves a motivation to complete more research on this topic. Although the classification of surgical procedures serves as an exploration of applicable topics for PWJ application, conclusions on the best possible application might be biased. The complexity of experimental studies in one surgical fields is not the same as in another, possible leading to skewed results.


Figure 7: Wordcloud of the treatments performed using water jet surgery as found in the systematic review. In total, 35 different treatments were identified. The size of the words represent the count of the treatment within the data set. Submucosal dissection was the most found treatment, with a total of 42 appearances.

From the papers several devices were mentioned as a golden standard comparative to the use of water jet surgery. Also several version of surgical water jet devices were identified. To get an overiew of the existing market in surgical instruments, Table 1 is presented below. From the table we can conclude that most surgical technology is produced by a few large Med-Tech companies. These are Medtronic, Ethicon (subsidiary from Johson & Johson), Olympus and Erbe. Other manufacturers are much smaller and specialise on one technology. Although very little information could be found on the Aquabeam and SpineJet, it could be concluded that devices that use water jet technology all used a CWJ. A limitation of this systematic review is that no clinical outcomes for these devices have been acquired. Also risks and and disadvantages were not fully documented.

Table 1: An analysis of the competitor market for surgical devices. Devices have been identified from the systematic review and supplemented by the results from the stakeholder interviews in Section 8.

| Technology | Device | Brand |
|---|---|---|
| **Water jet** | Erbejet | Erbe |
| | Versajet | Smith & Nephew |
| | Aquabeam | Procept BioRobotics |
| | SpineJet | HydroCision |
| **Electrosurgery** | LigaSure | Medtronic |
| | Enseal | Ethicon |
| | Aquamantys | Medtronic |
| | Erbe VIO | Erbe |
| | Dualknife | Olympus |
| | FlushKnife | Fujifilm |
| | HybridKife | Erbe |
| **Ultrasonic** | Thunderbeat | Olympus |
| | Harmonic | Ethicon |
| | CUSA | Integra |
| | Sonicision | Medtronic |
| **Plasma** | PlasmaJet | Plasma Surgical |
| | PlasmaBlade | Medtronic |
| **Laser** | $CO_2$ Laser | Deka |
| | Nd:YAG Laser | Biolitec |

# 5 Clinical need

This chapter will outline the clinical need that inspires the innovation of a surgical water jet device. Using the literature and outcomes from the systematic review, associated health problems, prevalence, impact and current standard care will be further elaborated. The idea of a surgical water jet device was already established in the 1980's by Papachristou et al. [31]. In its broadest scope, water jet technology was adapted for medical use because of possible improvements in surgical cutting. Surgical cutting is still a fundamental aspect of modern medicine. It is aimed at treating a wide range of health issues, from life-saving interventions to simple procedures enhancing the quality of life. It allows for the removal of damaged or diseased tissue, the resection of tumours, and the correction of anatomical abnormalities, by birth or through trauma. On estimation, over 300 million major surgical procedures are performed worldwide each year, and the need for surgical interventions is increasing with population growth and ageing [32]. The overall goal, apart from the surgical procedure itself, includes the prevention of unintended tissue damage and scarring, reduced recovery times and control of bleeding and visibility during the procedure [33, 34]. Current methods for surgical cutting still face many challenges reaching these goals. Therefore, improving surgical cutting methods and the progression of innovative inventions is crucial for enhancing patient outcomes, reducing the risk of complications, and enabling more complex surgical procedures.

Various surgical cutting techniques are currently utilised in modern healthcare. The following is a brief overview of some of the most common methods. Soft tissue cutting is performed using either a scalpel, electrosurgery, laser surgery, ultrasonic or other novel techniques still under development such as plasma surgery [35–38]. These techniques have been widely used for many years and their success mainly depended on their ability to achieve the surgical goals as mentioned earlier. The extent to which these goals are reached, especially the affected damage zone of the surgical procedure, is dependent on the cutting mechanism [39]. Conventionally, the scalpel was the most used cutting method because of its ease of use, accuracy, and low cost [40]. Apart from bleeding, a major drawback of the scalpel is that it becomes dull, requiring a change of the scalpel blade, which takes time and can induce harm to the operator [41]. Also, its rigidity limits the effectiveness in tight space applications. With the increase in technological possibilities, new methods that could overcome these disadvantages were developed. Electrosurgery is the golden standard in most western countries today [42]. Studies reported that in modern western medicine, the use of electrosurgery accounts for up to 80 % of all cutting and coagulation in surgeries [43, 44]. The technique uses radio frequency current and the natural electrical resistance of tissue to convert electrical energy into heat [45]. The resulting thermal damage is used to desiccate, coagulate, or cut soft tissue. In electric tissue cutting, the cut is a result of a sudden increase in tissue temperature above the boiling point that leads to tissue fragmentation. In pure cutting, there is little coagulation on the incision walls and little haemostasis. However, by changing the electrical current mode, all levels of coagulation and haemostasis can be achieved [46]. This is also the main advantage of this method compared to tissue dissection with a scalpel, which does not induce immediate haemostasis or coagulation. In electrosurgery, larger blood vessels may still require additional spot coagulation to achieve haemostasis. The different cutting mechanisms and their effect on tissue is displayed in Figure 8. Electrosurgery has disadvantages as well. Due to high temperatures, tissues surrounding the intended cut can damage. In addition, complications might occur because the electrical current, that

induces the thermal dissection, does not follow the intended path. Direct or capacitive coupling and insulation failure are examples of such complications [47]. In these cases, there is electrical interference within the applicator itself or between the applicator and other medical devices. Other complications involve toxic surgical smoke and shocks that can lead to fire incidents [48].

Some authors reviewed the advantages and disadvantages in surgical instruments that make use of different energy sources and came to the conclusion that electrosurgery, laser surgery and ultrasonic energy all still lead to heat induced complications [43]. To show how much is still to be improved, some relevant numbers with respect to electrosurgery were investigated. Baines et al. found that more than 50% of all adverse events that happen in an operation room (OR) were related to surgical procedures [49], and Wubben et al. show that 16% of incidents during surgical procedures are equipment related [50]. In particular, the use of electrosurgical devices is often associated with hazards that may seriously influence the outcome of the procedure [51].

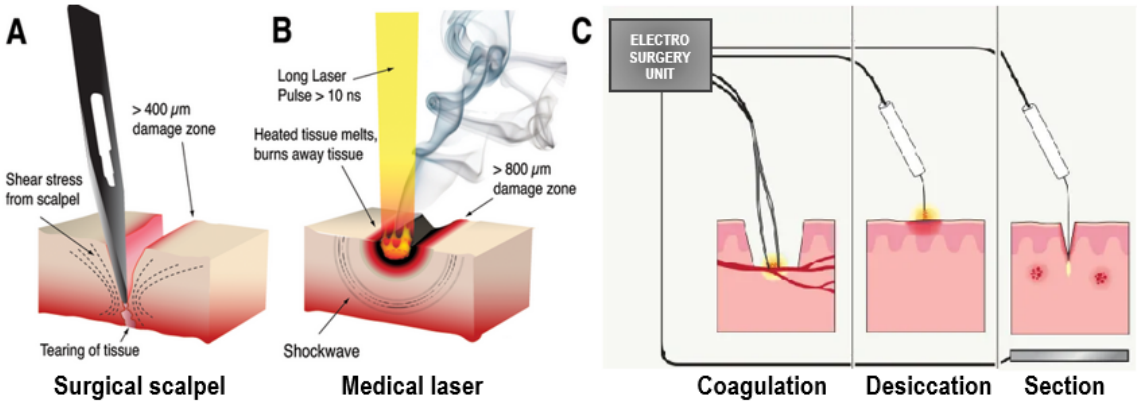


Figure 8: Common methods of tissue dissection. A) Conventional scalpel. B) Laser surgery. C) Different types of Electrosurgery. Electrocoagulation means slowly heating the tissue below the boiling point for denaturation of tissue, focussing on blood coagulation. Dessication is slow heating above boiling point, resulting in tissue drying and superficial ablation. Electrosection is the rapid heating of tissue above boiling point, leading to explosive tissue evaporation and fracture.

To reduce the negative effects of current methods, a clinical adaptation of the technique of water jet cutting is now posed as possible improvement [8]. Water jet cutting can resolve disadvantages from conventional cutting. Since water jet cutting is a cold machining technique, thermal damage to surrounding tissue can be avoided. Also, the risks of toxic surgical fumes and fire hazards due to electrical shocks are eliminated. Many studies show that the technique of water jet surgery can be effective in numerous clinical settings as can be seen in Chapter 4, where the current research on water jet surgery has been categorised. Commercial, certified surgical water jet products such as the Erbejet [52] and Versajet [53] are already used in experimental, trial or clinical settings. Although there are examples of studies that investigate the possibilities of water jet cutting in bone or cartilage, from the systematic review in Chapter 4 we can conclude that water jet cutting mainly focuses on its benefits in the resection and cleaning of soft tissue.

From the numbers on complications and adverse events in current surgical cutting techniques, the added benefit of water jet technology is not yet evident. To make accurate estimations of the potential impact on clinical outcomes and cost savings, the PWJ tech-

nology should be compared to the current standard care. This is only possible by making the comparison as small as possible by selecting a specific intervention. You would need input data for the effectiveness of the PWJ device on that specific intervention, based on existing literature and preclinical data. Also, the size of the patient group should be known as well as the effectiveness and costs of current standard care. Retrieving such data is time consuming and largely depends on the availability of the data. Especially for a technology that has a very broad scope, it is hard to determine which interventions should be investigated and which might be a waste of resources. This study aims to provide the three most prominent interventions that should be first to be assessed on clinical impact. The choice for these interventions will be made based on the results from the systematic review, results from stakeholders interviews, and all other relevant data presented in this paper and will be further discussed in Chapter 9.

# 6 Technology description

In a previous thesis, titled "Design and development of a second generation pulsed water jet device for precise tissue cutting" [23], the author of this study describes the complete process of the development of the prototype that is currently researched at the University of Twente. This chapter will provide a summary of this process so that the reader understands the basic functions and requirements of the technology and the state of the art. For a detailed description of the water jet device including its theoretical foundation, mechanism of action, instructions, and any relevant technical specifications, please refer to the thesis of the author [23]. This chapter will also include a short summary of the preclinical data has already been obtained.

## 6.1 Function and requirements

At the start of the project, first the basic concepts of a water jet cutting device were explored. This included a description of the theory, which special attention tot the differences between CWJ cutting and PWJ cutting. A function analysis of the device was performed to get a comprehensive view of what the device should do. A list of primary component requirements was formulated to make sure that the prototype functions accordingly and can be used as proof of concept. For a complete requirement management plan (RMP), requirements must be unambiguous (measurable and testable), traceable, complete, consistent, and acceptable to key stakeholders. In the most extensive way, a RMP should also document how requirements will be captured, measured, analysed, and managed. For the study a complete RMP was out of scope. A requirement list, including the requirements per component, budget requirements and physical constraints was deemed sufficient. The requirements were established by the researchers at the University of Twente and are based on their experience in the medical device industry. The requirements still have to be validated with stakeholders ideas and wishes. Therefore, requirement specification will also be part of the stakeholder interviews in this study. The primary requirements were sufficient to build a working prototype that could be used in an experimental setting. However, validation studies and subsequent design changes still have to be implemented before clinical trials can be performed. The previous study also disclosed the technological challenges for each component to identify knowledge barriers. To progress from initial ideas to final design, multi criteria decision analysis (MCDA) tools were used to select the best alternative components for a prototype that fits the requirements accordingly. The prototype was experimentally tested and validated in order to make improvements for the next generation prototype. The report concluded with final recommendations and future steps.

Apart from similar concepts found in literature, such as the Erbejet [52] and previous research done by Verdaasdonk et al. [54–57], the basics of a new concept device mainly came from the current water jet machines in industry, thereby utilising other technologies that are already on the market but with different intended use. In Appendix A at the end of this report, the schematic overview of the complete setup of the prototype is shown. For simplicity, the device is divided into seven sections: 1. Water intake, 2. Air intake, 3. Pressure pump, 4. Tubing, 5. Valve, 6. Nozzle, 7. Controller. Each section has its own requirements, depicted in Table 2. The device aims to fulfil a set of primary functions to achieve its intended purpose of improving surgical outcomes and ensuring patient safety. These functions are listed below.

**Function 1: Precise and controlled dissection**
The primary function of the PWJ device is to deliver precise and controlled cutting during surgical procedures that reduces bleeding compared to conventional tissue cutting. The device should be capable of generating a high pressure water stream that can effectively penetrate and cut through human tissues, while minimising fluid output. The cutting action should be accurately directed and adjustable to achieve desired surgical outcomes.

**Function 2: Optimal tissue selectivity**
The PWJ device should aim to preserve the function and viability of structures surrounding the target tissue as much as possible. It should selectively dissect intricate soft tissues while preserving blood vessels, nerves and other relevant structures. It should be designed to minimise thermal damage, reduce unwanted mechanical trauma, and avoid unnecessary disruption of other tissues during the cutting process. This function is crucial in ensuring optimal tissue preservation, promoting faster healing, and minimising postoperative complications.

**Function 3: User friendly operation**
The PWJ device should be designed for user-friendly and safe operation. Preserving a clear view of the incision by reducing water discharge is pivotal. Also, the device should ensure that surgeons can easily learn, adapt and utilise the device in a clinical setting. This function involves intuitive control interfaces, ergonomic considerations, and clear visual feedback. By providing a user-friendly experience, the device can improve surgical efficiency and optimise the learning curve for surgeons.

**Function 4: Integration with existing surgical practices**
The PWJ device should aim to seamlessly integrate with existing surgical practices and workflows. This function involves considering the compatibility of the device with standard surgical instruments, operating room infrastructure and sterilisation processes. By facilitating easy integration, the device can enhance surgical efficiency, minimise disruptions, and promote its widespread acceptance and adoption within the clinical practice.

Table 2: List of requirements per part.

**LIST OF REQUIREMENTS**

| Part | Nr. | Title | Description |
|---|---|---|---|
| **Pressure source** | 1.1 | High pressure generation | The pressure source should be capable of generating a water stream that is able to cut soft tissue. It should provide a pressure range of 1 to 20 MPa, adjustable as per surgical requirements. |
| | 1.2 | Pressure Stability | The pressure source should maintain a stable output pressure throughout the surgical procedure to ensure consistent cutting performance. The pressure fluctuations should be within ± 10% of the set pressure. |
| | 1.3 | Rapid Pressure Response | The pressure source should exhibit a rapid response time to changes in pressure settings. It should be capable of adjusting the pressure within tenths of a second to accommodate dynamic cutting requirements. |
| **Tubing and connectors** | 2.1 | High Pressure Resistance | The tubing and connectors should be constructed from materials capable of safe operation with pressures up to 20 MPa, without deformation or leakage. |
| | 2.2 | Safe and Secure Connections with easy (Dis)assembly | The tubing and connectors should facilitate secure and leak-free connections throughout the device. They should be designed to prevent any accidental disconnection or leakage during surgical procedures. Simultaneously, they should be designed to allow for quick and convenient (dis)assembly, enabling versatile use and efficient maintenance. |
| | 2.3 | Compatibility and Standardization | The tubing and connectors should be compatible with industry-standard fittings and connectors to ensure ease of integration and interchangeability. They should adhere to established standards for medical device connections to promote compatibility with existing surgical setups and equipment. |
| **Valve** | 3.1 | Precise Timing and Control | The high-speed valve should offer precise timing and control over the on/off mechanism of the water jet. It should be capable of delivering rapid pulses with adjustable frequency and pulse time to optimize cutting efficiency and cutting selectivity. A frequency range of 0-100 Hz and a pulse time in the order of 100 µs–10 ms should be achieved. |
| | 3.2 | Response Time | The high-speed valve should exhibit a fast response time, allowing for rapid opening and closing to enable precise control over the water jet pulsation. The response time, from signal to opening/closing should be less than 1 millisecond. |
| | 3.3 | Durability and Reliability | The high-speed valve should be constructed from durable and reliable materials capable of withstanding high-pressure water streams and repetitive operations. It should be designed to have a long lifespan and minimal maintenance requirements, ensuring consistent and reliable performance. Corrosion resistance is of extra importance as the intended use of the valve is with saline. |

**LIST OF REQUIREMENTS (continued)**

| Part | Nr. | Title | Description |
|---|---|---|---|
| **Nozzle** | 4.1 | Precise Jet Formation | The nozzle should be designed to produce a precise and well-defined water jet for accurate cutting. It should enable the formation of a thin, high-speed jet with minimal dispersion or divergence, ensuring focused and controlled cutting action. The speed of the jet leaving the nozzle should be in a range of 10 to 50 m/s. |
| | 4.2 | Tissue friendly design | The nozzle should be designed in a manner that prevents direct tissue damage upon contact. It should incorporate features such as smooth edges, rounded surfaces, or protective coatings to minimize the risk of tissue laceration or abrasion. The design should prioritize tissue safety and ensure that the nozzle does not cause unintended harm when in contact with delicate or sensitive tissues. |
| | 4.3 | Adjustability or interchangeability | The nozzle should enable to operate with a variety of nozzle diameters within a range of 0.1-1mm. Also the needle length should be adjustable from 1-20mm. Therefore the nozzle should allow for quick disassembly and reassembly without compromising the precision and integrity of the water jet. |
| | 4.4 | Easy Cleaning and Maintenance | The nozzle should either be disposable or be designed for easy cleaning and maintenance because it may come into contact with tissue or other test specimens. This will ensure safety and consistent cutting performance. |
| **Controller** | 5.1 | Intuitive User Interface | The controller should feature an intuitive user interface that allows surgeons to choose pre-set operation modes based on cutting depth and tissue type. Researchers and developers should easily adjust cutting parameters such as pressure, pulsation frequency, and pulse time. It should provide clear visual feedback and be straightforward to operate, minimizing the learning curve and enhancing user experience. |
| | 5.2 | Real-Time Monitoring and Safety Features | The controller should incorporate real-time monitoring capabilities for pressure, cutting parameters, and safety measures. It should display relevant information and alerts to ensure safe and optimal operation. The controller should include emergency shut-off mechanisms and safety interlocks to prevent potential risks and protect the well-being of the surgical team and the patient. |
| | 5.3 | Data Logging and Connectivity | The controller should enable data logging and connectivity to facilitate data collection and analysis. It should allow for the storage and retrieval of surgical parameters, cutting profiles, and performance metrics. The controller should also support data transfer capabilities for further analysis, development, and quality improvement. |
| **Budget** | 6.1 | Budget limit | The PWJ device should be designed with cost-effectiveness in mind, leading to a market competitive treatment option. The overall development, manufacturing, and maintenance costs should be optimized without compromising the performance, safety, and reliability of the device. The components and materials used should be reasonably priced and readily available in the market. Additionally, the device should be designed to minimize recurring costs, such as consumables or specialized tools, to ensure long-term affordability and accessibility for healthcare institutions. |
| **Physical constraints** | 7.1 | Compact design and flexibility | The PWJ device should have a compact design that allows for easy integration into existing surgical setups and operating room environments with limited workspace areas. Additionally, the device should incorporate a flexible design that enables its use in various surgical approaches, including laparoscopic surgeries that need high manoeuvrability and accessibility. The device should be able to operate as a stand-alone unit, not depending on other medical equipment. |

## 6.2 Preclinical validation

So far, the preclinical data that has already been obtained was collected during a set of functional experiments as part of the development process of the first prototype. Experiments were performed at the University of Twente and were designed to give an answer to the following research questions:

1. What is the mass per pulse, jet velocity and mechanical pressure that can be generated using the PWJ;
2. How do the water pressure, pulse width, pulse frequency and nozzle diameter affect the cutting depth of the PWJ device in a tissue mimicking gel.

The experiments were conducted using a high speed camera set up, and by use of Poly Acryl Amide gel, which is representative for the mechanical properties of soft tissue. Pressure levels ranged from 5 to 200 bar, a pulse frequency of 1-30 Hz was used, a pulse width of 0.5-6 milliseconds, and a nozzle diameter between 0.3 mm and 0.8 mm. The most important findings are summarised in Table 3.

For the mean cutting depth in PAA gel including standard deviation, please refer to Figure 9. Cutting through PAA gel proved to be feasible. All parameter values could be tested. Significant increase in cutting depth with increased pressure, pulse width and frequency was identified. The stand-off distance did not significantly affect the cutting depth. The needle diameter shows significant differences, and a needle with a diameter around 0.413 mm seems to have the most effective cutting performance. Increased scanning velocity decreases the cutting depth, although this effect is much larger at lower velocities than at high velocities. Measurement with a tissue layer on top of the gel showed that the PWJ could easily penetrate the tissue. As a last experiment, demonstration videos were made that showed how the device could cut through PAA gel, liver and kidney tissue specimen (cow) and muscle tissue samples (chicken). These videos are now available for demos and proof of concept in stakeholder engagement.

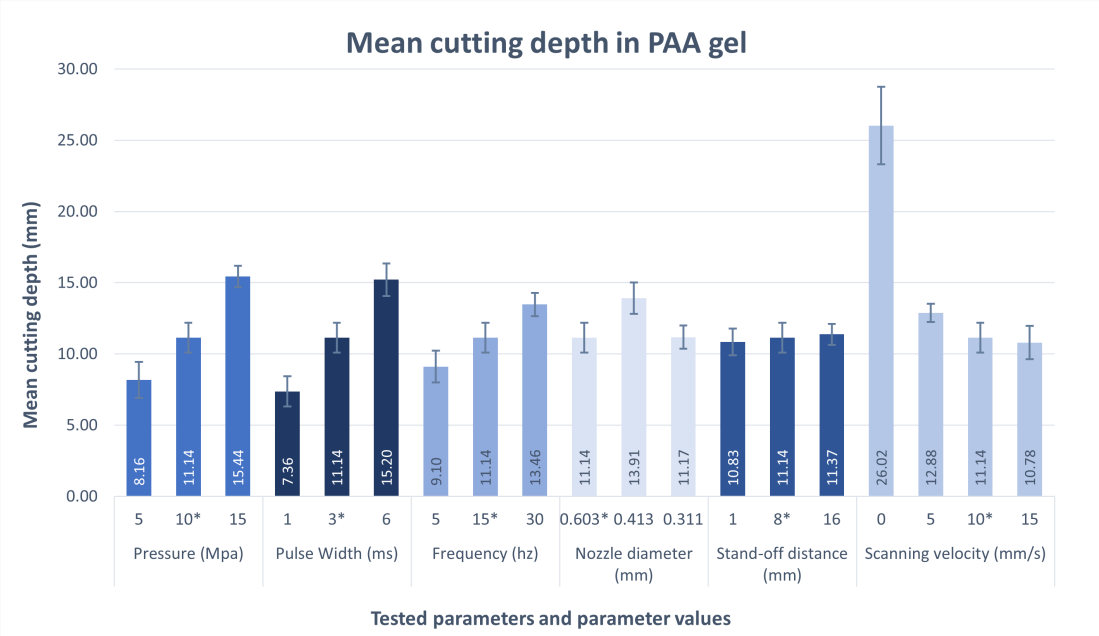


Figure 9: Mean cutting depth in PAA gel. The parameter baselines are denoted with ∗.

Table 3: Summary of most important finding and conclusions from the experiments. The symbols used are pulse mass ($m$), jet velocity ($v$), Pulse width ($T_p$), Pressure ($p$), Nozzle diameter ($d$) and Nozzle length ($L_N$). The clinical implications still need to be validated with clinicians and in verification experiments.

| *Subject* | Found relations | Key findings | Explanation | Clinical implications |
|---|---|---|---|---|
| **Used methods** | - | Calculated velocities are higher than measured velocities, angle of incidence has little affect on exerted pressure. | The whole water column has to start up and accelerate before the calculated average velocity is reached. The jet tip is still accelerating during video measurement. | Small tilting movements from the surgeon will not affect clinical outcome. |
| **Pulse width** | $T_p \propto m$, $T_p \uparrow \Rightarrow v \uparrow$ | Increased pulse width resulted in higher jet velocity and cutting depth. Although pulse width is linearly related to the impulse of the pulse, cutting depth does not increase linearly. | The jet is still accelerating, a 'start up effect' is apparent. This influences short pulses more than longer pulses. | Cutting with short pulses is more efficient in terms of water usage. |
| **Pressure** | $m \propto v \propto \sqrt{p}$ | Pressure is related to pulse velocity and pulse mass in square root function. Theoretical pressures are much higher than measured values. | The system has significant energy losses, discharge coefficient of 0.23. | Pressure settings can be controlled predictably and consistently and are a good tuning parameter to realise cutting of different tissue types. |
| **Frequency and scanning velocity** | $m, v$ stay constant | Pulse frequency has no effect on pulse mass or jet velocity but is very important in cutting depth performance. Frequency and scanning velocity determine the spatial distance between pulses | Subsequent pulses could make new holes or connect to previous holes depending on the spatial distance. | Cutting performance depends largely on the movement speed of the operator. This could be solved by increasing the pulse frequency. |
| **Nozzle diameter** | $v \propto 1/d^2$, $d \downarrow \Rightarrow m \downarrow\downarrow$ | Thinner nozzles increase jet velocity but reduce mass per pulse. | The nozzle diameter shows the interplay between friction, mass flow and jet velocity. There is an optimal nozzle diameter in terms of impulse delivery. | Thinner nozzles look more beneficial clinically. Reduced flow will preserve better visibility and might reduce splashing. |
| **Nozzle length** | $L_N \uparrow \Rightarrow v \downarrow, m \downarrow$ | Longer nozzles result in reduced mass flow and jet velocity. The effect is only significant for thin nozzles. | Longer nozzles induce more friction according to Hagen-Poiseuille's law. | Long nozzles that might be needed for specific clinical procedures, such as arthroscopy, might pose functional problems. |
| **Stand-off distance** | - | Stand-off distance had no significant influence on cutting depth. | In literature a larger stand-off distance reduces the cutting depth. This difference can be explained by the fact that the jet is still accelerating when it exits the nozzle. | Slight variations in distance to the tissue will not influence the performance of the surgeon and clinical results will vary less between operators. |

### 6.3 Technology readiness

In the methods section, the Health-Tech innovation cycle is proposed as a way to map the phases of the development process. Using the full version of the cycle provided by CIMIT [27] and the information above, the progress of the surgical PWJ device is rated at level 3: Proof of Concept (also see Figure 1). Another well known method for assessing progression of a technology is by the Technology Readiness Levels (TRL) [58]. The TRL scale, displayed in Figure 4, originated from NASA in the US, and was later adopted by the European Union as a standardised way of assessing the maturity of a technology as part of funding appraisals. Also, the Dutch government uses TRL in subsidy schemes [59]. According to the European definitions, surgical PWJ technology would be rated at level 3 or 4.

Table 4: Technology readiness levels

| TRL | European definition |
|---|---|
| 1 | Basic principles observed |
| 2 | Technology concept formulated |
| 3 | Experimental proof of concept |
| 4 | Technology validated in lab |
| 5 | Technology validated in relevant environment |
| 6 | Technology demonstrated in relevant environment |
| 7 | System prototype demonstration in operational environment |
| 8 | System complete and qualified |
| 9 | Actual system proven in operational environment |

# 7 Stakeholder analysis

The technical report, preclinical data and demonstration videos mentioned in the previous chapter were deemed sufficient to start stakeholder engagement. Stakeholders play a pivotal role in the success and adoption of a new technology, especially in health care. Stakeholders contribute knowledge and resources that can be used to identify and overcome technical challenges and implementation barriers. In the same way, they can help to navigate through the regulation and certification processes. Knowing who the key decision-makers are for each part of the development process allows for targeted communication and stakeholder engagement. It also helps to manage stakeholder expectations during the development process. Different stakeholders often have varied goals and concerns that might even be contradicting. For instance, healthcare professionals may be concerned about the clinical efficacy, workflow integration and safety of the technology, while investors may prioritise financial returns. Understanding and mitigating these expectations early in the development process allows for realistic goal setting and ensures that the final product is designed with the end user in mind while aligning with other stakeholders needs. Since the development of the PWJ device has been performed at a Dutch institution, this analysis will restrict to Dutch stakeholders.

Before stakeholders could be asked for their input, first a stakeholder analysis was performed to identify the relevant stakeholders for the development and implementation of the surgical PWJ device. Although stakeholder involvement is emphasised in all three frameworks presented in the methods section 3, they do not explicitly outline how to perform a stakeholder analysis. However, they do give handles on how to identify stakeholders. In the Med-Tech innovation guide, stakeholders are identified as: “individuals, organisations, or functions that can directly or indirectly impact or be impacted by the project” [26]. The NASSS framework provides many examples of stakeholders in their methods to identify implementation barriers and facilitators, especially in the case studies they present. Using this to validate our input, we constructed seven different stakeholder categories:

1. Developer
2. Patient
3. Clinicians
4. Manufacturer
5. Insurer
6. Regulatory bodies
7. Society

For each of these categories, we investigated the stakeholder characteristics and relevancy to this phase of the development process. With this analysis we aimed to map priorities in stakeholder engagement, identify new requirements and gather information to aid in planning and decision-making. The results of the stakeholder analysis were used as input to decide which stakeholders to pursue for an interview.

## 7.1 Developer

So far, the research on the technology and the development of this specific prototype has been performed by the research group Health Technology Implementation at the University of Twente. The University of Twente is known for its strong focus on high-tech disciplines, including engineering, science and technology. The university has a well established reputation for encouraging an entrepreneurial mindset among its students and

faculties, winning the prize of most entrepreneurial university in the Netherlands multiple times [60]. Together with excellent research facilities including state-of-the-art equipment and a supportive academic community, the University of Twente provides a constructive environment for translating academic research into real world applications. However, as an educational institution, the University will always focus on research and might not be interested in an executing a business case. Moreover, product realisation should be performed with use of a quality management system, imposing strict rules for the organisational structure and management, which academic institutions usually do not comply to. Therefore, it is wise to collaborate with developers and manufacturers that are known in the field of medical technology.

In this phase of the development process, other Med-Tech developers should be consulted to validate current progress and to identify missing requirements and future steps. If successfully engaged, their input can push the design and the business case towards a next level by contributing resources, facilities and expertise. Furthermore, certification processes might be much smoother for organisations that have certified before and are known to the regulatory bodies. To ensure that the university will profit from external collaborations, IP strategies should be investigated. To have a clear overview of what services the University of Twente can provide for the team of developers, think about assistance in IP, business development and medical ethics committee applications, it is suggested to plan an interview with an employee.

## 7.2 Patient

The patient is the person that has the need for surgery and undergoes the treatment with the new device. At this phase of the development, it is not clear what the specific application will be for the PWJ device, and therefore only general statements about the patient characteristics can be made. Principally, patient safety, well-being, and clinical outcomes are the most prominent requirements for use of the device according to patients. Currently, the clinical outcomes for PWJ surgery have not been identified yet. However, we can say that patients expect the treatment to maximise their quality of life and that it should be better than current standard care. Once the application of the PWJ surgical device is better defined, disease specific clinical outcomes should be used to evaluate the device. Organisations like the International Consortium for Health Outcomes Measurement (ICHOM) [61] performed research on which clinical outcomes matter the most to patient for different types of health issues.

Patient and treatment characteristics can limit design possibilities, which is important to consider for determining the application area of this new technology. Also, shared decision-making is becoming more and more prominent in health care policy [62]. Therefore, it is necessary to make a strategy on how risks can be communicated to patients. In practice, patient interests are often guarded by patient organisations. Because the technology will be used as general OR equipment it is not necessary to explain to each patient in detail how the technology works, however, all information on the treatment and technology should be available to the patient on request.

Once the scope of PWJ technology is narrowed down to a specific procedure, and thus a specific patient group, patient characteristics and requirements should be investigated. This can either be done through literature review, or by applying well known methods such as Patient Preference Elicitation (PPE) [63] and Patient Reported Outcome Measures

(PROMs) [64]. PPE evaluates the relative importance of requirements in the experience of patients. PROMs are a way of measuring how well your device and treatment score on those requirements. In contrast to PPE, each method for PROMS is specifically directed to a patient group, and/or designed to evaluate a specific requirement. Below, the PROMS are listed that are relevant in the appraisal of surgical water jet technology:

- Pain Assessment: Brief Pain Inventory (BPI), this questionnaire assesses the severity of pain and its impact on daily functioning, which is crucial after a surgical procedure.
- Functional Status: SF-36 Health Survey or PROMIS Physical Function, these measures evaluate the patient's physical functioning and ability to perform daily activities, providing insights into the impact of the surgical procedure on functional outcomes.
- Wound Healing and Recovery: Wound-Quality of Life (Wound-QoL), This questionnaire specifically focuses on the impact of wounds on patients' quality of life, which is particularly relevant in surgical settings.
- Site-Specific Measures: Depending on the type of surgery and the area affected, you might consider surgery-specific PROMs. For example, when the water jet device would be used for liver dissection, the following measures are of importance:
  - Liver Disease Quality of Life (LDQOL) questionnaire
  - FACT-Hep (Functional Assessment of Cancer Therapy-Hepatobiliary) module
  - CLDQ (Chronic Liver Disease Questionnaire)
- Patient Satisfaction and Experience: Patient Satisfaction Questionnaire (PSQ), This type of questionnaire assesses patients' satisfaction with their healthcare experience, including aspects related to the surgical procedure.

PPE can be performed early in the development process, but directed at patients its added value is debatable because patient do not have much influence on the surgical methods used by the surgeon. Therefore, this study will not include an interview with patient representatives. Preference elicitation aimed to identify design preference of other stakeholders on the other hand might be very interesting. Knowing to what extent hospitals and surgeons value simplicity over effectiveness or ergonomics over cost can be valuable insights for further design and development. PROMs are only useful as soon as clinical trials are started with a working, certified device and patients are treated. By gathering PROMS eventually the patient outcomes can be compared to that of other surgical methods to prove the added benefit of the PWJ device.

## 7.3 Clinicians

This stakeholder entails the surgeon, supportive clinicians and the hospital. The surgeon is the person operating the device during surgery. The supportive clinicians are those who assist the surgeon in doing so. Clinicians have clinical knowledge and skills to successfully treat patients. They focus on effective and efficient care for the patient. Research has already been done to map general factors that facilitate the implementation of new devices in the OR in the perspective of the clinician [65–67]. Clinicians disapprove complexity and imprecision of current care. Moreover, revised treatment should provide better health outcomes, time savings and/or be more convenient in use than current care. Consistency

and reliability are also key factors for the clinicians to use a device [68]. Training requirements and learning curves should also be manageable within the skills of the clinicians. For the surgeon specifically, convenient use and ergonomics are key factors. For supportive clinicians, the workflow of supportive tasks such as preparation, cleaning and maintenance are essential. Although clinicians usually are willing to cooperate for research purposes, a conservative culture is standard with respect to workflow changes. They should be involved to check clinical feasibility. Additionally, in clinical studies, the developer is reliant on surgeons willing to test the device. So, inspiring surgeons to cooperate in further research is crucial to book progression. From the systematic review, multiple potential fields of application of water jet surgery were identified. The medical specialist working in those fields therefore are interesting stakeholders. To involve them, and to collect their opinions and insights on this new technology, they will be part of this thesis in a stakeholder interview. These interviews, the different medical specialists and their profiles will be discussed in Chapter 8.

The hospital as organisation can also been seen as a clinical stakeholder. The hospital procurement policy can have a large influence on successful implementation. Also, safety regulation and general facilities can influence design requirements. According to implementation frameworks like the Med-Tech innovation guide [26] consulting surgeons has the highest priority in the development process, but understanding how health technology procurement policies work is also important from early on. Therefore, also an interview with a staff member of the department of medical technology at a large hospital will be scheduled and discussed in Chapter 8.

## 7.4 Manufacturer

The manufacturer is the stakeholder that is responsible for the production and certification of the final product. Moreover, the manufacturer can be involved in the development and testing of the product. They should have technological knowledge and experience in the production of various solutions to health problems. They will want to deliver innovative solutions and produce profitable end products. Their focus is on commercial viability and competitive edge. It is wise to take into account that they might be interested more in making money than the best care for the patient. A manufacturer should always be involved to check producibility and costs of new technology.

Compared to the stakeholder 'developer' described earlier in this analysis, the manufacturer is less involved in research activities, but more in product realisation. When an analogy is made to the CIMIT innovation cycle [27], you could say that up to the proof of concept, the developer is dominant. In the translation phase (proof of feasibility until validation of solution) the responsibility gradually shifts from developer to manufacturer, and in the commercialisation phase the manufacturer takes the lead. The development of the water jet device so far has been executed by a research team from the University of Twente. At this moment they work on proof of concept, so soon manufacturers should be involved to realise the eventual product. For this, an analysis of potential business partners was done. First by looking at Med-Tech companies in close contact with the University of Twente. Existing contacts might have a lower threshold for collaboration, and if not interested in a partnership, might still be able to provide valuable input. Secondly, manufacturers of similar products were investigated. They have the appropriate knowledge and their products can serve as examples for requirement specification and product validation

### 7.4.1 Producers of similar products

- ERBE Elektromedizin GmbH [52, 69]

  Overview: ERBE Elektromedizin GmbH is a renowned company in the field of medical technology with over 1600 employees worldwide. While based in Germany, ERBE has a global presence, with its products also being used in hospitals in the Netherlands. They are dedicated to the development and manufacturing of innovative surgical systems for professional use for a variety of medical applications. Their key disciplines are gastroenterology, general surgery, gynaecology, bronchoscopy, and urology. The company's advancements in medical technology aim to enhance the capabilities of healthcare professionals in these fields and improve patient outcomes.

  Key areas of expertise:
  1. Electrosurgery: ERBE is known for its expertise in the field of electrosurgery, offering advanced technology and surgical instruments for precise and effective procedures.
  2. Endoscopy and laparoscopy: The company provides solutions for endoscopic procedures, contributing to the advancement of minimally invasive techniques in the medical field.

  Product range: ERBE's product portfolio includes a range of surgical instruments, devices, and equipment. The basis is a complete electrosurgery workstation that has additional options for specific procedures. Apart from electrosurgical applicators, also endoscopic, laparoscopic, plasma or hydrosurgery elements can be added to the workstation.

  Suitability for collaboration: ERBE has developed a hydrosurgery system called the Erbejet 2. This system has already been through clinical trials and is available on the market. It is advanced and integrated within an electrosurgery unit including suction and irrigation. Although this system mainly focuses on the function of saline injection for tissue elevation, it also has an applicator for dissection with a high pressure water jet.

- Olympus Corporation [70]

  Overview: Olympus Corporation is a multinational Med-Tech giant headquartered in Tokyo with over 10000 employees. While Olympus is also present in other business segments, including imaging and audio products, Olympus has a significant contribution to the medical technology sector. In the medical field, Olympus focuses on combining the knowledge of all business sectors to provide the most innovative solutions for healthcare professionals.

  Key areas of expertise:
  1. Endoscopy: Olympus is a major player in the field of endoscopy, offering a wide range of endoscopic devices and systems. This includes equipment for gastrointestinal, respiratory, and urological endoscopy, among others.
  2. Surgical technologies: The company develops and manufactures advanced surgical technologies, including minimally invasive surgical instruments and systems. These technologies aim to improve surgical precision and patient outcomes.
  3. Medical imaging: Olympus is involved in medical imaging solutions, providing equipment such as microscopes and imaging systems for diagnostics and research.

Product range: Olympus offers a comprehensive range of medical products and solutions. Not only do they offer primary therapeutic instruments, but also an extensive list of safety and supportive equipment. The core of this company is endoscopy, and most surgical and imaging instruments are developed to support endoscopic procedures. Apart from this, some instruments for minimal invasive surgery, implants and general surgery equipment are available.

Suitability for collaboration: Olympus equipment is already being used in many Dutch hospitals and is very well know. Integration of hydrojet technology within one of their systems will not only speed up development and certification but also acceptation and integration within current care.

### 7.4.2 Close connections

- DEMCON [71]

  Overview: DEMCON is a technology development and engineering company based in Enschede, the Netherlands with around 850 employees. The company is involved in providing solutions across different sectors, including energy, high-tech systems & materials and medical technology.

  Key areas of expertise:
  1. Medical technology: DEMCON has a presence in the medical technology sector, contributing to the development of innovative solutions for healthcare applications. This includes medical devices, diagnostics, and e-health technologies aimed at improving patient care.
  2. High-tech systems: Beyond medical technology, DEMCON is known for its expertise in developing high-tech systems across various industries. This involves precision engineering, mechatronics, and system integration.

  Product and service range: DEMCON emphasises on research and development services rather than an extensive range of readily available medical products. DEMCON's experience in the medical technology sector include the development of devices for minimally invasive surgery, critical care systems such as a respiratory device, diagnostics and medical wearables.

  Suitability for collaboration: Demcon originated as a spin-off from the University of Twente. Their headquarters are located next to the terrain of the University and the collaboration between Demcon and University is still strong. Shared projects are not uncommon and they are accessible for communication. Their facilities and experience in the development of health care technology can boost especially the prototyping and testing phase of the development process. The downside of a local, more research focussed company compared to the larger Med-Tech distributing companies is that DEMCON has much fewer ties to hospitals or other potential buyers.

- BAAT medical [72]

  Overview: BAAT medical is an engineering and consultancy company based in Hengelo, the Netherlands, with around 60 employees. They help medical startups and entrepreneurs get their products to market.

Key areas of expertise:
1. Orthopedics: BAAT medical has specialised in projects involving orthopedic treatments. They helped in the development of orthopedic instruments, (active) implants, external fixation and orthoses.

Product and service range: BAAT medical is a service centered Med-Tech company working on projects for other Med-Tech partners rather than developing their own line of medical products. They offer medical device design consultancy, development consulting, regulatory consulting, device marketing strategy, quality testing and consulting.

Suitability for collaboration: The company has worked on projects for renowned Med-Tech companies such as Zimmer Biomet and Ethicon and also have relevant ISO certification, proving their competences. Links between the University of Twente and BAAT medical have already been established in previous shared projects which could make them more approachable. The advantage of working with a company as BAAT is that the current development team keeps full control over the design process and intellectual property, while in other cases the technology is transferred more to the other company. The downside is that this could mean that BAAT expects a higher fee for their service.

## 7.5 Insurer

The Netherlands provides a well-organised and accessible health care system characterised by a combination of public and private elements. In recent years, the role of health insurers has become increasingly prominent in shaping the trajectory of medical technology development, also in the field of surgical equipment. Therefore, it is important to understand the Dutch health care system and how health insurers contribute to the advancement of surgical technology. The Dutch health care system is structured around the principles of accessibility, affordability, and quality of care. Key components include mandatory health insurance for all Dutch citizens, a robust primary care network, and a regulated market for health care providers [73]. The health insurers act as intermediaries between patients, health care providers, and other stakeholders. The competitive nature of the health insurance market encourages insurers to seek innovative solutions that improve patient outcomes and cost-effectiveness. Especially innovations that have a large impact on health care budgets, are closely monitored by insurers. Insurers collaborate with medical technology developers to establish reimbursement strategies that align with the value proposition of innovative medical devices. Effective engagement with health insurers should be initiated during the development process of a new health care technology that aims to be included in standard care. At the conceptualisation and prototyping phases, developers can present their technology to insurers, providing a preliminary understanding of the device's potential benefits. Early engagement facilitates alignment with insurers' priorities and can influence the development trajectory [74].

Implementing a new surgical tool into standard care also involves a collaboration with hospitals, and medical professionals. While insurers provide critical input based on economic considerations, hospitals evaluate the clinical efficacy, safety, and overall feasibility of integrating the technology into existing practices. A successful partnership between these three groups enhances the chances of a new device becoming an integral part of standard care.

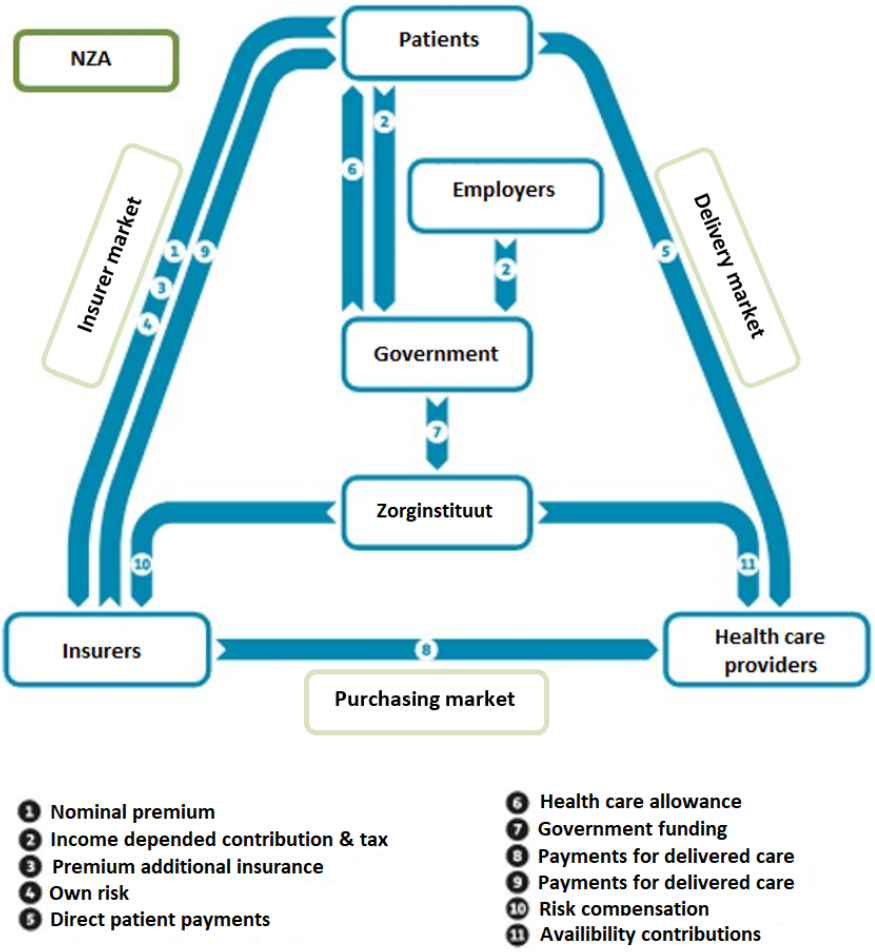


Figure 10: Three Market model of the Dutch health care system, including cashflows and regulating bodies. The 'Nederlandse Zorg Autoriteit' (NZA) determines healthcare price rates, treatment definitions and budgets and monitors compliance.Adjusted from [75]

Interaction between stakeholders in the health care markets can be summarised using the three market model, which shows the cash flow between the different organisations [76]. Figure 10 shows the scheme of all the relationships between the stakeholders involved in performing surgery in the hospital. According to the three market system, the first market in the scheme is the delivery market which consists of the clinicians (the hospital, the surgeon and other staff that perform the surgery) and the patient. The second market is the insurance market. This market is more complex compared to the delivery market. The 'Zorginstituut Nederland' (ZIN) from the Dutch government is the regulator in this market. The ZIN is the owner of the 'Zorgverzekeringsfonds', which is a fund that is established for the risk equalisation ('risicoverevening') for the health insurers. Risk equalisation is necessary because the health insurers are obligated to accept all patients. Because individuals have differences in health risks, it is necessary to compensate health insurers for accepting high risk individuals. So, the compensation is one of the incomes of the health insurers. This forms almost half of the budget spent on healthcare by insurers. The other income is the premiums and the own risk ('eigen risico') from the insured individuals. The premium depends on the health insurer. There is one nominal premium for the basic

insurance package, determined by the government, and every health insurer can add an additional premium to this nominal premium. The basic package of the health insurance is also determined by the government, that is the minimum content of this package. The health insurers can decide for themselves if they want to extend this basic package. In case of surgery in the hospital, the hospital delivers the care to the patient, the patient pays the health insurance the premium for the basic package and also has to contribute the amount for own risk. The health insurance pays the hospital for their care. In this case, the availability contribution is not part of the cash flow, because the availability contribution is a subsidy for special care (e.g. medication for rare diseases), which is not the case for most surgeries. The third market is the selling/purchasing market. To deliver health care to patients, the insurers buy care from caregivers. In that way, the caregivers are paid. It is also possible that patients are not insured for specific treatments (when they do not have an additional health care package and the treatment is not included in the basic package). In that way, the patients need to pay for the health care themselves (sometimes indirect via the insurer). In the case of performing surgery in the hospital, the health insurance has already contracted the hospital to deliver this care and price and/or volumes are predetermined.

The insurer wants to get the best care for the best (cheapest) price, and the hospital wants to deliver the best care for the best (highest) paid price. By negotiating, the best option for both parties will come out. Negotiations between the caregiver and the insurer are done before the individuals buy their health insurance. In this system, a developer of new technology should inform and engage insurers because the benefits of increased health outcomes and possible cost savings from the technology can also end up at the insurer, much depending on the type of contract between insurer and care provider. In this stage of the development, insurers do not need to be consulted directly. Reimbursement strategies can be relevant in the value proposition of the new device, but procurement by hospitals and a viable business case for a manufacturer are much more prominent. Therefore, a description of the insurer as stakeholder above is deemed sufficient and no further interviews will be done with specialists in this area.

## 7.6 Regulatory bodies

In the insurance system, we have already seen how the government organisations influence the market via legislation. In the Netherlands there are two major laws that regulate health care inventions and health care innovations, the Dutch WMO ('Wet Medisch-wetenschappelijk Onderzoek met mensen', or Medical Research Involving Human Subjects Act) and the European MDR (Medical Device Regulation). These laws are executed and regulated by several organisations that all play an important role in the development of a new medical device [77]. Because medical devices are inherently related to medical risks, the complete process from initial development up to the point post market trials and surveillance, is regulated by authorised regulatory bodies.

The WMO is a Dutch law that regulates the ethical and legal aspects of medical research involving human subjects in the Netherlands. It applies to clinical trials and other medical research involving human participants, ensuring the protection of their rights, safety, and well-being. The WMO mandates ethical review of research proposals by accredited review committees to ensure that studies are conducted ethically. It establishes requirements for obtaining informed consent from participants, emphasising transparency and voluntary participation. The WMO outlines procedures for monitoring the safety of participants

during the research. Also, it requires thorough documentation of the research process, including protocols, informed consent forms, and study results.

The MDR is a regulation of the European Union that governs the regulatory framework for medical devices to enhance patient safety and ensure the quality and performance of medical devices on the market [78]. It applies to a wide range of medical devices, including surgical tools, and covers their entire life cycle, from design and manufacturing to postmarket surveillance. The MDR classifies medical devices based on risk, with higher-risk devices subject to more demanding requirements [79]. It mandates a conformity assessment process to ensure that devices meet essential requirements before being placed on the market. If the medical device successfully passes the conformity assessment, the manufacturer is awarded the CE mark to the product. The CE certification indicates that the device meets the essential requirements of the MDR and can be legally placed on the market within the European Economic Area. The MDR emphasises continuous monitoring of devices on the market to detect and address safety issues promptly. The MDR, which has only existed from 2021, introduces stricter requirements for clinical evidence compared to its predecessor, including the need for extra clinical investigations.

Both the WMO in the Netherlands and the MDR at the European level are regulatory frameworks that need to be taken into account from the start of the development process. Because regulation and certification can consume considerable time and resources, planning this process is essential for project viability. As was already evident from the development framework in Figure 1, the development of a new medical technology is an iterative process of building, evaluating and implementing evidence on the added benefit. This means that the health technology regulation process has the same iterative, stepwise dynamics. Before the final goal of CE certification, first preclinical tests, animal studies, and eventually several clinical studies need to be performed. Before the developer can start with these steps, approval from the corresponding regulatory body is mandatory. For example, before animal studies can start, first an approval from the DEC ('Dierenexperimentencommissie') needs to be obtained. The DEC promotes the principles of the 3Rs in line with international standards: Replacement, Reduction, and Refinement. These principles state that animal studies can only be performed if there are no good alternatives, with the least number of animals, and in a way that minimises the effect on animal welfare. For clinical studies on living humans, the WMO and MDR are binding.

The CCMO ('Centrale Commissie Mensgebonden Onderzoek', or Central Committee on Research Involving Human Subjects) and the IGJ ('Inspectie Gezonheidszorg en Jeugd') are the organisations that execute the WMO and MDR. The CCMO supervises smaller councils called the METC ('Medisch Ethische Toetsingcommissie', or Medical Ethics Review Committees). The METC work as independend committee to which you can submit your research documentation for ethical approval. In the context of developing a surgical tool, the METC evaluates the research plan, participant consent forms, and any potential risks to human subjects. The CCMO operates more on policy and legislation but also supervises the METC. In some cases, the CCMO can also function as an additional review committee for approvals with a higher risk profile or that involve vulnerable patient groups. On the website of the CCMO the developers can find the guidelines for application for a clinical trial [80]. The standard framework consists of the main documents listed in Table 5. Identifying the safety class of your device, which is also part of the CE certification process, clarifies which documents are required.

Table 5: Main documents for clinical trial application via METC or CCMO

| *Document* | *Content* |
|---|---|
| **Application form** | A short summary of the application that is used for the Euopean database for medical devices. |
| **Clinical investigation plan** | The protocol of the clinical study. It should describe the relevancy, objectives, study design, methodology, monitoring plan, statistical considerations and information about the involved organisations. |
| **Clinical evaluation plan** | Describes how clinical evaluation will be done. The clinical evaluation is the systematic process of collecting and analysing already existing data that is relevant for the performance or safety of the device. |
| **Investigator's brochure** | A technical brochure that contains all relevant information with regard to the medical device itself, including design, functional elements, technical drawings and device specifications. Also, preclinical data that prove safety, risk classification and information on the intended patient group and treatment should be given. |
| **Investigational Medical Device Dossier (IMDD** | A more extensive framework for documenting technical information. Should be used for devices that do not yet have the CE mark. Not all information requested in the IMDD framework has to be delivered at once. The IMDD is build step wise, including new requirements for more advanced (pre)clinical studies, eventually including all information required for CE certification. |
| **Signed Safety statement** | The safety statement should be signed to show the device adheres to all relevant safety requirements apart from the ones that are tested in the clinical investigation. Every precaution has to be taken to protect the health and safety of potential study subjects. In case of devices with a higher risk profile, the CCMO might issue an external party to advise on the required safety measures |
| **Subject information sheet** | An information sheet specifically directed towards the study participants, which later should be used to explain the study goals and protocol to the participant during the inclusion process. |
| **Informed consent** | A subject should sign a form stating he consents to participation in the study. |
| **Proof of Insurance** | The research institution is obliged by the WMO to have insurance for all subjects. |

### 7.6.1 Norms and standardisation

To help developers to reach a certain level of quality within their products, services, systems and organisation, there are well accepted norms and standards [81]. These norms and standards describe almost all steps of a standard development process for medical devices. The most well known examples are the standards from the International Organisation for Standardisation, commonly known as ISO. ISO's mission is to develop and publish international standards to facilitate international trade and ensure the quality, safety, and efficiency of all technical products. ISO standards are developed through a process of voluntary consensus, involving the participation of experts, industry stakeholders, government representatives, and other relevant parties. If developers can show that they operate according to these ISO standards, they can obtain a certificate as proof.

In healthcare, standardisation is promoted in the first place to ensure patient safety. Moreover, standards contribute to the interoperability of health care technology. You can imagine that it is easier to integrate a surgical water jet device if all hospitals use the same standardised connections for pressurised air, water and electronic systems. On a

global scale, standardisation improves the efficiency of health technology, resulting in cost reduction, a patient centred care, and a higher quality of health care in general. Below you find a list of the ISO standards that are most applicable to this project [82]. Apart from these, depending on the final design, standards with regard to sterilisation, packaging, or endoscopy also exist.

Table 6: ISO norms that could apply to the technology of surgical water jet cutting

| Norm | Description |
|---|---|
| ISO 13485:2016 | Quality management systems in Health-Tech organisations |
| ISO 14971:2019 | Application of risk management to medical devices |
| ISO 14155:2020 | Clinical investigation of medical devices for human subjects |
| ISO 10993 series | Biological evaluation of medical devices |
| IEC 62366 series | Application of usability engineering to medical devices |
| ISO 32:1977 | Gas cylinders for medical use |
| ISO 7396:2016 | Medical gas pipeline systems |
| ISO 10524:2018 | Pressure regulators for use with medical devices |
| ISO 2768:1989 | General tolerances for precision |
| ISO 7153:2016 | Materials for surgical instruments |
| ISO 18250:2018 | Connectors for reservoir delivery systems for healthcare applications |

ISO certification is not mandatory for medical device developers. However, the MDR law obligates developers to implement a quality management system and a risk management system before a product can get the CE mark. ISO developed standards that describe exactly these facets applied to the Med-Tech sector. As regulatory bodies that execute the MDR recognise the excellence of ISO, if an organisation has the correct ISO certification, this is accepted as proof of compliance to the European MDR law. The process of certification (both ISO and CE) is executed by so called notified bodies who, by law, are responsible for thorough investigation of the device and the organisation by reviewing any documents, procedures and protocols but also by on-site auditing. The two notified bodies in the Netherlands that are accredited for ISO standards on reusable surgical instruments are DEKRA and the BSI Group. As explained above, ISO certification can be part of the CE certification process, but can also be done in earlier stages as part of CCMO applications. Sometimes ISO certification is requested by insurers, hospitals or other stakeholders before they are willing to invest.

### 7.6.2 ISO 13485 & ISO 14971

The ISO standards for a quality management system and for risk management are two important standards that apply to all medical devices. They are broader standards that emphasise the need for a systematic and process-oriented approach to ensure the safety and effectiveness of medical devices. They apply to the complete life cycle of medical devices, from design and development to production, installation, and servicing. ISO 13485:2016 is based on quality management principles. This means that it aims at a strong customer focus by using a process approach and by striving for continuous improvement. Fact-based

decision-making, qualified leadership and mutually beneficial stakeholder relationships are key factors for the success of a quality management system. The ISO norm covers requirements for five major domains, each separately described in one of its chapters. These are summarised in table 7 and the interrelations between the different components of ISO 13485 are depicted in Figure 16 in Appendix B.

Table 7: The Quality management system according to ISO 13485

| Chapter | Main requirements |
|---|---|
| Documentation | All agreements, protocols and procedures should be documented. Two main deliverables: 1) The quality handbook including the quality policy/objective statement, overview and planning of quality processes, procedures for document and record control, internal audit methods, corrective and preventive actions. 2) Medical device dossier with all the information of the device, including intended use, specifications, safety information. |
| Management Responsibility | Responsibilities, commitment and accountability of project management should be established. Among other things, this contains dedication to patient/customer centered business operations, responsibility for a quality system framework and quality system reviews. |
| Resource Management | Availability of resources to complete quality processes should be assured. This includes sufficient qualified personnel that is aware of their roles and responsibilities, correct infrastructure to support (quality) processes, and information management plans. |
| Product Realisation | Planning of the complete process from product conceptualisation to implementation. Establish product requirements, identify development and production processes and their inputs and outputs. Include risk management, product validation strategies and procedures for manufacturing, outsourcing and purchasing. |
| Analysis and Improvement | Determine ways to analyse business processes. Evaluating if all processes adhere to quality rules. Collect feedback on product safety. Perform internal audits and continuously improve the quality system |

It can already be seen from the quality management norm that risk management is also an important requisite in the medical device industry. ISO 14971 is a norm that specifically addresses that part of the development process. Because patients trust the expertise of the developers, and often unknowingly accept the risk that come with the use of medical devices, risk management is an integral part of medical device regulation. To be clear, the risk management as discussed in this chapter does not apply to business risk management. The steps in risk management are very well described in ISO 14971 and can be summarised in Figure 11

There is a very strong relation between risk management and design controls. Design controls are 'tests' that demonstrate that the design meets certain requirements and criteria. In development phase of the device, it is common practice to first define the user needs, then define design requirements, to eventually produce design outputs. These outputs are then subjected to verification (to check the device on the requirements), and validation (to check the device on the intended purpose and user needs) and eventually a design review. Risk management should feed risk controls into this process, with each identified risk prompting a new user need, design requirement or design output. These will lead to new verification and validation processes that serve as a design control proving that the device is safe.

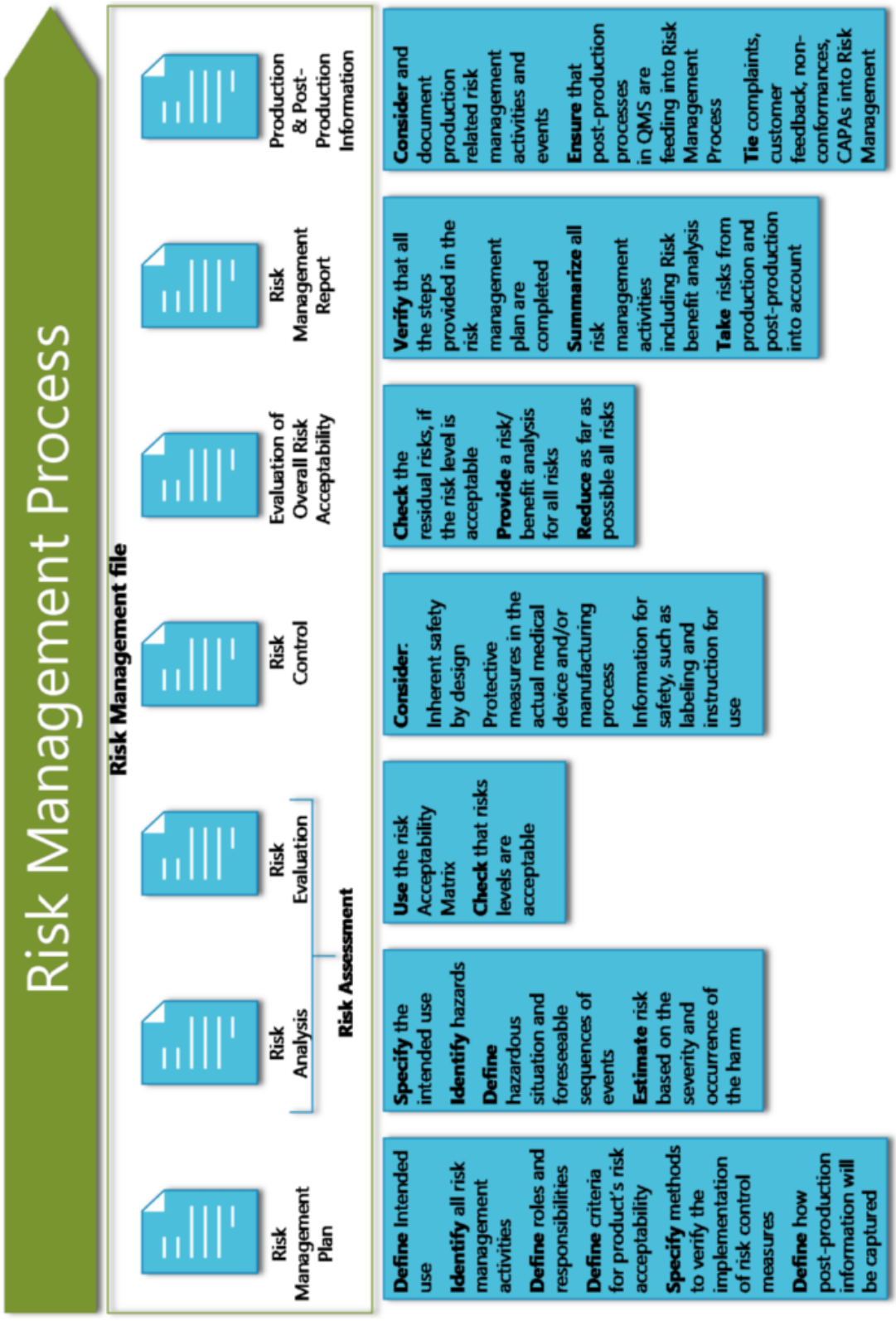


Figure 11: Overview of a risk management system as described in ISO14971

## 7.7 Society

In general, society wants the best care for everyone within the available resources. A revised treatment should be more efficient in terms of resources and better in terms of health outcomes. Transparency on the device's benefits and potential risks are crucial to prevent scepticism. The Dutch health care system operates within a complex structure, full of outside influences. Public opinion, political considerations, and media coverage can play pivotal roles in health care decision-making. Society, through collective opinion and advocacy groups, has the power to influence health care policies. Examples include public campaigns advocating for improved access to mental health services or calls for increased funding for innovations aimed at rare diseases. Media outlets also play a crucial role in shaping public perception of health care issues. High-profile cases or sensationalised stories can bring attention to specific health challenges, resulting in public discussion and influencing political agendas. The media's framing of healthcare topics can contribute to the prioritisation of certain issues over others, ultimately impacting policy decisions and resource allocation. Also, it is not uncommon that project funding is inspired from publications within the scientific community or in the media. This can be taken into account when choosing the final application of the water jet device. For example, choosing an application such as breast cancer resection not only has the benefit of a large patient group, but also advances in this field are encouraged by patients groups because of its importance for both health and aesthetics. Another example is that for treatments with a very small patient group, a business case might not be viable. To compensate for this, public organisations sometimes support research and development for these rare disease treatments.

# 8 Stakeholder interviews

To elicit the opinions and expectations of the stakeholders, interviews were conducted. These interviews aimed to further evaluate which specific clinical treatment has the most potential benefits from use of the water jet surgical device and should be the focus of further development. Also, these interviews aim to identify any factors that could enable or hinder implementation and to find any (non-technical) requirements that are not identified yet in the development process.

## 8.1 Interview inclusion

The participants were selected based on the results of the systematic review and the stakeholder analysis. Each clinical speciality that was relevant in the systematic review results was sought for an interview. Also, other relevant stakeholders determined in the stakeholder analysis, that either represent regulatory bodies, the hospital, or society were retrieved for an interview. This came down to a total of ten interviews representing six different medical fields and three other stakeholders:

Table 8: Interviewed specialists and their area of expertise

| **Participant** | **Abbreviation** | **Profile/Speciality** |
|---|---|---|
| Vascular surgeon | VS | Bypass surgery, stents and aneurysms. Especially in arteries/veins in the legs, the carotid arteries and arteries close to the heart. |
| Ear-Nose-Throat surgeon | ENT | Gland and node resection in neck area. Tumour resection on larynx, pharynx and paranasal cavities. |
| Urologist | URO | Male fertility, ureter and bladder surgery, kidney stone removal. |
| Gastroenterologist 1 | GE1 | Endoscopic procedures of colon, rectum and eusophagus. |
| Oral and Maxillofacial Surgeon | OMS | Oncology in head-neck region. Reconstruction of skull and jaws. |
| Hepatobiliary and Pancreas surgeon | HBP | Liver surgery, gall bladder surgery and pancreas surgery. |
| Gastroenterologist 2 | GE2 | Laparoscopic surgery on gallbladder, stomach, colon and intestine. |
| Implementation specialist | IMP | Health-Tech innovation/implementation specialist at a big Health-Tech company. Knowledge on frameworks and workflow. |
| Medical Device Regulation specialist | MDR | Medical (research) regulations specialist at a large research institution. Experienced in CCMO/METC applications. |
| Clinical Physicist | CP | Responsible for the procurement, safety measures, and correct use of medical devices at a large Dutch hospital. |

Each interviewee could be included if they were regarded as an experienced specialist within their field of work. Most interviews came up from the network of the HTI research group. Interviews were performed online or on-site and were in Dutch. The time duration aimed for was approximately 30 minutes per interview. Longer interviews would be of interest for us as developers, but are not realistic within the overloaded time schedules of clinicians.

## 8.2 Structure of the interview

A semi structured interview guide was used. The interview questions were based on the NASSS interview framework (see Appendix B). This framework was narrowed down to four categories: the context, the technology, the application, and the implementation. For these four categories, a combined total of 13 questions were drawn up in preparation and with an additional three questions in case there was time left. The interviewees received a 2-page info sheet one week prior to the interview, that contained images of the water jet device and explained the basic idea behind water jet surgery. Also, a very short summary of the project, the goals of the interview, and the questions to be asked were included. During the interview, first the interviewee was asked questions on clinical context and problems in surgical cutting without input from the interviewer. This was done to prevent the interviewer from influencing answers. After this part, the interviewer explained the vision of the developers and how, according to literature and preclinical results, they believe water jet technology can benefit their specific field. This was followed by a semi structured discussion on the technology, application, and implementation. Interviews were recorded with consent, but the analysis will be anonymised.

## 8.3 Analysis and results of medical specialists

The analysis of the interviews was performed by first separating the analysis of the interviews with a medical specialist from that of other stakeholders. For the medical specialist, the interview results were transcribed and manually coded according to ten main codes:

- Type of treatment
- Anatomical site of surgery
- General technique
- Technologies/devices
- Current problems and challenges
- Recommended application
- Requested preclinical data
- Additional requirements
- General attitude
- Important conclusions.

The codes were predetermined and based on the interview questions. They were used to structure the data, and to facilitate comparisons between the medical specialists. After coding, the codes were grouped in themes for a thematic analysis [83], so that per theme the most recurring items could be identified. Below, the insights gained this way are summarised.

### 8.3.1 Surgical context

There was only one interviewee who mentioned to have heard about research on water jet surgery before. For all other interviewees this technology was completely new. The technology that most closely resembles water jet cutting is water jet injection. This technique was mentioned by gastroenterologist 1 (GE1) who used it during Endoscopic Mucosal

Resections to elevate the tissue under and around the tumour in the colon wall. Also, adrenaline and dye were mixed in the saline injection to demarcate the tumour edges and to motivate vessel contraction. However, GE1 never heard of the idea to explore this technology for its cutting capabilities.

Six out of seven specialists reported to frequently use minimal invasive surgical techniques such as laparoscopy, endoscopy, endovascular surgery or ureterorenoscopy. For five specialists, these techniques accounted for 80% of the procedures or more. In case of open surgery, most surgery is performed using an operating microscope for increased precision. Another trend is the use of robot assisted surgery, especially in the laparoscopy of the gastroenterologist 2 (GE2) and hepatobiliary and pancreatic surgeon (HBP). The standard surgical techniques in all seven participants included some form of electrosurgery. Also, the use of traditional (laparoscopic) knife and scissors was reported in many cases, except for endoscopic procedures where blunt devices are required. The identified technologies, devices and manufactures were added to the results in the sytematic review in Chapter 4, Table 1.

### 8.3.2 Current challenges and problems

Two specialists mentioned that, during their treatments, sometimes the goal is to uncover blood vessels from their surrounding tissues. During bypass surgery, which is often performed in the legs, the vascular surgeon (VS) has to reveal and prepare the healthy artery below and above the blockade in order to make the bypass. The oral and maxillofacial surgeon (OMS) uses similar techniques to harvest and implant vessels in the head-neck area for reconstruction purposes. Surgeons use haptic feedback from their surgical tools to prevent them from cutting through the blood vessel while trying to reach or reveal it. However, they sometimes fail, especially less experienced surgeons, which results in significantly prolonged surgery times.

Another challenge that was reported (n=4) is to preserve blood vessels during endoscopic and laparoscopic procedures. One reason is to retain a clear visual from the endoscope and laparoscope (but also laryngoscope, microscope etc) . GE1 explained that during endoscopic surgery, most small blood vessels are coagulated upon contact or can be instantly coagulated once detected. However, sometimes a vessel ruptures that is a larger than can be coagulated with the current settings of the electrosurgery device, or, due to the unclean nature of the gastrointestinal tract, the source of the bleeding is hard to find. In both cases time is lost by adjusting device settings and localising the bleeding and as a result more blood enters the working field, further fouling the view of the endoscope. Solving this can be very time-consuming. According to the urologist (URO), similar problems sometimes even results in change of treatment from ureterorenoscopy to laparoscopic surgery. The ear-nose-throat surgeon (ENT) described that bleeding, but also carbonisation from electrosurgical devices or medical lasers, can result in an unclear working field, in which the surgeon cannot distinguish different tissue types sufficiently. Lastly, two clinicians expressed that heat induced smoke during laparoscopy can be troublesome because of reduced sight. Suction of smoke or excess blood requires extra devices and time, delaying the procedure.

A common problem specified by the interviewees is not only the preservation of blood vessels, but also the preservation of functional tissue in case of tumour resection in the parenchyma of important organs. Current methods result in heat damage, especially from

electrosurgical devices. That is why, if possible, ultrasonic cutting devices (n=3) or laser surgery (n=2) were reported to be used for precision surgery. Although these techniques provide improvements, they can be very expensive and the challenge still remains to remove and necrotise as less functional tissue as possible. The HBP explained that in liver tumour resection, surgery is challenging as the clinical outcomes heavily rely on the ability to fully remove the carcinoma, while retaining the function of the liver by keeping healthy tissue, bile ducts and blood vessels intact. For HBP and URO in respectively liver and kidney surgery, larger vessels can be damaged without notice or immediate bleeding, but eventually rupture in the first hours after surgery. This is a big complication leading to resurgery and often a much larger part of the organ needs to be removed. GE1 reported that in the endoscopic treatment of polyps gastrointestinal tract, the heat of electrosurgical devices can lead to gastrointestinal perforation which is a serious complication leading to re-surgery and possibly even death.

Especially OMS and VS expressed that water jet technology could solve current problems in surgery around important nerves. In oral and maxillofacial surgery, the removal of tumours that are located close to the ear and the facial nerve, which is responsible for facial expression, is a very challenging procedure. Not because it is hard to remove the tumour tissue, but because it is very hard to do so without damaging this crucial nerve. This can be the same for a VS in areas with a lot of nerves, such as the neck and thigh.

### 8.3.3 Preferred application

Each interviewee was also asked what, in their opinion, would be the preferred application of water jet surgery. Their opinions will be stated below, with extra attention to common factors in their answers.

The HBP and GE2 both stated that water surgery could be an added benefit in liver surgery. Especially in the laparoscopic resections of hepatocellular carcinoma in the deeper parenchyma of the liver. During the interview, VS and ENT also mentioned that the liver is a highly vascularised organ (blood vessels and bile ducts) in which surgery can be challenging. HBP and GE2 clearly stated that the application of water jet surgery in laparoscopic resections of the gallbladder, stomach and intestines is very limited. This because current technology already is fast, cheap and effective. Another treatment that is very similar and that was mentioned by both the HBP and URO as preferred application, is the laparoscopic resection of renal cell carcinoma during partial nephrectomy.

Another reoccurring application is the endoscopic dissection in the (sub)mucosa. The reason for this type of surgery is the removal of polyps to prevent cancer, or to threat first stage cancer tumours. This type of surgery was quoted by both GEs and the URO, as these treatments are typical for organs in the gastrointestinal tract and the urinary tract.

The ENT and OMS both suggested the use of water jet surgery for the resection of lymph nodes in the neck, to reduce, bleeding, smoke and evaporation of fatty tissue during electrosurgery. For the same reason, although ENT and OMS do not perform this treatment themselves, they both suggested water jet surgery for resection of the (para)thyroid gland. GE2 came with the suggestion to use water jet surgery in breast conserving surgery. He explained that during this type of surgery, natural cutting lines between the fatty tissue and the mammary glands are very hard to identify. Therefore, the surgeon makes broad cuts, necrotising both glands and fatty tissue which is undesired for function preservation

and aesthetics. The GE2 continues with the fact that breast cancer surgery has a very large patient group, which makes slight improvements already impactful.

Several interviewees (n=4) recommended to use water jet surgery for the treatment of tumours in close proximity of important nerves. OMS proposed salivary gland resection, with special focus on the parotid gland, which is very close to the facial nerve. But also glomus caroticum tumours which are close to the facial nerve and carotid artery. VS explained that he had recently operated on the carotid artery and during the procedure he had troubles working around a nerve. VS reported it happens more often, especially in cases of atypical anatomy. Another proposed application is rectum surgery (both laparoscopic and endoscopic) as this area also contains many nerves that have severe consequences if damaged.

Lastly, the ENT named the tonsils as possible application. The HBP surgeon included endometriosis surgery as an option. The reason for this is that he had heard from gyneacologist that this procedure is very difficult as natural resection lines are hard to determine and risk of damage to other organs is high, with a strong association to complications as a consequence.

### 8.3.4 Implementation

After describing the progress of the current project, the interviewees were also asked about their view on follow-up research and future steps. Table 9 on the next page shows the results. Moreover, the interviewer tried to find any extra requirements for the development process that were not included in the design yet. These requirements could apply to the medical procedure that the specialist had in mind for the water jet device, or for the water jet device in general. From the interviews we could conclude that requirements could be divided in general requirements, requirements for laparoscopy, requirements for endoscopy and requirements for open surgery. The specific distinction between these surgical techniques was not realised before. Table 10 shows all identified requirements.

Table 9: Preclinical data that was requested before the device can be used in patients.

| REQUESTED PRECLINICAL DATA | |
|---|---|
| Type | Data |
| **Cutting properties** | Control of cutting depth |
| | Volume of removed tissue |
| | Amount of splashing |
| **Tissue selectivity** | Size of blood vessels that are spared. |
| | Blood vessels and nerves that are weaker than surrounding tissue |
| | Influence of scar tissue |
| | Influence of tissue inflammation |
| | Influence of presurgical radiation therapy |
| **Infection chances** | Infection of other tissues due to splashing/washing/injection |
| | Protective measures for the surgeon due to evaporation of tissues. |
| **Added benefit** | Patient outcomes. (e.g., complications, postoperative pain, restore of function, postoperative-bleeding, long term scarring) |
| | Time savings |
| **Dynamics of target tissue** | Influence of the perfusion of blood vessels |
| | Influence of tension on target tissue |
| | Effect of stacked tissue layers. |
| **Methods** | Animal tissue studies |
| | Living animal surgery studies |
| | Postmortem human studies |

Table 10: Requirements obtained from interviews with the clinicians, coded per surgical procedure type.

Endoscopy Laparoscopy Open Surgery All Techniques

**ADDITIONAL REQUIREMENTS**

| Category | Requirement |
|---|---|
| | Adding drugs and dye to the stream |
| | Integrate with electrosurgical cutting and coagulation |
| | Integrate injection mode |
| | Integrate low pressure irrigation mode |
| | Integration in ultrasonic coagulators/scissor |
| | Integration with robotic systems |
| | Suction system |
| | Clean cutting edge that can be stitched |
| | No tissue splashing |
| | Short nozzle, support of the elbow should be possible |
| | Appropriate nozzle length, diameter, and flexibility |
| | Disposables vs Sterilizability,<br>In terms of hygiene, sustainability, and costs. |
| | Thrust force should not undermine precision |
| | Prevent droplets on the camera |
| | Aiming tool |
| | Only a very small part of the device in the camara view. |
| | Everything in the view of the camara should be recognisable |
| | Noise level |

## 8.4 Results other specialist

For the interviews with the clinical physicist (CP), implementation specialist (IMP), and MDR specialist, a different interview structure was used. Each of these participants had a semi-structured interview with questions specifically tailored to their specialism. The goal of these interviews was to obtain as much relevant information as possible. The following paragraphs will discuss the key elements of these interviews if they have not yet been discussed previously in this report.

### 8.4.1 Clinical physicist

One of the main realisations from this interview was the differences in the procurement process of two different types of technology investments in a hospital. The hospital differentiates between replacement devices and expansion devices. The CP explained that the average lifetime of a medical device is around ten years. At a total of around eighty million euros on medical devices, this means on average each year around eight million euros worth of medical technology needs to be replaced at the hospital the CP works in. This is one reason to start the procurement process. The other reason she elaborated was for expansion and innovation. In this case, medical specialists or device manufacturers can submit compelling business cases to explain why expansion is necessary and/or beneficial. The complete procurement process is illustrated in Figure 12. In the device evaluation, not only the technology, costs and benefits are evaluated, but also an extensive risk analysis is performed. Moreover, the impact of hospital specific integration with IT, facilities, safety measures and storage is estimated.

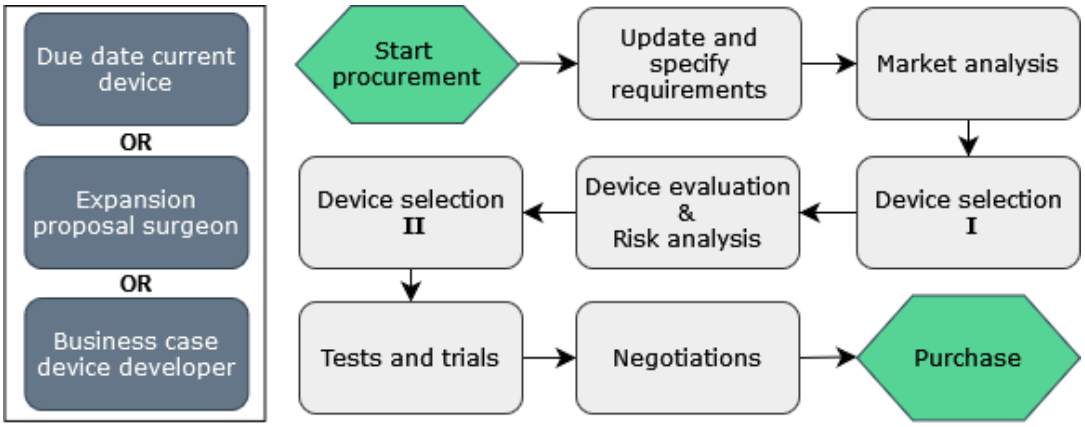


Figure 12: Procurement process of new medical device in a Dutch hospital

In case your device is determined to replace existing devices, the new device should be able to check off all functions of the current device and perform at least as good. So the emphasis lies on the capabilities and efficiency of your technology. Also, in this case, a device with multiple functions is desirable because it could substitute more devices. In expansion investments, the emphasis is on the added benefit of the device and the impact it will make. This means it is also very important to describe how often it will be used, as it should eventually earn itself back.

A less obvious way to increase the impact of your device is by reducing costs for safety measures. For example, laser surgery is popular because of its superior clinical outcomes compared to electrosurgery in some procedures, however, laser surgery needs to be per-

formed in designated ORs, equipped with special glass, doors and other safety equipment. If a new device makes these obsolete, this could be a major benefit. Lastly, the CP notified us that hospitals also have their own safety and feasibility committee that has to approve experiments if they take place in one of their ORs.

## 8.5 MDR specialist

The key insights gained during this interview were related to approvals for clinical studies, the process of CE certification and standardisation protocols. Especially, the difference between medical device developing on paper, and the real world practice were illustrated.

According to the MDR specialist, the goal of regulations is to step-wise reduce risks in the technology as high risks can result in non adoption of the device. Other possible reasons for non adoption mentioned were if benefits are too small or unclear, if the impact on work flow is too high, or if the initial costs and thereby financial risks are too high. In the experience of the MDR specialist, a good tactic therefore is to structure the R&D process around the highest risks. First tackle this risk, by doing more research and by implementing solutions. Then, if the risk is reduced, another risk will be the highest one, so start solving that. When applied to our project, one of the biggest risks would be that the device does not cut selectively. So it is advised to first make sure to prove this. Also, the MDR specialist confirmed that early interviews with medical specialist are key to determine the added benefit of the device.

The MDR law specifies the rules and regulations for medical device developers. In practice, at the start of development, a scientist can try out and test without need to consult to the MDR law, just as a proof of concept. However, the MDR law sets requirements for when research involves tests on human beings. The METC want a mild version of the CE mark documentation. The IMDD is the start, but from there they also want to know the other points from MDR Annex 1, or explain why they are not applicable. More over, before clinical tests are allowed, the goal is that your device is completely built under a quality system. That quality system should adhere to certain standards, which also apply to the organisation as a whole. This means that there should be procedures for everything. The team should be sufficiently qualified. The design documentation should be of a high level. Everything should be continuously reviewed. Also, if you aim to further develop the device, you should at least do usability tests and risk management with early prototypes before human studies can be performed. Once you implemented quality management, risk management and usability testing, it is allowed to do the first clinical studies. These should show the added benefit of the device, but also that risks are sufficiently mitigated. The MDR states that you should predefine how you compare your device to the current ones, which outcome measures do you choose and how do you justify them. The same steps apply to risk management.

In practice, the change between low-key research for proof of concept to a professional development process is often done with a hard cut. Because such a hard cut consumes a lot of time and resources, it could be take years before it is justified. However, the longer you wait, the higher the costs for illegitimate design choices. Once decided to implement the hard cut, people experienced in quality systems should start the design from the ground up to make sure all quality processes are integrated. Often big Med-Tech companies are involved in this process because of the high investment costs. Therefore the easiest way to get results is by transferring the technology from university to a Med-Tech

company and start a cooperative project. In such cooperation, strategies for intellectual property and non-disclosure agreements are crucial. Patenting could also be an option to enforce company collaboration. Potential manufactures might refuse to cooperate if they have intellectual conflict, meaning they have been developing similar technology and do not want a mix-up of whose idea it was.

To summarise, surgical devices are inherently related to higher risk, so regulatory bodies will expect a very high level of quality management and risk management before tests on humans are allowed. This means that in practice, developing the device might be only possible with help from a company, or at least by involving experienced engineers. The focus of the early trials should be on animal studies. These are also regulated by a committee, but these are not as strict as the METC. Especially if studies are designed with little extra burden on animals. For example, by testing on animals that are already involved in other studies. For applications of animal studies or clinical trials, the University of Twente has staff that is available to help out.

## 8.6 Implementation specialist

The IMP provided valuable information about innovation and implementation processes. It was confirmed that a development process has a lot of common steps which are very well described in literature and frameworks (see also Chapter 3). The IMP provided input for methods to use these frameworks to answer the research questions of this paper. Moreover, ideas for requirement identification were discussed.

One of the main realisations of this interview was that, up until this point, the development of the surgical water jet had mainly focussed on the clinical and technological aspects of the development process. However, to determine the eventual application of your technology, also the business factors play an important role. The Med-Tech innovation framework illustrates the business themes and the steps to be taken very well. To add to this, Med-Tech companies often perform opportunity assessments to explore the market attractiveness for a specific product. In this way, not only the potential clinical benefits play a role in the decision for scope and intended use, but also the feasibility to penetrate the market and the impact on the market. In short, the IMP called this "the ability to win". So, future steps should not only look at the best application clinically, but should also assess if the application has a winning business model. As depicted in Figure 13, an opportunity assessment you should obtain a knowledge base for each potential field of application that is useful to make further decisions.

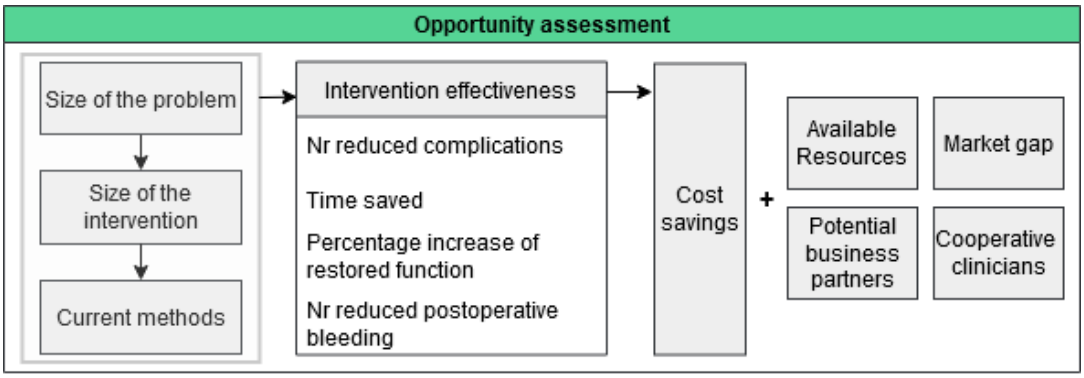


Figure 13: Components in an opportunity assessment

To derive all the data necessary for such an assessment, assumptions have to be made in the beginning. For example, the intervention effectiveness is determined by quantifying the most prominent benefits of the technology. These can be different per application. Often this data has not been determined yet in clinical studies. So, based on literature studies and preclinical data, educated estimates have to be made. In the Netherlands, but definitely in the US, data is published on the exact number of patients for each type of treatment. Asking medical stakeholders directly on their opinion and estimated benefits of the device is also a valid method and could be applied during interviews. Sometimes looking up the relevant information of a patient group, like size, cost of standard care, clinical outcomes, cost of complications and more, is a study on its own. However, describing if the information is available can already be very useful. Eventually the goal is to link patient groups and standard care, to the benefits of the new device to give an overview of the increased health outcomes and costs savings.

To get more insight in the design requirements that are not related to the clinic, several tools can be useful. A tool to specifically look at the business requirements and the value proposition of the new technology is the Business Model Canvas [84]. Another helpful tool can be to classify the requirements identified in other interviews and meetings with stakeholders using the existing frameworks. This makes a good overview and can help structure future design phases and next steps. Moreover, look at which other information is still missing to make a successful business case. Lastly, an approach that could also be useful is by looking at the work flow of the device. For example, by making a list of jobs to be done when a clinician would use it, but also for preparation, cleaning, maintenance and storage. This is a method to identify working requirements that have not been included yet and to make sure the device can be integrated in existing practices.

# 9 Discussion

In this chapter, the results from the systematic review, the information retrieved in the stakeholder analysis, and the results of the stakeholder interviews will be used to answer this paper's research questions. This discussion is structured by first addressing the results on the identified stakeholders, discussed per stakeholder, after which the newly endorsed requirements and their implications will be discussed. At the end of this chapter, the important strategic decisions and the future focus of this project are considered.

## 9.1 Stakeholders

Stakeholders were identified according to literature by use of the frameworks mentioned in the Methods (section 3). Although the list of stakeholders corresponded to literature, the list was not validated by the stakeholders themselves. This can be done in the future to possibly identify or retract stakeholders. Clinical stakeholders were further defined by the outcome of the systematic review. Most of the procedures that were mentioned in the systematic review were presented in the stakeholder interviews, but because surgeons only perform specific treatments within their specialism, it was not feasible within the time frame of this study to acquire all representatives. Nonetheless, we managed to interview all major specialisms except neurosurgery. Since no qualitative research has been done yet in the development of the PWJ device, it is only a minor limitation that not every treatment from the systematic review is represented.

**Developer**
From our results we can conclude that at this stage of the development process the University of Twente is the most important stakeholder because they 'own' the project. They will stay important for coming research activities during the proof of concept and proof of feasibility phases. However, they should realise that product realisation will not be possible without external developers. From the start of clinical trials it is important to find other Med-Tech developers and manufactures to assist in final design, business plan and regulatory process. The University of Twente has employers that can help with setting up an IP strategy. They should be consulted before external companies are engaged.

**Patient**
The patient is a stakeholder that is relevant once we have determined the application of focus. Or, multiple patient groups in case it is decided to work on multiple applications. With a known patient group, the patient characteristics and resulting patient specific requirements should be identified. This includes a study on which clinical outcomes are most valued by this specific patient group. This could be done using existing tailored outcome sets, such as those from ICHOM [61], making new patient preference studies redundant. As the PWJ device has not yet been evaluated on clinical outcomes, this is a critical step in proof of value. In clinical trials, PROMS can be used to measure patient outcomes. Other clinical outcomes, such as survival, adverse events, procedure time and length of stay should be collected by the developers of the PWJ during clinical studies. Retrieving the data on clinical outcome measures is not only important to patients and patient representatives, but also to build a business case, to convince clinicians and to obtain approval from regulatory bodies and the general public.

**Clinicians**
Preference elicitation applied to clinicians is relevant to validate requirements and the relative importance of requirements. For most of the development process, the surgeon is a key medical stakeholder that can facilitate or obstruct progress. Apart from the patient outcomes, for clinicians key requirements are reliability, consistency, time saving, ease of use and ergonomics. Supportive clinicians are mainly important to identify and check requirements for maintenance, preparation and cleaning. The hospital is relevant during the procurement process and also monitors compliance to regulation. For the PWJ device, the GE1 and the OMS had the most positive attitude towards the new technology. They both offered to help in the setup of clinical trials and indicated that they expected water jet surgery will be used in the future. They still have little knowledge of the technology and will need preclinical data and demo's to be convinced for participation in studies. The requested preclinical data and the additional requirements (see Table 10 & 9) that were identified during the stakeholder interviews should be incorporated in next design cycles of the device. That is, if applicable. One of the main realisations of this study is that a choice should be made between use of the PWJ device in open surgery, laparoscopic surgery or endoscopic surgery. This decisions also determines which preclinical studies to perform and which design chances to make.

**Manufacturer**
It is hard to say when exactly to include a manufacturer in the development process, because this depends much on the willingness of the University of Twente to dedicate resources to the project. It is crucial to make a strategy for IP before the technological details of the project are shared with other producers. If an external manufacturer would be contacted, a producer of similar products is preferred. With the complexity of medical device development, and the high risk profile of surgical technology, the process demands experienced stakeholders to steer development. Therefore, in next design cycles it is recommended to engage in a collaboration with Erbe first, after which a collaboration with other surgical technology manufacturers should be explored. In the stakeholder analysis Olympus has been assessed as producer of similar products. In fact, Ethicon or Medtronic have similar company profiles and are equally suitable for cooperation. If these companies are unwilling to construct new partnerships, existing close connections like DEMCON can be consulted. It should be taken into account that manufacturers often are most interested in a winning business case, not in research or the best care for patients. Therefore, it is wise to have a first version of a business case before manufacturers are contacted.

**Insurer**
For application to the Dutch market, the insurer is not a relevant stakeholder at this stage of the development. The reason for this is that in the Dutch health care system, the hospitals themselves are in charge of the procurement for surgical equipment. They will benefit the most from the advantageous offered by the surgical PWJ device. Insurers could be engaged later in the development process, as they have a lot of experience in cost-effectiveness analysis and health care budget impact analysis. Guidelines on economic evaluations can also be found in publications of the Zorginstituut [85]. Moreover, insurers might play a role in the wider adoption of the technology as standard of care.

**Regulatory bodies**
The regulatory processes in medical device development request a comprehensive set of activities as part of MDR compliance. This includes extensive documentation. This will help structure the design process, but will also cost a lot of time and resources. The way to tackle regulatory processes is by starting small. First by applying for animal studies at the METC. Then small, low risk clinical studies can be performed if sufficient evidence is gathered on the device's performance, risk and safety. In this way, more and more evidence can be collected to prove the merits of the device. CE certification is the goal, but many intermediate evaluations should determine if this is feasible. ISO norms (or others) should be used to help identify requirements for the device and to look at good practices in medical device development. Risk management has not been done yet for the PWJ device and should be incorporated with high priority because it influences design requirements and design controls. Additionally, the safety class according to the MDR law for the PWJ device can be determined. This will help to map the expected steps in risk management. A quality management system should be applied further in the process in collaboration with a manufacturer.

**Society**
Including society as a stakeholder is important in the later stages of the development phase. As explained in the stakeholder analysis, public opinions can influence the progress of the surgical PWJ device. Therefore, it is recommended to analyse the public perception of surgical procedures. For example, the Societal Readiness Level (SRL), which is a derivative of the TRL used in the technology description, is an approach to assess the level of societal acceptance of a certain technology or product [86].

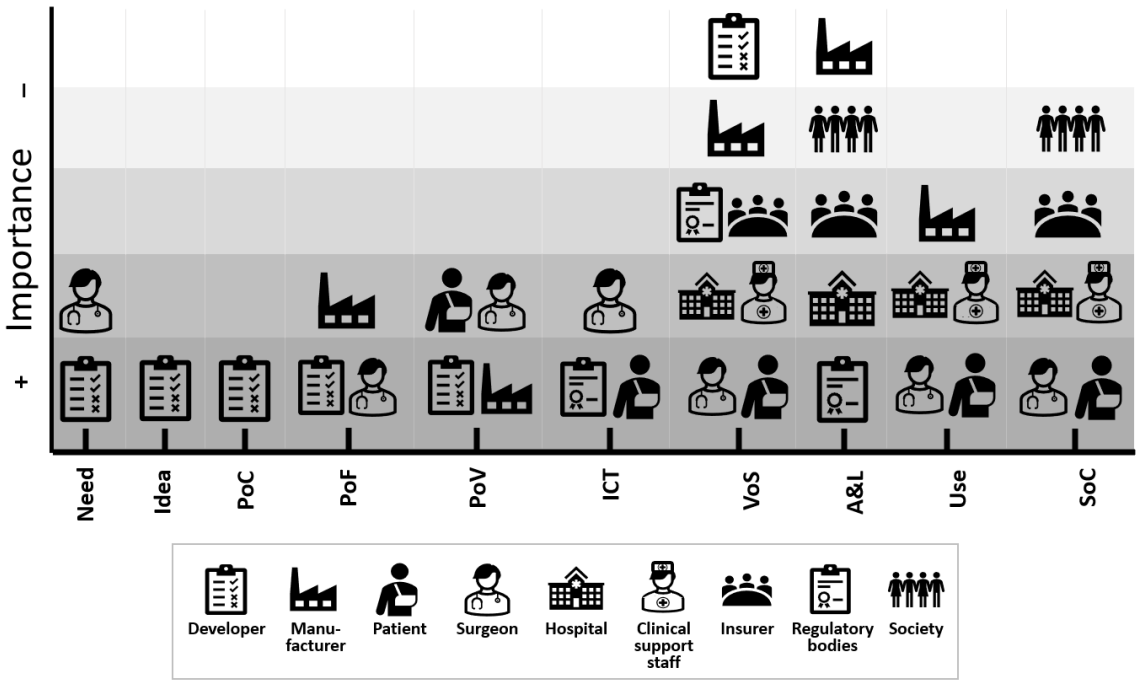


Figure 14: Analysis of the relevance of stakeholders during the development process. Steps in the process are as defined by the CIMIT innovation cycle (see Figure 1).

## 9.2 Strategic decisions

Within this study, sufficient information was gathered to identify important strategic decisions that need to be made early in the development process. Since this study is performed in an early stage of the development process, for most dilemmas it is too early to provide a definitive answer. However, realising the choices to be made ensures straight forward decision-making, proportional resource allocation and a more efficient development process.

### 9.2.1 Surgery type

One of these considerations is which general method of surgery should be focussed on. The methods that were reported in the stakeholder interviews were open surgery, laparoscopy, endoscopy, endovascular surgery, ureterorenoscopy and laryngoscopy. This decision is important as these methods have a completely different set of design requirements, as also became evident from Table 10. To further illustrate, for open surgery the device can function similarly like the current prototype with a short nozzle tip. Naturally, a lot of improvements still need to be made, also adaptations to facilitate open surgery with a camera or microscope, but the technical concept stays the same. This is an advantage, but open surgery also incurs disadvantages. An excess of water, splashing and diffusion of tissue with as result contamination, are serious risks that require substantial research before safe use can be guaranteed. In contrast, in endoscopy the target tissue is never clean and splashing and excess water are common. So in this case, the main challenge addresses the complex dimensions of the endoscope. For use in endoscopy, the technology needs to be validated for use with a very long nozzle (up to two metres). This might pose a problem with the working principles of the technology, as a long nozzle results in a loss of pressure. Laparoscopy has requirements that are somewhere in the middle of this spectrum between open surgery and endoscopic surgery. Ureterorenoscopy and laryngoscopy are much smaller genres of surgery and are used only in specific procedures. Committing to one of these types of surgery should only be done if the benefits are explicit.

### 9.2.2 Disposables vs sterilisability

Another strategic decision is to design the device with the use of disposable parts, or with reusable parts with the option of sterilisation. With surgical instruments, disinfection, sterilisation or both is mandatory depending on the type of instrument. It is so important that ISO composed multiple norms for this topic. This issue can be analysed in terms of design, cost and sustainability. For the design, disposables seem to be the best option. Plastics are very versatile in production possibilities, and if well-designed, they should be easy to integrate as presterilised disposable part of the PWJ device. Designing the device with reusable, sterilisable parts might be harder because the device materials will need to be tailored to the method of sterilisation. In most cases, disposables are also the cheaper option. The mass production of factory sterilised disposables is less resource consuming than the time and equipment that is needed for clinicians to sterilise devices on site. The during the stakeholder interviews, 2 surgeons mentioned that the topic of sustainability in OR is becoming more prominent. This could be an incentive to invest in the reusability and sterilisability of the PWJ device to reduce waste from disposables.

### 9.2.3 Target tissue

To find the most ideal application for PWJ surgery, it helps to find the type of tissue that is best dissected using the PWJ technology. From the technology description we can already conclude that the cutting characteristics can be tuned by changing input parameters, enabling dissection of various tissues. Also, in a previous thesis [23], cutting mechanisms and tissue effects have been studied. However, the current work is not sufficient to make accurate conclusions on which tissue types can be most effectively and accurately dissected, and to which extent tissue selective cutting is possible. In the systematic review, different procedures with different target tissues were explored, and with the input from the stakeholder interviews the following target tissues should be considered;

Table 11: Possible target tissues

| Tissue | Explanation |
|---|---|
| Parenchyma | The functional (soft) tissue of organs such as the liver, kidney, brain and glands. |
| (Sub)mucosa | Soft tissue that lines the body's canals and organs in the digestive, respiratory and reproductive systems. Dissection between the different layers of the mucosa. |
| Connective tissue | Nerves, blood vessels or glands can be dissected from their weaker supportive tissues without damaging them. |

Experimental studies should show the potential gains and losses comparing different tissue types. Choosing the target tissue will enable design optimisation and improved performance. The developers should also take into account that the reason for surgery mostly is tumour resection or for the treatment of inflammation. Sometimes scar tissue can also be present.

### 9.2.4 Target application

If conclusions can be made on the target tissue, the target application can be considered next. This is important because it is too much work to evaluate all possible applications. The applications with the best cost-benefit ratio should be further refined. From stakeholder interviews, three preliminary applications were identified that appeared to be feasible and had the highest potential according to clinicians.

- One application could be the resections of tumours that are close to a nerve or blood vessel. The two most prominent cases of this are tumours in the neck region and in colorectal surgery. These surgeries are known for their high complication rate and long surgery time.
- Another recommended application is the laparoscopic partial resection of the liver or kidney. These organs are well vascularised and the conservation of tissue is crucial for clinical outcomes. First clinical studies showed promising results.
- The most researched application of water jet surgery is Endoscopic submucosal dissections (ESD). The added value compared to conventional ESD has been proven.

Erbe integrated a CWJ dissector in an electrosurgical unit that can be used for ESD. However, in practice it is mostly used for injection and elevation, with electrosurgery as primary dissector. For this application it is key to prove that our prototype, with PWJ instead of CWJ, has superior outcomes.

- Although this application could not be confirmed by the clinicians that participated in this study, the dissection of breast tissue during tumour resection might be worthwhile investigating. One of the gastrointestinal surgeons hypothesized that the tissue types (mostly fat and gland tissue) are hard to distinguish for the operating surgeon. PWJ surgery could be much more accurate, sparing surrounding tissue.

These applications described various patient group sizes. This means that the potential economic impact also varies. This should be taken into account in further analysis. Furthermore, different risk levels are associated with the recommended applications, making research easier for some applications. To further specify which of these four applications should be focuses on, an opportunity assessment could be made for each case.

### 9.2.5 Target market

From analysing the health care system, the current market and the interview with the clinical physicist, multiple strategic decision regarding the target market were identified. To start, the surgical PWJ device could be introduced to hospitals using two different types of purchasing schemes: as a substitution device that replaces a current device, or as an expansion device that comes as an extra option for the clinicians to use. Since the current version of the PWJ device can not operate as a stand-alone unit, because some method for coagulation will always be necessary, the developers should aim at a purchasing strategy for on expansion device. However, if due to a collaboration, the PWJ device can be integrated into coagulation equipment, it could be sold as a complete solution. This is what Erbe has done for endoscopic mucosal resection. The HBP surgeon for instance suggested integrating the PWJ device in the beak of an ultrasonic sealer device. The extent to which the PWJ device can integrate additional functions such as suction, (drugs) injection and irrigation will also influence if existing devices can be substituted. The two different purchasing schemes have a different burden of proof, and therefore this strategic decision should be managed closely during the development process.

Another aspect of the target market are the market competitors. In this report we have identified several competitors (please refer back to Table 1). A part of the value proposition of PWJ technology is that the device outperforms competitors. On the other hand, the expertise and resources of competitors could be very useful in collaborations. Choosing how to manage this contradiction is a strategic decision in future development. In either way, it is recommended to map unmet needs and disadvantages of competitor products and use their products as benchmark for performance. Moreover, an indication for cost of development and cost of product can be derived form competitors.

Lastly, worldwide there are many differences in health care systems, market competition and Med-Tech regulation. This means that developing a product for these markets will request a different interaction between stakeholders. Also, the value proposition of the device could be affected. Assessing the opportunities of other markets is one of the future strategic decisions that should be made in the future.

### 9.2.6 Go/No-go & minimally viable product

Presently, the research done on the surgical PWJ device is low cost, exploratory research as proof of concept. From this report it has become evident that before clinical studies can be performed, a 'Go/No-go decision' should be made. This means that from that point in time, the stakeholders should commit more time and resources to the project. The reason for this is that for clinical studies with a surgical device, considerable time and resources are required for validation research, regulatory processes and the implementation of a quality management system. The Go/No-go decision should be made based on experimental data and input from all stakeholders. A 'Go' is only possible if a willing surgeon is found and if a cooperation with a manufacturer has been established. Another condition for a 'Go' should be that the minimal viable product is defined. This means that stakeholders have agreed on the total set of requirements that should be met and validated before a clinical study can be started. This includes not only product requirements, but also business requirements, organisational requirements, regulatory requirements and so on.

## 9.3 Future focus

This report has exposed many future research activities, stakeholder actions and strategic decision. To promote this study as innovation and implementation framework for next development cycles, recommendations for future development are discussed. Below, the future steps that should be focussed on are listed up until the start of clinical studies:

1. Focus on technical requirements, advance the prototype and assess feasibility for use in endoscopy and laparoscopy. Obtain preclinical data in laboratory experiments.
2. Focus on building a business case and IP strategy, collect economic data by means of early HTA and opportunity assessment.
3. Focus on engaging clinicians, manufactures and possibly other stakeholders.
4. Focus on the implementation of risk management.
5. Focus on the setup of animal studies.
6. Define clinical and patient outcomes, define minimal viable product and revisit the prototype.
7. Go/No-go for setting up clinical studies.

# 10 Conclusion

This implementation analysis was set out to summarise, evaluate and build new evidence on the surgical application of the pulsed water jet device developed by the University of Twente. A systematic review was performed to explore current research in surgical water jet technology. Using the steps described in existing implementation frameworks, relevant stakeholders were identified and analysed. In this way, additional requirements and future steps in stakeholder engagement were disclosed. Stakeholder interviews modeled after the NASSS framework were performed for participants that were selected from the stakeholder analysis. Seven clinicians and three other experts contributed to the mapping of current challenges in surgical technology, possible uses of PWJ technology, additional requirements, and future steps in (pre)clinical validation of the PWJ prototype. This report outlines in what way the University of Twente can start stakeholder engagement and what strategic decision should be made in future design. This report can be used as an innovation and implementation framework for next development cycles of the surgical PWJ device. Also it can provide as a guideline to implementation theory for medical device development in general.

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# Appendices

## A Setup of the PWJ prototype

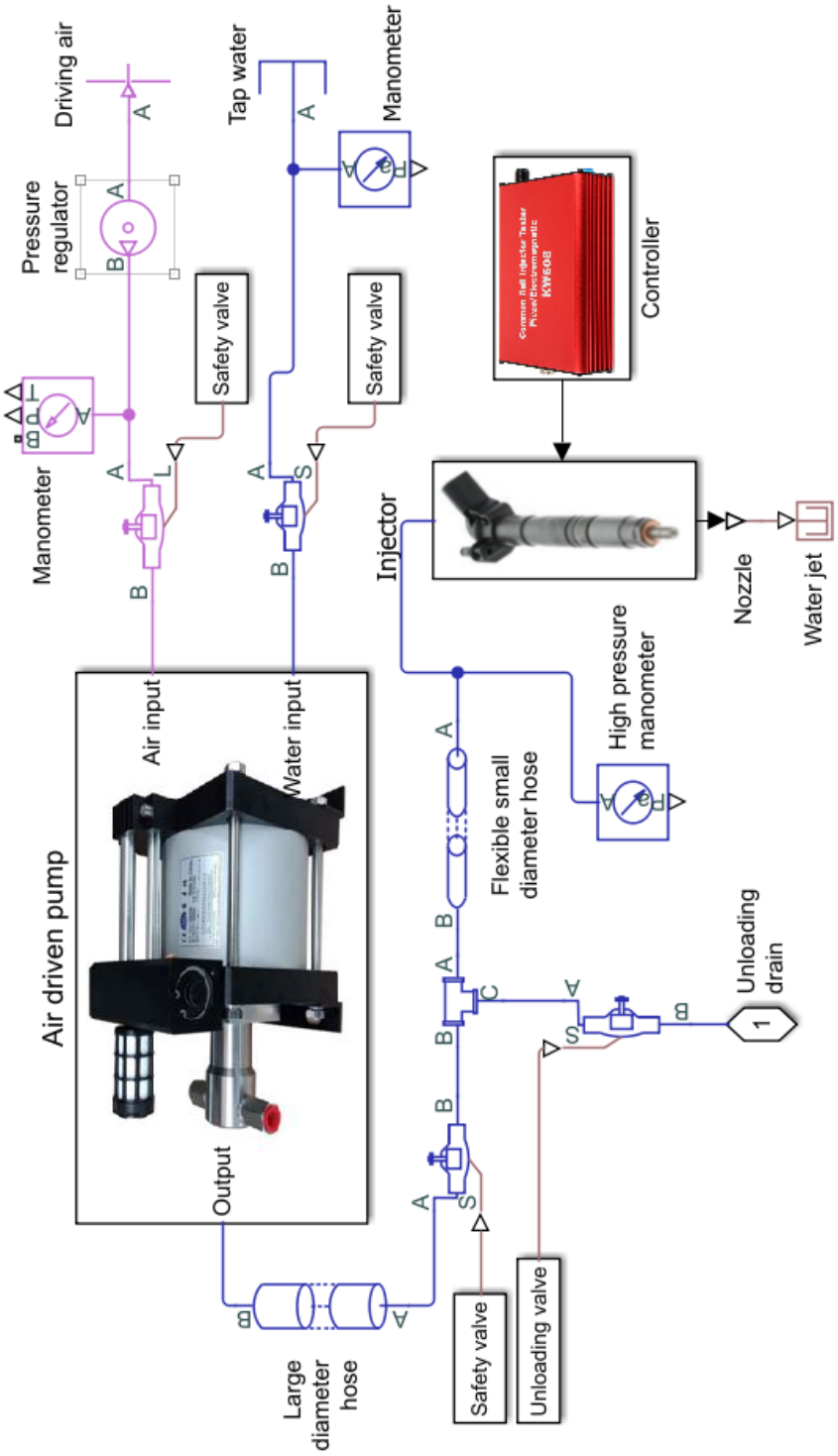


Figure 15: Flow diagram of the final PWJ prototype

# B The quality management system

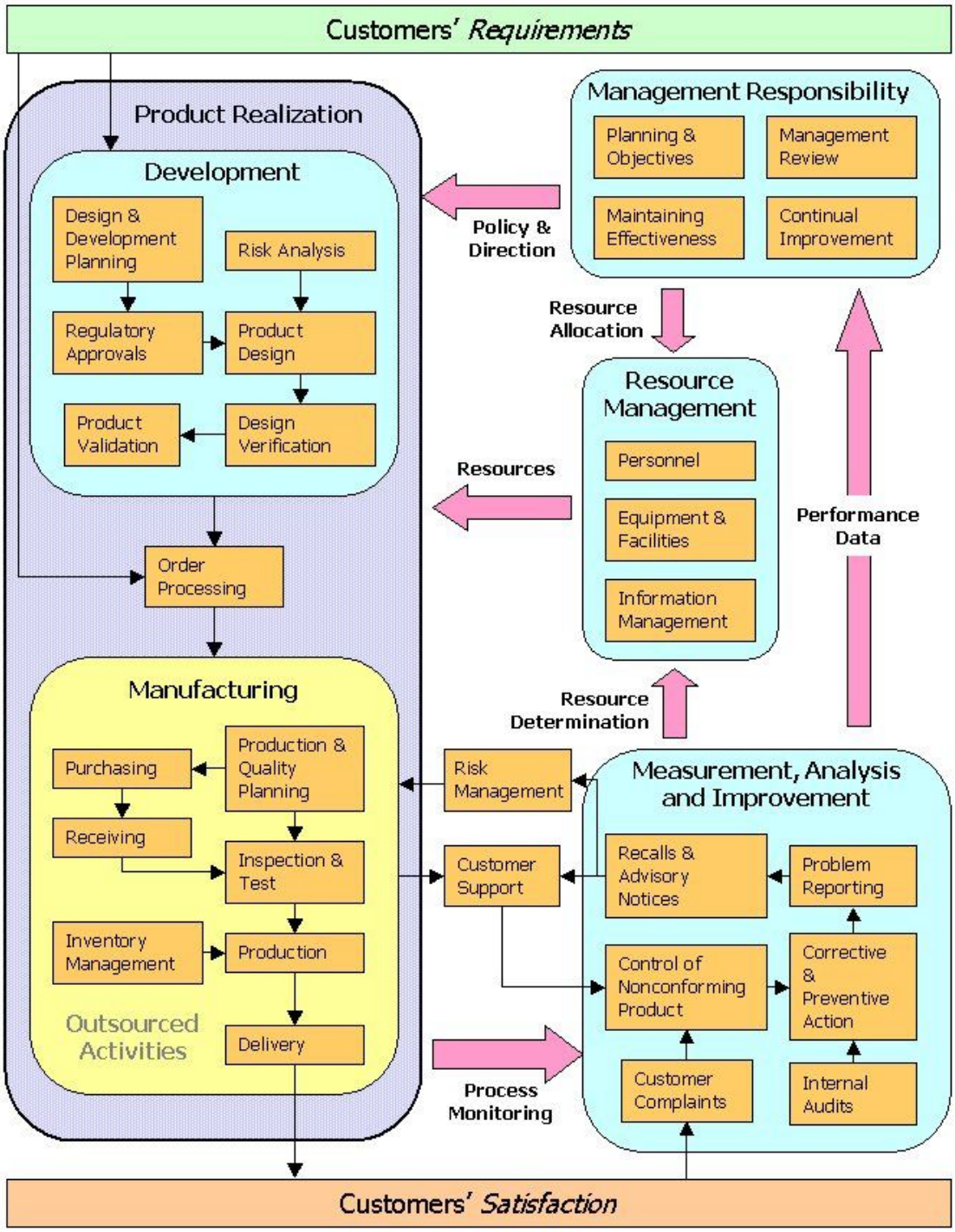


Figure 16: Summary of ISO 13485

# NASSS-CAT (INTERVIEW VERSION)

# RESEARCHING IMPLEMENTATION OF TECHNOLOGY PROJECTS



*Introduction*

This set of prompts for semi-structured interviews covers the different domains in the NASSS framework shown below. It will need to be adapted to suit the particular project that you are researching.

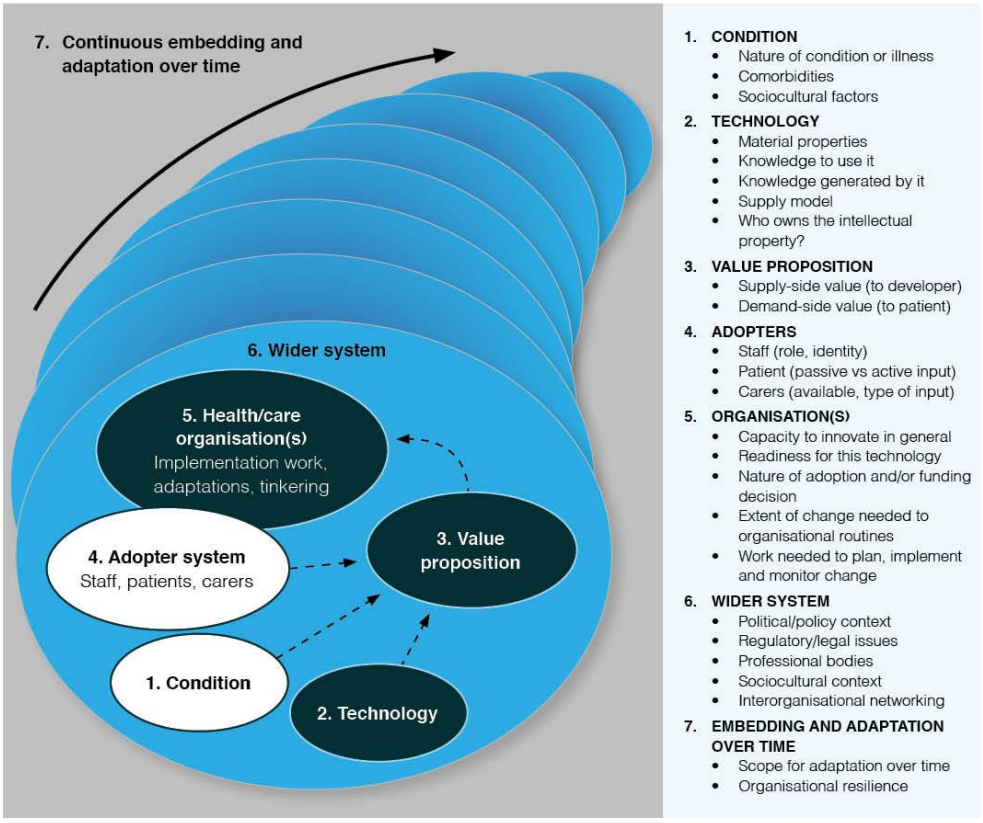


**Diagram: The NASSS framework** (© Greenhalgh at al J Med Internet Research 2017; 19 (11): e367)

*© Based on Greenhalgh et al 'Beyond adoption' (NASSS framework): J of Med Internet Research 2017; 19 (11): e367 and Maylor et al 'How hard can it be? Actively managing complexity in technology projects.' Research Tech Management 2013; Jul-Aug; 45-51.*

## DOMAIN 1: THE CONDITION OR ILLNESS

*Ask these questions of a clinician, social worker or someone else who understands the underlying illness or condition for which the technology was designed*

1. Tell me about the illness or condition for which this technology was [is being] designed.

   *Prompts:*
   - *Is the condition well-defined? How much is known about it?*
   - *Do you know how many people are be affected by the condition, and in what way?*
   - *Does the condition affect people in different ways? If so, can you give examples?*
   - *Would people with the condition need input from more than one specialist or be in more than one care pathway?*

2. Do people with the condition tend to have other illnesses or factors that need to be taken into account when designing the technology?

   *Prompts:*
   - *Are there physical co-morbidities (e.g. does it affect the very old or those with a pre-existing condition)?*
   - *Do some of the people affected have cognitive impairment, learning difficulties or communication difficulties?*
   - *Do people with the condition tend to be in multiple care pathways or see more than one provider?*

3. Do the target population for this technology have social or cultural factors that need to be taken into account when designing the technology?

   *Prompts:*
   - *Are some of them likely to be socio-economically disadvantaged, homeless or socially excluded?*
   - *Might some have religious restrictions or expectations that would affect how they manage their condition and their acceptance of technologies?*
   - *Are some likely to have low health literacy (poor understanding of what is wrong and how to manage it)?*
   - *Are some likely to have low system literacy (poor understanding of how to navigate the health or care system)?*
   - *Are some likely to have low digital literacy (poor understanding of technologies and how to use them)?*
   - *Are some of them likely to have problems understanding the language used by staff?*

4. How do you think the condition and the population it affects might change over the next 3-5 years?

   *Prompts:*
   - *Is the prevalence likely to increase or decrease?*

## DOMAIN 2: THE TECHNOLOGY (or other innovation)

*Ask these questions of the technology developer or someone else who knows the design aspects and technological detail.*

1. What exactly is the technology?

   *Prompts:*
   - *Does it exist yet? If not, how much uncertainty is there around what it will be like?*
   - *Is the technology easy to define – or are there some vague elements e.g. connects with hidden infrastructure, supplier does not disclose full details?*
   - *Is the current version of the technology the definitive version?*

2. Where will the technology come from?

   *Prompts:*
   - *Has a supplier been identified?*
   - *Is the supply chain in place?*
   - *Is the technology easily substitutable (e.g. if the supplier withdrew, would it be possible to get this or a similar technology from elsewhere)?*

3. How would you rate the technology's performance and dependability?

   *Prompts:*
   - *Does it capture, and where appropriate transmit, data accurately and reliably?*
   - *Are there any privacy or security concerns?*

4. To what extent do you think the technology is usable by, and acceptable to, its intended users?

   *Prompts:*
   - *Can people try it out before committing to it?*
   - *Do they understand what it does and the data it generates?*
   - *What are the challenges of actually using it in practice?*
   - *Have you observed people trying to use it? What do they say?*
   - *What help do you offer users (e.g. helpdesk, hands-on support)? What has been the experience of supporting the introduction of the technology?*

5. Are there any key technical interdependencies?

   *Prompts:*
   - *Are there plans to make the technology connect with existing infrastructure?*
   - *Does it need to be installed across multiple technical systems to achieve 'integration'?*
   - *Will there need to be an upgrade to the organisation's IT system (e.g. new hardware, better bandwidth) to support use of the technology across the organisation?*
   - *Would any target users have to upgrade their personal device(s) or home IT system?*

6. To what extent do you think this technology implies major changes to the way healthcare is delivered?

   *Prompts:*
   - *To what extent would implementing the technology require staff to do their jobs in a different way and/or interact with different people or teams?*
   - *To what extent would implementing the technology require new or different steps in the care pathway (e.g. new administrative processes)?*

7. To what extent do you think the technology (and/or the service model it supports) will become obsolete or require updating in the next 3-5 years?

   *Prompts:*
   - *To what extent can the technology be adapted to take account of future changes?*
   - *To what extent will the technology supply model change?*

**DOMAIN 3: THE VALUE PROPOSITION (costs and benefits of the technology)**

*Ask these questions of the technology developer or business lead for the organisation.*

1. What is the commercial value of the technology?

   *Prompts:*
   - *If the technology does not yet exist in a definitive form, how strong is the case for investing in its [further] technical development?*
   - *Is there a plausible business case for developing the technology (including up-front investment, a well-defined customer base and market drivers, consideration of competing products and realistic assessment of challenges of implementing at scale in a public-sector health or care environment)?*

2. What is the value of the technology to the patient or client?

   *Prompts:*
   - *Are there any high-quality studies (e.g. randomised controlled trials) to demonstrate the technology's efficacy for this patient/client group?*
   - *What evidence is there that the technology's benefits outweigh its potential harms?*
   - *Have the technology's efficacy and safety been measured in terms of an outcome that matters to patients/clients?*

3. What is the value of the technology to the clinician or other professional?

   *Prompts:*
   - *Does the technology create work – if so, for whom?*

- *Have the technology's benefits to the clinician been shown to outweigh the hassle of using it?*

4. What is known about the value that this technology could bring to the health or care system?

   *Prompts:*
   - *Has the technology (or the technology-supported care model) been shown to have an overall advantage over existing practice?*
   - *Has technology been shown to be effective and cost-effective in terms of how much benefit it will bring for a given financial outlay?*
   - *Are there any safety concerns about the technology or the care model it supports?*
   - *Has this technology-supported care model been successfully implemented in a similar context to the one being contemplated?*
   - *Are there concerns that the technology, whilst improving care for some patients, could widen inequalities?*
   - *Are regulatory and other approvals for the technology in place?*

5. What is known about the value that this technology is likely to being to this particular organisation?

   *Prompts:*
   - *Will new technical infrastructure be needed?*
   - *Will the organisation need to introduce substantial changes to organisational routines and pathways?*

6. Could the technology generate a negative value (i.e. costs would be more than gains) for some stakeholders?

   *Prompts:*
   - *Potential loss of income?*
   - *Destabilising a provider?*
   - *Hidden or knock-on costs?*

7. Is the value proposition likely to change over the next 3-5 years?

   *Prompts:*
   - *A new, better technology is on the horizon?*
   - *The market for the technology could change significantly?*
   - *A key regulatory decision could be made or reversed?*

## DOMAIN 4: THE INTENDED ADOPTERS OF THE TECHNOLOGY

*Ask these questions of anyone who uses, or is expected to use, the technology.*

1. What do patients and carers think of the technology?

   *Prompts:*
   - *Does the technology require substantial input from the patient or their immediate carer?*
   - *What is the meaning of the technology to the patient? (Do they like using it? Do they mind having it in their home? Does it remind them of an illness they would rather forget about?)*
   - *What are the practicalities of using the technology? (Are they prepared to learn to use it? Can they make it work? If not, why not?)*

2. What do front-line staff think of the technology?

   *Prompts:*
   - *Do staff question the value proposition for the technology (e.g. do they feel that adopting it would jeopardise the quality or safety of patient care, or do they think it is more time-consuming than existing practice)?*
   - *Would the technology require staff to do their jobs differently and perhaps take on a new, unwanted, role and identity (e.g. 'data entry person')?*
   - *Do individuals or teams have the resources, time, space or support to learn to use the technology?*
   - *Are staff confident to be creative and flexible when implementing technologies, and is there organisational support for this adaptive approach?*

3. Are there people who are indirectly affected by the technology?

   *Prompts:*
   - *Would technology require input from others (e.g. relatives, care home staff), who may be unable or unwilling to learn to use it?*
   - *Would the technology would make someone else's job obsolete or more difficult?*

4. How do you anticipate that individual users' perceptions of the technology will change over the next 3-5 years?

   *Prompts:*
   - *Do you think patients or their lay carers are likely to change their views on the technology?*
   - *Do you think key staff groups are likely to change their views on the technology?*

## DOMAIN 5: THE ORGANISATION(S)

*Ask these questions of people who know the organisation and the challenges it faces e.g. board member, human resources lead, staff representative.*

1. How would you rate the organisation's overall capacity to take on technological innovations?

   *Prompts:*
   - *How strong is the leadership?*
   - *Are the organisation's mission and values are clear?*
   - *How good are internal relations, especially between managers and clinicians?*
   - *Would you describe the management structure as flat and egalitarian or top-down and hierarchical? (For example, are individual departments discouraged from horizon-scanning for new products and ideas, and are they frowned upon if they introduce innovations?)*
   - *What is the organisation's track record of introducing any kind of change?*
   - *To what extent are there slack resources (people or money) to channel into innovative projects?*
   - *To what extent is it a learning organisation (in which staff are encouraged to meet and talk about new ideas and projects, there are measures in place to capture data and monitor progress, and risk-taking is encouraged?*
   - *What is the current level of digital maturity?*

2. To what extent do you think the organisation is ready for this particular technology/innovation?

   *Prompts:*
   - *Is there a good fit between the organisation's mission and the innovation?*
   - *Are there any key people (especially senior management) who oppose the innovation or are unconvinced of its value?*
   - *Is the business case strong and accepted?*
   - *Are the implications (e.g. work required) of introducing, implementing and evaluating the technology have been adequately and realistically assessed?*
   - *If money is needed, has a budget line been allocated?*

3. To what extent do you think organisational routines, pathways and processes will need to change to accommodate the technology/innovation?

   *Prompts:*
   - *Will different kinds of staff (e.g. new hires) need to be involved in the process or pathway once the technology has been introduced?*
   - *Will a new (or radically revised) process or pathway will need to be developed?*
   - *Will the core process or pathway need to link differently with other key processes and pathways in the organisation?*

4. Are there any relevant challenges in procurement processes that would make it harder for the organisation to invest in this technology?
   *Prompts: For example…*
   - *Is the provider on the organisation's procurement framework*
   - *Are there any existing contracts that need to expire first?*
   - *Are there aspects of the procurement process that are not yet clear (e.g. Who will fund this? Who will be liable for costs? Is there an identified budget? It is capital or revenue? Is the funding recurrent? Are there issues with timing/accruals of funding?)*

5. To what extent do you think the work of implementation has been realistically assessed and adequately resourced?

   *Prompts:*
   - *Work to bring people on board and develop a shared, organisation-wide vision for the change?*
   - *Work to develop, implement and mainstream new care pathways and processes?*
   - *Work to coordinate the project across more than one organisation or sector?*
   - *Work to evaluate and monitor the change?*

6. To what extent do you think the organisation(s) are likely to have significant restructurings or changes in leadership, mission or strategy over the next 3-5 years in a way that will impact on this project?

## DOMAIN 6: THE EXTERNAL CONTEXT FOR INNOVATION

*Ask these questions of people work outside the organisation or a 'horizon-scanner' who looks beyond the organisation.*

1. What do you think of the political/policy climate as it relates to this innovation?

   *Prompts:*
   - *External political or economic changes impacting on the organisation which could threaten the introduction of the innovation?*
   - *Current policy priorities that conflict with this initiative?*

2. Do you think professional organisations support or oppose this innovation?

   *Prompts:*
   - *Concerns about quality or safety of care?*
   - *Concerns about confidentiality and wider information governance?*
   - *Concerns about professional workload?*
   - *Other pressing priorities?*

3. Do you think patient organisations and lobbying groups are likely to support or oppose this innovation?

   *Prompts:*
   - *Concerns about quality or safety of care?*
   - *Concerns about privacy and/or what will happen to the data*
   - *Other pressing priorities?*

4. Is the regulatory context supportive or adverse for this innovation?

   *Prompts:*

- *Have quality standards and regulatory requirements for using the technology in a health or care setting been fully defined?*
- *Do key stakeholders do not know about and accept these standards and requirements?*

5. Is the commercial context supportive or adverse for this innovation?

   *Prompts:*
   - *Does the technology industry view this innovation (or similar products) positively or negatively?*
   - *Does the technology use industry-standard components?*

6. Are there opportunities for learning from other organisations?

   *Prompts:*
   - *Is the innovation up and running elsewhere – or are others planning to implement it in a similar time frame?*
   - *Are there established inter-organisational knowledge exchange networks (e.g. quality improvement collaboratives) or could these be set up?*

7. Are there other external changes that could threaten introduction of the technology?

8. How do you think the policy, regulatory and economic context for this innovation is likely to change over the next 3-5 years? Is there likely to be turbulence?

   *Prompts:*
   - *Change of government?*
   - *New policy priorities?*
   - *Economic recession?*
   - *New regulatory framework?*
   - *Withdrawal of industry commitment?*