Degree Project in Computer Science & Engineering

Second cycle, 30 credits

Haptic Feedback Levels in Surgical Simulation

Surgeons' Preferences in a Simulated Hysteroscopic Myomectomy Procedure

FILIP FORSBERG

Haptic Feedback Levels in Surgical Simulation

Surgeons' Preferences in a Simulated Hysteroscopic Myomectomy Procedure

FILIP FORSBERG

Master's Programme, Computer Science, 120 credits
Date: June 23, 2026

Supervisors: Alessandro Iop, Inga Steinberga, Mario Romero
Examiner: Tino Weinkauf

Host organization: Karolinska Institutet
Swedish title: Haptiska Återkopplingsnivåer i Kirurgisk Simulering
Swedish subtitle: Kirurgers Haptiska Preferenser vid en Simulerad Hysteroskopisk Myomektomi Procedur

© 2026 Filip Forsberg

Abstract

A hysteroscopic myomectomy is a surgical procedure for removing non-cancerous growths, myomas, from inside the uterine cavity. The procedure itself is minimally invasive and is performed by a surgeon using a hysteroscope, a handheld instrument. A challenge to patient safety during the procedure is the soft tissue of the uterus, which provides poor haptic feedback through the instrument. A complication of the procedure is accidental perforation of the uterine wall. This study focuses on the challenging haptic environment of the surgery, and asks the research question: *What levels of haptic feedback are preferred by surgeons during a hysteroscopic myomectomy?*

This study aims to answer this question by developing a computer simulation that replicates the surgical environment and uses a haptic feedback device as a controller. Participating surgeons can then freely choose their preferred levels of feedback when interacting with the environment inside of the simulation. In order to reach further insights, a semi-structured interview was done with the participating surgeons in order to learn about their thought process and reflections.

The participants' preferred levels of haptic feedback tended to stay around their perceived realistic levels of haptic feedback in the simulation, which can be ascribed to wanting to perform surgery under familiar circumstances and that some participants had misinterpreted the study as being a simulation for surgeons to practice with. In the semi-structured interviews, participants reflected more on the potential benefits of having a different haptic profile than what they are used to. A trend of participant desire for greater distinction in the haptic feedback from a myoma and the uterine wall was shown in the interviews. Clear arguments, both for and against altering the haptic profile of the procedure were also given from the perspective of patient safety.

Keywords

Hysteroscopic myomectomy, Haptic feedback, Augmented haptic feedback, Surgical simulation, User study, Human-machine interaction.

Sammanfattning

En hysteroskopisk myomektomi är ett kirurgiskt ingrepp för att avlägsna icke-cancerösa utväxter, myomer, från insidan av livmodern. Själva ingreppet är minimalt invasivt och utförs av en kirurg med hjälp av ett hysteroskop, ett handhållet instrument. Några utmaningar för patientsäkerheten under ingreppet är den mjuka vävnaden i livmodern, som ger svag haptisk feedback genom instrumentet. En komplikation av ingreppet är oavsiktlig perforering av livmoderväggen. Denna studie fokuserar på den utmanande haptiska miljön under operationen och ställer forskningsfrågan: *Vilka nivåer av haptisk feedback föredras av kirurger under en hysteroskopisk myomektomi?*

Denna studie syftar till att besvara denna fråga genom att utveckla en datorsimulering som replikerar den kirurgiska miljön och använder en haptisk feedback-enhet som styrenhet. Deltagande kirurger kan sedan fritt välja sina föredragna feedbacknivåer när de interagerar med miljön inuti simuleringen. För att få ytterligare insikter görs en semistrukturerad intervju med de deltagande kirurgerna för att lära sig om deras tankeprocess och reflektioner.

Deltagarnas föredragna nivåer av haptisk feedback tenderade att ligga runt deras upplevda realistiska nivåer av haptisk feedback i simuleringen, vilket kan tillskrivas en önskan om att utföra operationen under välbekanta omständigheter och att vissa deltagare hade misstolkat studien som en simulering för kirurger att öva med. I de semistrukturerade intervjuerna reflekterade deltagarna mer över de potentiella fördelarna med att ha en annan haptisk profil än vad de är vana vid. En trend med deltagarnas önskan om större skillnad i den haptiska feedbacken från ett myom och livmoderväggen visades i intervjuerna. Tydliga argument, både för och emot att ändra procedurens haptiska profil, gavs också ur patientsäkerhetsperspektiv.

Nyckelord

Hysteroskopisk myomektomi, Haptisk återkoppling, Förbättrad haptisk återkoppling, Kirurgi simulering, Användarstudie, Människa-datorinteraktion.

Acknowledgments

I would like to express my sincere gratitude to my supervisors, Alessandro Iop, Inga Steinberga, and Mario Romero, for the guidance, support, and valuable feedback throughout the process of writing this thesis. Your insights and encouragement have been instrumental in shaping the direction of this work.

I would also like to thank the participants of this study for their time and valuable contributions. Their input made this research possible.

Finally, I would like to thank my family and friends for their continuous support and encouragement throughout my studies.

Contents

1 Introduction **12**

1.1 Introduction 12

1.2 Research Question 13

1.3 Research Objectives 13

2 Background **15**

2.1 Background 15

2.1.1 Hysteroscopic Myomectomy 15

2.2 Related Work 18

3 Methodology **20**

3.1 Ethical Considerations 20

3.2 Material Resources 21

3.3 Evaluation 23

3.4 Limitations 24

4 Results **26**

4.1 Haptic Feedback Levels in Experiments 26

4.2 Semi Structured Interviews 28

4.2.1 Themes Discovered 28

4.2.2 Preferred Levels of Haptic Feedback 28

4.2.3 Safety Concerns 29

4.2.4 Confusion about the study and not thought out answers 29

4.2.5 Realism in the Simulation 30

5 Discussion **32**

5.1 Limitations 34

5.1.1 Number of Participants 34

5.1.2 Researcher Experience and Bias 34

5.1.3 Misinterpretation of Study and Participant Bias 35
5.1.4 Hardware and Software Limitations 35

6 Conclusions and Future work 36
6.1 Conclusions 36
6.2 Future Work 37

A Consent Form 42

B Semi-Structured Interview Questions 45

Chapter 1

Introduction

1.1 Introduction

Hysteroscopic myomectomy is a surgical procedure that is performed on the inside of the uterus [8]. The purpose is to remove myomas, also known as fibroids, which are growths made up of muscle and fibrous tissue [4] that are found in the uterine cavity. The procedure is performed with an instrument called a hysteroscopic resectoscope, the instrument is shown in figure 2.1.2. The instrument is fitted with an electrical wire to cut with and a camera. This allows the surgeon to follow the procedure on a screen mounted in the operating room as they methodically cut away the unwanted tissue.

One of the possible complications during the procedure is accidental perforation of the uterine wall, which occurs in $0.12-3.0\%$ of cases [1]. The haptic, sensation of touch [9], feedback felt through the instrument can help guide the surgeon during the procedure and make it easier to distinguish the different tissue types. However, operating a stiff metal rod on soft tissue relays a dull haptic feedback experience. Perhaps if the current haptic feedback profile could be altered, it may lead to an overall improved safety in the procedure.

To the best of my knowledge, there is no research focusing on the usage of haptic feedback in hysteroscopic myomectomy. There are studies that look at introducing haptic feedback into systems that have disconnected the surgeon and their tool with the patient, such as robotic surgery [10, 12, 24]. However, none of the previous research have focused on what can be done with haptic feedback for procedures using handheld

tools directly on the patient.

Unlike previous research that focuses on introducing or restoring haptic feedback in robotic surgical systems, this study investigates the haptic preferences of surgeons performing a procedure in which natural haptic sensations are already present. The motivation is to explore whether insights from these preferences could contribute to the future augmentation of haptic feedback during the procedure. According to Islam et al. [9], haptic feedback is a type of sensory input that is conveyed to a user, often within a virtual simulation. For the purpose of this thesis, augmented haptic feedback refers to the intentional alteration of the haptic feedback transmitted through a physical surgical instrument, resulting in a haptic feedback profile that differs from what is naturally felt during the procedure.

In terms of patient safety, allowing surgeons to better distinguish between tissue types through augmented haptic feedback may improve their awareness of the operating environment in situations where visual information alone is insufficient. This, in turn, may contribute to safer instrument handling and potentially reduce the occurrence of complications such as uterine perforation.

This research begins to fill this gap by exploring the preferences of haptic feedback of the surgeons performing the procedure. What levels of haptic feedback are preferable to surgeons when given freedom of choice to design their own feedback profile for the procedure?

1.2 Research Question

The research question for this study is as follows: *What levels of haptic feedback are preferred by surgeons during a hysteroscopic myomectomy?* To see which levels of haptic feedback are realistic and what level is preferable, evaluation with experienced surgeons is necessary.

1.3 Research Objectives

1. To evaluate expert surgeon preferences for haptic feedback levels.
2. To qualitatively probe expert surgeons to gather further insights and reflections on the potential use and role of augmented haptic feedback in a hysteroscopic

myomectomy surgery.

Chapter 2

Background

2.1 Background

About one in three women who suffer from fibroid growths develop symptoms such as [4]: heavy or painful periods, abdominal pain, back pain, a frequent need to urinate. Fibroids also vary in size and range from a size that is hard to spot for the naked eye, to the size of a grapefruit [23]. In some cases fibroids can even cause infertility [4].

2.1.1 Hysteroscopic Myomectomy

Hysteroscopic myomectomy is a surgical procedure performed in order to remove submucosal fibroids from inside the uterus [8], which are growths made up of muscle and fibrous tissue [4]. An image showing the location of different types of fibroids is shown in figure 2.1.1, where submucosal fibroids are shown in the top left and middle right.

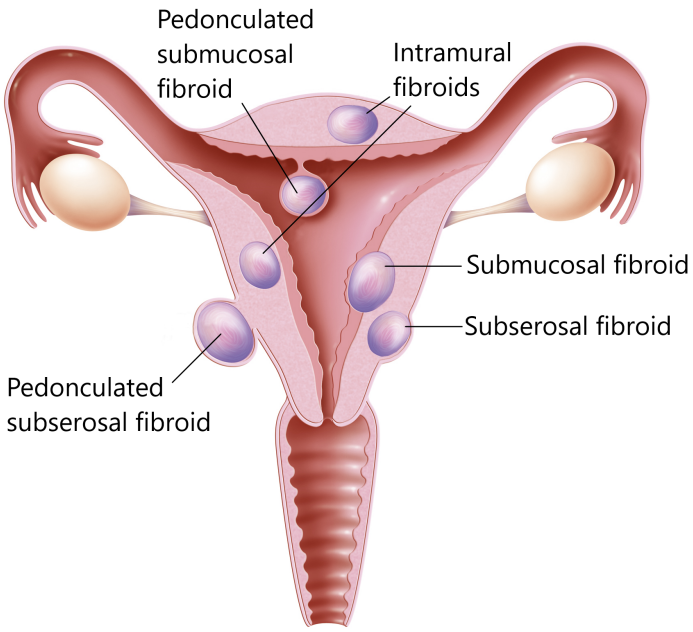

Figure 2.1.1: Types of fibroids. A hysteroscopic myomectomy is performed to remove submucosal fibroids. Image based on [11].

A surgeon uses an instrument called hysteroscopic resectoscope, shown in figure 2.1.2. On one end is a handle for the surgeon to hold onto, on the other is a camera, a light, and a resectoscope attachment. The tool is also equipped with fittings for tubes that are used to continuously circulate a saline solution inside the uterus to limit the bleeding caused by the cuts, keep the uterus stretched and open, and to flush out any tissue that has been cut [7]. The surgeon cuts out the fibroids by using a resectoscope attachment. The resectoscope attachment is an electrosurgical wire-loop that is attached at the top of the instrument. It moves back and forth by pushing a lever with the thumb, and the electrical wire is turned on and off using pedals on the ground. When the electrical wire is turned on, it cuts through the tissue and cauterizes the cut at the same time to stop excessive bleeding. Only one camera is attached at the front of the hysteroscopic resectoscope, which gives the surgeon a camera feed with only a 30 degree field of view.

Figure 2.1.2: Hysteroscopic Resectoscope. Tool equipped with light source, camera, wire loop, and tube fittings. Used by a surgeon during a hysteroscopic myomectomy. Image from [14], permission to use image granted. Copyright by Olympus Europa SE & Co. KG.

The instrument is inserted into the uterine cavity through the vagina and passed through the cervical canal. Once in place, the surgeon checks the surroundings using the camera and the light mounted at the top of the instrument. To cut the fibroids, the surgeon uses a pedal that activates the electrosurgical wire loop which is then used to carefully "shave" the fibroid away from the uterine wall, and at the same time cauterizes the tissue to prevent excessive bleeding [13]. The expected recovery time after the procedure is generally only a few days [8].

Perforations of the uterine wall during operative hysteroscopy occur in $0.12 - 3.0\%$ of procedures. Perforations often heal on their own, however they can in some cases lead to a hysterectomy, removal of the uterus, or could be a potential cause for uterine rupture during pregnancy [1].

2.2 Related Work

To the best of my knowledge, most studies on haptic feedback and its effect on surgeries focus on robotic surgery (RS). RS is inherently different from hysteroscopic myomectomy since it is performed using a robotic device, which is steered by wire, and therefore has no direct haptic feedback. A hysteroscopic myomectomy is performed using a handheld tool, a hysteroscopic resectoscope, which is directly linked to the surgeon and therefore provides direct haptic feedback. However, it is performed with a rigid tool on soft tissue, making it difficult to accurately discern the texture of different types of tissue. Research on haptic feedback in RS may provide valuable information when considering the limited haptic feedback experienced in the context of hysteroscopic myomectomy.

Tholey et al. [20] showed that the combination of visual and haptic feedback for tissue characterization with robotic arms showed statistically significant improvements than visual or haptic feedback alone. However, in comparison to direct exploration, where the test subjects interact with the tissues directly with their fingers, all variations of haptic feedback usage fell short since direct exploration showed a 100% success rate in correctly identifying the different tissues.

A similar study by Gwilliam et al. [5] tested the forces used during a palpation task for RS. The results of the study showed that subjects use less force during the palpation task when haptic feedback is included and more force when it is not. In fact, several studies show that the introduction of haptic feedback in the context of simulated RS tasks results in a decrease in the forces used [2, 10, 19, 22, 24], which is of importance considering one of the most common complications during operative hysteroscopy is perforating the uterine wall [1].

In the study presented by Wottawa et al. [24] the authors discovered a positive correlation between tissue damage and the levels of force used when handling the tissue. This was shown in an experiment in which they let participants control two robotic graspers, mechanical pliers, with tactile feedback to their fingertips. The participants were tasked with passing a porcine bowel, a proven model for abdominal surgery, between the graspers back and forth until they had grasped the bowel approximately 10 times with each grasper. The locations of tissue damage were counted before and after each trial and grasping forces were registered throughout. From the results of the experiment, a positive correlation was found between incidents

of tissue damage and higher levels of force used.

Research by Poliakov et al. has focused on the validation of the simulation of in-office hysteroscopy with haptic feedback [16, 17]. In-office hysteroscopy refers to hysteroscopic procedures performed in an outpatient clinical setting, without the need for general anesthesia or an operating room. In 2020 they conducted a feasibility study of creating a simulation platform [16], which led to a second study that evaluated the platforms training capability [17]. Worth noting is the fact that Poliakov's studies assume an office hysteroscopy, and focuses on tasks other than a hysteroscopic myomectomy. The simulation's purpose is to train surgeons in objectives such as passing the cervical canal without any prior dilation, which is a difficult task that can lead to accidental perforation [1]. Further, the simulation involved no cutting motion or simulated cutting training. Instead, the goal in the experiments was to enter the uterine cavity and "collect the checkpoints" — grasping 1 mm radius colored spheres using hysteroscopic forceps — as fast as possible while applying minimal force [16, 17]. The second study measured "integral force", i.e. the integral of the forces over 1 N in the experiment, and total execution time. Both measurements showed improvements with repeated trials and the simulation environment shows promise for future applications [17].

Meli et al. [12] conducted an experimental evaluation of magnified haptic feedback for robot-assisted needle insertion. For the experiment, they let a user control a robotic arm with a haptic controller. The robotic arm had a needle attachment, which was used to puncture through two soft artificial tissue models with different densities and that were placed in a stacked position with the denser one at the bottom. The participants were blindfolded and tasked with inserting the needle into the phantoms from the top and were instructed to stop as soon as they noticed a difference. Data was gathered by measuring the puncture depth of the needle. The test was performed both by direct hand interaction and with the use of robot assistance. Force sensors on the robot arm sent information to the haptic controller which was then relayed as haptic feedback to the user. The haptic feedback sent from the force sensor was magnified before it was relayed to the user. The results showed a 306% improvement for the robot-assisted with magnified haptic feedback over direct hand interaction.

Chapter 3

Methodology

Little research has investigated the specific field of altering the haptic experience of a handheld tool, not much is known or can be assumed. Therefore, a broad qualitative approach was chosen to gain insight into the field by cooperating and asking experienced professionals for their initial thoughts and input. Further, the pool of surgeons available to this project with experience of performing a hysteroscopic myomectomy is so small that no quantitative data could be considered conclusive. Because of these reasons, I decided to let the participating surgeons first get some hands-on experience by performing different tasks concerning the haptic profile of the procedure inside a simulation environment, and following it up with a semi-structured interview that was later transcribed and used as the basis for a thematic analysis.

3.1 Ethical Considerations

Each participant was informed about the study in the form of signing a consent form. This consent form contains information about how I used and stored their information and what the study is about. The participant's data was anonymized in the study and the data is also subject to GDPR laws. The complete consent form can be found in Appendix A.

3.2 Material Resources

A digitally simulated environment of a hysteroscopic myomectomy was developed, much like what has been done by Poliakov et al. [16, 17]. The Unity Engine[1] was used to develop the simulation environment because of its popularity within game development and that it was free to use for this project. In order to relay haptic feedback to the user, a special type of haptic controller was needed. For this the Touch X Haptic Device from 3D Systems [21] was used. 3D Systems software OpenHaptics [15] and their plugin on the Unity asset store [6] was used to connect the haptic device with the Unity engine. Since most of the available research on haptic feedback is focused on force feedback [12, 16–18, 20], only this type of haptic feedback was used with the haptic device. To further the realism of the simulation, the handle from a hysteroscopic resectoscope, such as the one found in figure 2.1.2, was attached to the Touch X device with tape and was used as the handle of the controller. An image of this connection can be found in figure 3.2.1.

[1]Real-Time 3D Development Platform & Editor. Unity Engine, url: https://unity.com/products/unity-engine (visited on 04/18/2025).

Figure 3.2.1: Setup Connections - An image showcasing the complete simulation setup with all of the connections. At the top is the screen, which is connected to the Touch X device, and taped to the handle of the Touch X device is the handle of a hysteroscopic resectoscope.

The simulation environment was constructed to replicate the inside of the uterus with what would normally be seen by the surgeon through the camera mounted on the tip of the hysteroscope. This view consists of a hysteroscopic resectoscope, the uterine wall, and a fibroid. A screenshot of the simulation can be seen in figure 3.2.2. The hysteroscopic resectoscope was controlled by the Touch X haptic device and translated haptic feedback back to the user when colliding with the uterine wall or the fibroid. The uterine wall and the fibroid have independently adjustable sliders, that are also present on the screen, that span from zero to a hundred percent and controls the effective

resistance of the tool. In other words, these sliders control how intense the user will experience the haptic feedback of each tissue type with which they interact within the simulation. A complete image showcasing how a person would interact with the full setup can be found in figure 3.2.3.

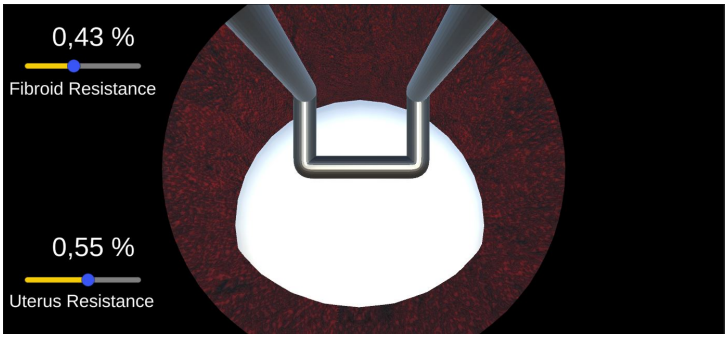

Figure 3.2.2: Simulation Screen - A screenshot of how what the screen looks in the simulation program.

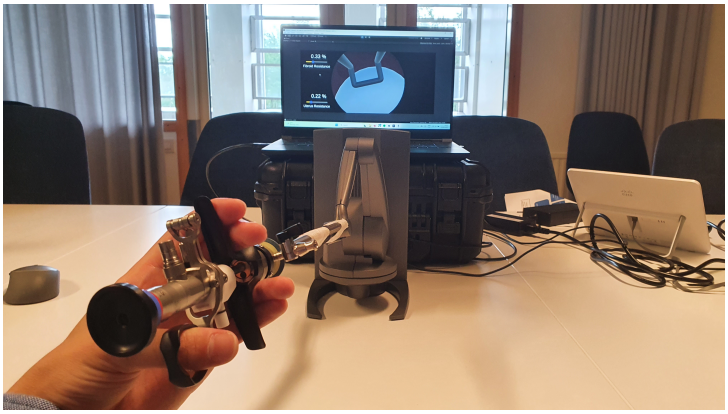

Figure 3.2.3: Full Setup - The complete simulation setup with the Touch X device with the added hysteroscope attached and the screen showing the simulation environment.

3.3 Evaluation

In order to answer the research question, four surgeons with experience of performing hysteroscopic myomectomies at Karolinska University Hospital (KUH) agreed to perform a short experiment within the simulation, followed by a semi-structured interview. The short experiment consisted of two tasks where the participants adjusted the haptic feedback levels within the simulation.

1. Adjust the haptic feedback to be as realistic as possible.

2. Adjust the haptic feedback level to what you would prefer to experience during a hysteroscopic myomectomy.

Immediately after completion, participants were invited to take part in a semi-structured interview about their experience of the simulation. They were also given questions that allow for reflection about the role haptic feedback has and could have in hysteroscopic myomectomies. The interview was transcribed and put under thematic analysis to interpret the data. All questions for the semi-structured interview were decided after consultations with Inga Steinberga, external supervisor & gynecological surgeon at KUH, and can be found in Appendix B.

Thematic Analysis

The thematic analysis workflow consists of six different steps in order to accurately present the data from the semi structured interviews [3].

1. Familiarization of the data, transcribing the interviews, re-reading, and making initial notes.
2. Systematically labeling and organizing different parts of the transcript.
3. Grouping the different labels into different themes.
4. Reviewing the themes and making sure they are present within the gathered data.
5. Refining the themes and making sure they correlate with the research question.
6. Writing the report

The themes are presented in the results section of the thesis as refined data gathered from the transcribed interviews.

3.4 Limitations

1. Surgeon Participants - With four surgeon participants, any form of quantitative analysis is not feasible and the results should be interpreted as exploratory rather than statistically generalizable.
2. Equipment Similarity - The Touch X and a functioning Hysteroscope are vastly different in size, weight, and feel. As such, only an approximation can be made

where the interaction for the user can be made somewhat similar but still quite different from the real experience.

3. Realistic Simulation - There are clear distinctions from the simulated experience to the real experience of a hysteroscopic resection. The simulation only approximates a real procedure because of my limited knowledge in simulated graphics and physics, time investments, and technical capabilities. Some approximations are the visual look of tissues, equipment, and tissue interactions such as cutting and dynamic movement.

Chapter 4

Results

4.1 Haptic Feedback Levels in Experiments

Here are the results of the participants setting the haptic feedback levels in the simulation environment. Realistic levels, table 4.1.1, are the levels for when participants were asked to adjust the haptic feedback to be as close as possible to what they experience in regular surgery. The preferred levels, table 4.1.2, are the haptic feedback levels they choose when given full autonomy on deciding for themselves what they would like to experience during surgery. A complete bar chart of the participant responses can be seen in figure 4.1.1.

For the realistic levels experiment, the results are shown in table 4.1.1. As can be seen in the table of data, there was a wide spread in the forces set by the participants. One participant deemed the uterine wall unrealistic for all levels, and as such could not put down any realistic force feedback level for it. The cause for this was later explained in the semi-structured interview with the reason being that they felt the instrument vibrate when it came into contact with the uterine wall.

Participant	Myoma (%)	Uterine Wall (%)
1	43	79
2	12	22
3	30	n/a
4	53	41

Table 4.1.1: Realistic levels of haptic feedback

For the preferred levels experiment, the results are shown in table 4.1.2. As can be

seen in the table of data, the wide spread is about the same as for the realistic levels. The same participant deemed the uterine wall feedback non-preferable for all levels for the same reason as previously mentioned. That they could feel the controller vibrate whenever it came in contact with the uterine wall.

Participant	Myoma (%)	Uterine Wall (%)
1	59	77
2	12	22
3	30	n/a
4	53	48

Table 4.1.2: Preferred levels of haptic feedback

Looking at the results for the two experiments side by side, we can see that there is not much of a spread between them. The levels put down as realistic and the preferred levels are almost the same. The data from both experiments are seen in figure 4.1.1.

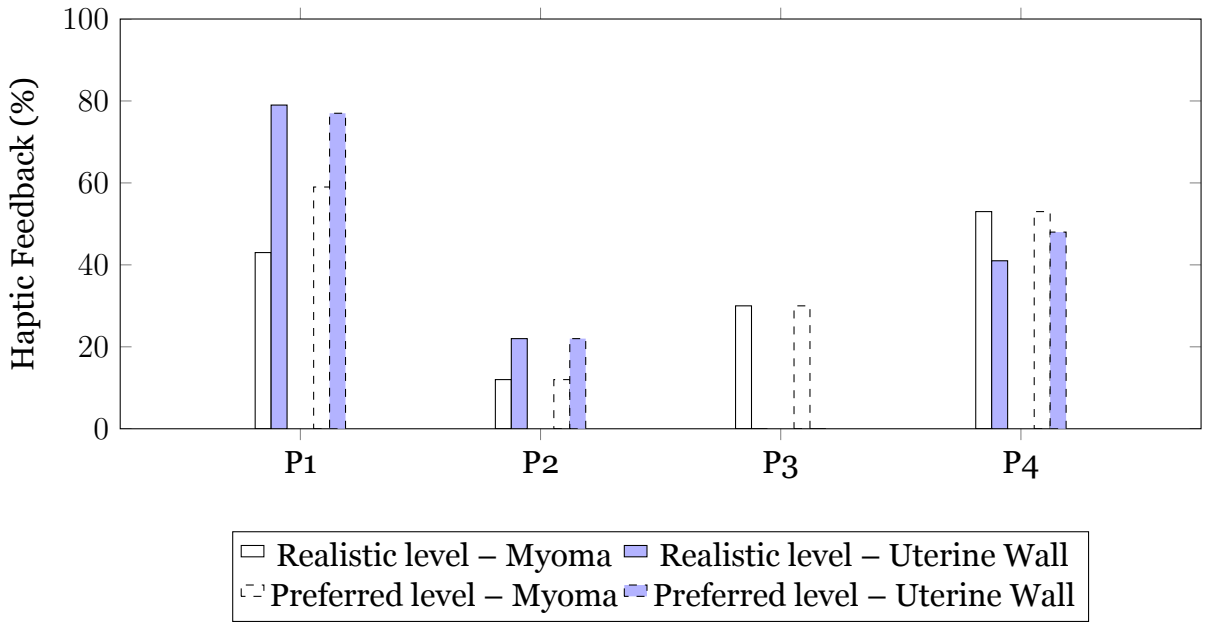

Figure 4.1.1: Bar chart showing participants' set haptic feedback levels for the myoma and the uterine wall during the realistic and preferred experiment.

4.2 Semi Structured Interviews

4.2.1 Themes Discovered

The general themes discovered from the semi structured interviews were:

1. Preferred Levels of Haptic Feedback
2. Safety Concerns
3. Confusion about the study and not thought out answers
4. Realism in the simulation

4.2.2 Preferred Levels of Haptic Feedback

This theme directly relates to the research question of surgeons' preferences in haptic feedback. However, the preferences and reflections varied between participants. In particular whether the myoma should have more or less resistance than the uterine wall.

Participants 2, 3, and 4, all got the question about resecting a submucosal myoma, an image showing a submucosal myoma can be found in figure 2.1.1, which is something that is not normally performed because of the safety risks involved. However, they all responded positively to the use of altered haptics in this scenario. The consensus was that altering the haptics to have a more noticeable change in feel between the different tissues is preferable in some situations. However, how they would design the haptic profile differ between participants. Participant 2 would appreciate a tougher feel in the myoma, specifically in the case of resecting inside the uterine wall, but they would not like it at other times since it would make it more difficult to resect something you can clearly see. Participant 4 would also like to have more noticeable difference. However, they explain that they would like a tougher resistance in the wall, rather than in the myoma, since they argue it would make it more difficult to accidentally cut into the uterine wall. *"I would prefer a considerably higher level of resistance in the uterine wall and considerably lower in the myoma"* - Participant 4.

4.2.3 Safety Concerns

The theme of safety is seen throughout all interviews as all participants discussed safety at one point in the interviews. Often showing both apprehension and optimism about the potential outcomes of altering the haptic experience of the surgical procedure.

Apprehension

Some participants were apprehensive when it came to altering the haptic profile of the procedure. They were concerned about accidentally perforating the uterine wall and being unable to trust their own senses. Some of them brought up a scenario where if everything feels different than what they are used to, how can they then rely on their experience? Participant 2 mentioned *"I'm used to operating, ..., you're used to living in reality"*. Another concerning scenario for them was if everything felt softer than reality, arguing that it would lead to a greater risk of accidentally perforating the uterine wall.

Optimism

Participants that showed optimism about altering the haptic profile for increased safety argued that a greater distinction between the haptic feel of different tissue types makes accidents less likely. For example, participant 3 mentioned that they would like to receive some sort of warning or feedback if the tissue density changes rapidly. This is because you may be resecting a myoma, but it can sometimes be difficult to see where the myoma ends and that they would like the haptic feedback to help her notice that transition. *"... now we've suddenly gone from a really dense tissue to a less dense tissue, and that it [the equipment] gives me some form of vibration or warning or something"* - Participant 3.

This theme ties back to the participants' preferences of haptic feedback as they formed some of their thoughts and reflections from this perspective.

4.2.4 Confusion about the study and not thought out answers

This theme shows how some of the participants had prior assumptions that were misaligned with the actual purpose of the study. It also brings up that participants revised or refined their responses during the interview.

Some participants explained that they would have given different answers had they not misunderstood the purpose of the study. They also would sometimes change their opinion after reflecting further on the potential of changing the haptic profile. Both participant 3 and 4 mentioned later in the interview that they would have changed their answers for the experiment in hindsight. The reasons were misunderstanding the purpose of the study, thinking it was meant as a simulation/training tool. *"... but as a simulation exercise like this..."* - Participant 4. And that they simply hadn't thought through the potential benefits enough prior to the experiment, *"I probably hadn't thought through what the benefits could be of not having it as realistic as possible"* - Participant 3.

This describes the relationship the participants had with the study as a whole and how it can relate to their reported experimental values.

4.2.5 Realism in the Simulation

This theme highlights the difficulty in replicating real life in a digital form, especially the sensation of haptic feedback. Participants provided varied responses to the realism in the simulation, which emphasizes the subjectivity of their responses, however most of the comments were about how the participants deemed the simulation to be unrealistic. The simulation lacked realism in three ways: technical problems, lacking features, and the type of haptic feedback.

Technical Problems

Participants brought up concerns about how the haptic feedback felt in the simulation. One participant felt unable to determine haptic feedback levels for the uterine wall because the controller would vibrate when they were interacting with the uterine wall. The haptic feedback also felt unpredictable to another participant that noted that they felt resistance when pushing on the floor of the uterine wall, but that the resistance would disappear when pushing laterally, on the sides, of the uterine wall. *"... I couldn't feel the resistance when I moved laterally towards the sides of the uterus"* - Participant 4.

Lacking Features

Some participants felt the simulation to be lacking in features. In real life, soft tissue moves as you interact with it. The myoma in the simulation was completely static and there was no way for the participants to interact with the myoma in a way that virtually moves it. Another shortcoming of the simulation was the static blade of the hysteroscope, in real life the blade is controllable in both extension and retraction by moving a thumb-grip forwards and backwards. This way the surgeon can cut with the blade without having to move the entire instrument. However, in this simulation the blade is statically positioned in relation to the rest of the instrument at all times. *"I couldn't move my instrument, this sling [the electrical wire] in and out."* - Participant 3.

Type of Haptic Feedback

The type of haptic feedback had mixed reviews from the participant about how it actually felt to interact with the simulated tissues. They would mention that perhaps the resistance felt realistic, but the feel was off. One participant mentioned that the feedback felt rubbery while another explained the feeling as if they were resecting a banana. *"If you were to resect a banana compared with a myoma, they are two different things"* - Participant 1.

This theme is mainly about the shortcomings of the simulation from the perspective of realism, it indicates how these shortcomings influences the reported experimental values. Especially as we can see in tables 4.1.1, 4.1.2, and in figure 4.1.1, that participant 3 chose n/a (not applicable) as their answer for haptic feedback levels of the uterine wall.

Chapter 5

Discussion

This study aims to explore surgeons' preferences of haptic feedback during hysteroscopic myomectomy surgery. Four major themes emerged in the data from the semi-structured interviews: an overarching theme of safety concern is apparent throughout the participants reflections, their thoughts about what is and is not realistic about the simulation, an overall confusion concerning the purpose of the simulation and the study, and each participants preferred level of haptic feedback. The expert surgeon participants in the study showed a wide range of responses during the interview. However, despite the variation in responses, considerations related to safety emerged consistently across participants. While the limited number of participants restricts broader generalization, the interviews provide valuable insight into how expert surgeons reason about haptic feedback in the context of hysteroscopic surgery.

The purpose of the study was not to identify an objectively correct haptic profile, but rather to explore how expert surgeons reason about augmented haptic feedback and which considerations emerge from it.

When analyzing the participants' responses as a whole, it is important to note that their thoughts and opinions did not stay static throughout the interviews. As noted in the result section, in the theme of confusion and not thought out answers, some participants had preconceived ideas about the study's purpose and answered accordingly. Other participants had simply not had the time to fully think through the possibility of altering the haptic profile. Because of this, the initially set experimental levels for preferred haptic feedback could have looked differently had the experiment

been performed after the interview.

When looking at the themes altogether, they tell more than when looked at individually. The idea of altering the haptic profile of a physical instrument seems novel, as indicated by the finding that participants changed and refined their ideas throughout the interviews. However, how a haptic profile should feel like may also be heavily influenced by subjective opinions. When looking at the themes of preferred haptic feedback and safety concerns together, we get several different combinations of what a haptic profile may look like. That is, having increased resistance in the myoma rather than in the uterus, having increased resistance in the uterus rather than the myoma, and having no changes in resistance at all. All of these haptic profiles were argued for, in part, from the perspective of safety by different participants. This indicates stark differences in subjective preferences.

Furthermore, the shortcomings identified within the theme of realism in the simulation may have influenced participants' perceptions of altering the haptic feedback profile. Safety emerged as a recurring concern throughout the interviews, with all participants raising the topic. As a result, limitations in the realism of the simulation may have reduced participants' confidence in the system and, consequently, affected how they evaluated the potential safety and usefulness of augmented haptic feedback.

Three out of the four surgeons were asked about resecting a submucosal, all three of which responded positively. The reasoning being that altering the haptic feedback may make it possible to securely perform an otherwise risky procedure. Which suggests that the overall procedure could have an increase in safety and that patients would experience fewer complications as a result from altering the haptic profile.

The study by Meli et al [12] found that by magnifying haptic feedback levels, you increase the ability to accurately discriminate between tissues of different stiffness during robot assisted surgery. They also reported a greater perceived effectiveness from the participants of their study. This runs contrary to the results in this study, which are a lot more varied in the preferences of the participants. Other than the previously mentioned reasons for this, confusion about the study, novelty of the idea, and differing subjective opinions, there exists two key differences between this study and that done by Meli et al. In this study, participants are experienced surgeons, and we compare the haptic feedback with their experience of performing it on real people

using a handheld tool. In the study by Meli et al, they do not have expert surgeons as participants, and they also have no real procedure in which to anchor their comparison with. In essence, they only compare different levels of haptic feedback and measure which is best at letting participants notice changes in stiffness during different tasks. Their study seems to be better at showing what haptic feedback levels would be best used in practice, as the participants are performing quantifiable tests. However, it also lacks the necessary input from surgeons who would be the end users in any clinical practice.

Something that was discussed indirectly under the theme of safety was tissue damage. Both viewpoints of apprehension and optimism, in terms of altering the haptic profile, argued with the goal of minimizing the risk of accidental perforation of the uterine wall. When looking at studies that have measured tissue damage in relation to haptic feedback levels in RS. It seems that introducing haptic feedback into a system that lacks it, such as RS, results in a decrease in overall forces used [2, 10, 19, 22, 24], which can arguably lead to a decrease in tissue damage. In fact, the study by Wottawa et al. [24] discovered a positive correlation between tissue damage and the levels of force used when handling the tissue.

5.1 Limitations

5.1.1 Number of Participants

Due to the limited availability of domain experts, the study should not be understood as a large-scale user evaluation intended to establish generalized haptic preferences. Rather, it functions more as an exploratory expert elicitation study aimed at identifying important considerations, reflections, and potential tensions related to adjustable haptic feedback in a simulated hysteroscopic surgery.

5.1.2 Researcher Experience and Bias

Personal preparation and theoretical knowledge of how to conduct a semi-structured interview can only take you so far. Lacking the practical experience of conducting research through semi-structured interviews is a factor to consider. As with most qualitative research, the interpretation of the interview data is influenced by the analytical perspective of the researcher. Since the thematic analysis was conducted

by a single researcher, alternative interpretations of the data are possible. To mitigate this, the analysis process was performed iteratively with continuous revisiting of the interview transcripts and themes.

5.1.3 Misinterpretation of Study and Participant Bias

Present as one of the themes, *4.2.4 Confusion about the study and not thought out answers*, some participants had misinterpreted the study as the development of a training simulation for surgeons to educate and practice with. Further, some participants noted that they had not thought of the potential benefits of considering other haptic levels than what they consider to be realistic. They relied on their own preconceived notion of what the surgery should feel like. These responses illustrate how strongly existing surgical experience and expectations shape the evaluation of altered haptic feedback. Rather than identifying a single preferred configuration, the interviews revealed how participants reason about realism, familiarity, and patient safety when introduced to the possibility of adjustable haptic profiles.

These findings suggest that the vision of the study and the idea of augmented haptic feedback were not fully clear to all of the participants. As discussed in the introduction, the motivation of the study was not merely to recreate realistic haptic sensations, but to explore whether an augmented haptic feedback profile could potentially improve tissue discrimination and surgical safety. Perhaps this could have been avoided by a more thorough introduction and explanation of the study's purpose and aim. However, before the interviews there was a conscious decision not to be overly explicit with the guidance. This decision was made with the goal of letting the participants be as unbiased as possible and to let them reflect on the simulation on their own terms.

5.1.4 Hardware and Software Limitations

Present in the theme, *4.2.3 Realism in the Simulation*. Technical problems and lacking features affects the results of the study. Some participants reflected that the type of haptic feel felt different from reality. Even if the force feedback was similar, the feel of the haptic feedback was different enough to be notable to the participants. There were also lacking feedback that is critical in a completely realistic simulation, such as dynamic tissue movement and the ability to perform resections.

Chapter 6

Conclusions and Future work

6.1 Conclusions

The values for haptic feedback levels varied greatly between participants for both the realistic levels and the preferred levels. However, no major changes were done for the preferred level when compared to each individual response for their realistic levels. This shows that the participating surgeons prefer to keep haptic feedback realistic. These results were also subject to misunderstanding of the purpose for the study, which may have otherwise shown different results. It also became apparent during the semi-structured interviews that participants had not been given enough time to reflect on the potential benefits of altering the haptic feedback profile of the surgery. This too could have affected the answers of the participants.

All participants value safety, which is apparent in the semi-structured interviews after the measurements of haptic feedback levels. There was however a mix in responses of the reasoning for safety. Some surgeons seem to prefer to keep a realistic level in order perform the surgery in a way that they feel comfortable with. Others argued that changing the haptic feedback levels could allow them to feel a greater distinction between different tissue types, making accidents less likely to happen.

Realism was difficult to attain in the simulation. There was a lack of features, such as resection and dynamic tissue movement, which was noted by some participants as making the simulation unrealistic when compared to a real surgery. Other problems such as the feel of the haptic feedback were also difficult to attain, some participants noted that although the feedback force was realistic, the feel of the feedback was

wrong.

Because of the small size of the study, no firm conclusions can be made. However, even in a small group of expert participants, there seems to be great variation of opinions when it comes to changing the haptic feedback of a hysteroscopic myomectomy procedure.

6.2 Future Work

Future work could focus on better preparing participants and letting them familiarize with both the equipment and the research question more closely in order to reduce misunderstandings. Future research could also work on improving the overall realism in the simulation, such as introducing resection and dynamic tissue movement. However, achieving fully realistic haptic feedback remains technically challenging due to current hardware and simulation limitations. The Touch X haptic device [21] used in this study is state-of-the-art technology, but a fully realistic haptic sensation was not achieved within the simulation. Future work should focus on getting enough participants to be able to analyze quantitative data.

Other improvements for future work include the introduction of measurable tasks. Similarly to what was done by Poliakov et al [16, 17], where they introduced tasks to complete and measured metrics such as attempts and total execution time. This could be a way to objectively measure the effect of different haptic feedback profiles and gain a better understanding of what works.

[1] Aas-Eng, Mee Kristine, Langebrekke, Anton, and Hudelist, Gernot. “Complications in operative hysteroscopy – is prevention possible?” en. In: *Acta Obstetricia et Gynecologica Scandinavica* 96.12 (2017). _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1111/aogs.13209, pp. 1399–1403. ISSN: 1600-0412. DOI: 10.1111/aogs.13209. URL: https://onlinelibrary.wiley.com/doi/abs/10.1111/aogs.13209.

[2] Abiri, Ahmad, Pensa, Jake, Tao, Anna, Ma, Ji, Juo, Yen-Yi, Askari, Syed J., Bisley, James, Rosen, Jacob, Dutson, Erik P., and Grundfest, Warren S. “Multi-Modal Haptic Feedback for Grip Force Reduction in Robotic Surgery”. en. In: *Scientific Reports* 9.1 (Mar. 2019), p. 5016. ISSN: 2045-2322. DOI: 10.1038/s41598-019-40821-1. URL: https://www.nature.com/articles/s41598-019-40821-1.

[3] Ahmed, Sirwan Khalid, Mohammed, Ribwar Arsalan, Nashwan, Abdulqadir J., Ibrahim, Radhwan Hussein, Abdalla, Araz Qadir, M. Ameen, Barzan Mohammed, and Khdhir, Renas Mohammed. “Using thematic analysis in qualitative research”. en. In: *Journal of Medicine, Surgery, and Public Health* 6 (Aug. 2025), p. 100198. ISSN: 2949916X. DOI: 10.1016/j.glmedi.2025.100198. URL: https://linkinghub.elsevier.com/retrieve/pii/S2949916X25000222.

[4] *Fibroids - NHS*. URL: https://www.nhs.uk/conditions/fibroids/.

[5] Gwilliam, James C., Mahvash, Mohsen, Vagvolgyi, Balazs, Vacharat, Alexander, Yuh, David D., and Okamura, Allison M. “Effects of haptic and graphical force feedback on teleoperated palpation”. In: *2009 IEEE International Conference on Robotics and Automation*. May 2009, pp. 677–682. DOI: 10.1109/ROBOT.2009.5152705. URL: https://ieeexplore.ieee.org/document/5152705.

[6] *Haptics Direct for Unity V1 | Integration | Unity Asset Store*. en. URL: https://assetstore.unity.com/packages/tools/integration/haptics-direct-for-unity-v1-197034.

[7] *Hystero-Resectoscope Assembly Quick Reference Guide - Olympus Professional Education On-Demand Library*. URL: https://www.olympusprofed.com/gyn/hysteroscopy/19199/.

[8] *Hysteroscopic Myomectomy | Stanford Health Care*. URL: https://stanfordhealthcare.org/medical-treatments/m/myomectomy/types/hysteroscopic-myomectomy.html.

[9] Islam, Md Shafiqul and Lim, Sol. "Vibrotactile feedback in virtual motor learning: A systematic review". In: *Applied Ergonomics* 101 (May 2022), p. 103694. ISSN: 0003-6870. DOI: 10.1016/j.apergo.2022.103694. URL: https://www.sciencedirect.com/science/article/pii/S0003687022000175.

[10] King, Chih-Hung, Culjat, Martin O., Franco, Miguel L., Lewis, Catherine E., Dutson, Erik P., Grundfest, Warren S., and Bisley, James W. "Tactile Feedback Induces Reduced Grasping Force in Robot-Assisted Surgery". In: *IEEE Transactions on Haptics* 2.2 (Apr. 2009). Conference Name: IEEE Transactions on Haptics, pp. 103–110. ISSN: 2329-4051. DOI: 10.1109/TOH.2009.4. URL: https://ieeexplore.ieee.org/document/4798161.

[11] *Livmoder med myom*. sv. Apr. 2015. URL: https://www.mynewsdesk.com/se/gedeon-richter/images/livmoder-med-myom-409522.

[12] Meli, Leonardo, Pacchierotti, Claudio, and Prattichizzo, Domenico. "Experimental evaluation of magnified haptic feedback for robot-assisted needle insertion and palpation". en. In: *The International Journal of Medical Robotics and Computer Assisted Surgery* 13.4 (2017). _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/rcs.1809, e1809. ISSN: 1478-596X. DOI: 10.1002/rcs.1809. URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/rcs.1809.

[13] *Myomectomy (Hysteroscopic Resectoscope) - Willis Knighton Health - Shreveport - Bossier City - Ark-La-Tex*. URL: https://www.wkhs.com/health-resources/wk-health-library/medical-procedures-tests-care-and-management/a-z/myomectomy-%28hysteroscopic-resectoscope%29.

[14] *OES Pro Resectoscope Urology | Olympus*. en. URL: https://www.olympus-europa.com/medical/en/Products-and-Solutions/Products/Product/OES-Pro-Resectoscope.html.

[15] *OpenHaptics Developer Software*. en. Oct. 2016. URL: https://www.3dsystems.com/haptics-devices/openhaptics.

[16] Poliakov, Vladimir, Niu, Kenan, De Vree, Bart Paul, Tsetserukou, Dzmitry, and Vander Poorten, Emmanuel. “A Virtual Reality Surgical Training System for Office Hysteroscopy with Haptic Feedback: A Feasibility Study”. en. In: *Virtual Reality and Augmented Reality*. Ed. by Patrick Bourdot, Victoria Interrante, Regis Kopper, Anne-Hélène Olivier, Hideo Saito, and Gabriel Zachmann. Cham: Springer International Publishing, 2020, pp. 115–127. ISBN: 978-3-030-62655-6. DOI: 10.1007/978-3-030-62655-6_7.

[17] Poliakov, Vladimir, Niu, Kenan, Tsetserukou, Dzmitry, and Poorten, Emmanuel Vander. “An In-Office Hysteroscopy VR/Haptic Simulation Platform for Training in Spatial Navigation and Passage of the Cervical Canal”. In: *IEEE Transactions on Medical Robotics and Bionics* 4.3 (Aug. 2022). Conference Name: IEEE Transactions on Medical Robotics and Bionics, pp. 608–620. ISSN: 2576-3202. DOI: 10.1109/TMRB.2022.3188438. URL: https://ieeexplore.ieee.org/document/9841088.

[18] Saracino, Arianna, Deguet, Anton, Staderini, Fabio, Boushaki, Mohamed Nassim, Cianchi, Fabio, Menciassi, Arianna, and Sinibaldi, Edoardo. “Haptic feedback in the da Vinci Research Kit (dVRK): A user study based on grasping, palpation, and incision tasks”. en. In: *The International Journal of Medical Robotics and Computer Assisted Surgery* 15.4 (2019). _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/rcs.1999, e1999. ISSN: 1478-596X. DOI: 10.1002/rcs.1999. URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/rcs.1999.

[19] Talasaz, Ali, Trejos, Ana Luisa, and Patel, Rajni V. “The Role of Direct and Visual Force Feedback in Suturing Using a 7-DOF Dual-Arm Teleoperated System”. In: *IEEE Transactions on Haptics* 10.2 (Apr. 2017). Conference Name: IEEE Transactions on Haptics, pp. 276–287. ISSN: 2329-4051. DOI: 10.1109/TOH.2016.2616874. URL: https://ieeexplore.ieee.org/abstract/document/7589098.

[20] Tholey, Gregory, Desai, Jaydev P., and Castellanos, Andres E. “Force feedback plays a significant role in minimally invasive surgery: results and analysis”. eng. In: *Annals of Surgery* 241.1 (Jan. 2005), pp. 102–109. ISSN: 0003-4932. DOI: 10.1097/01.sla.0000149301.60553.1e.

[21] *Touch X Haptic Device*. en. June 2016. URL: https://www.3dsystems.com/haptics-devices/touch-x.

[22] Ueda, Yuichiro, Miyahara, So, Tokuishi, Keita, Nakajima, Hiroyasu, Waseda, Ryuichi, Shiraishi, Takeshi, and Sato, Toshihiko. "Impact of a pneumatic surgical robot with haptic feedback function on surgical manipulation". en. In: *Scientific Reports* 13.1 (Dec. 2023), p. 22615. ISSN: 2045-2322. DOI: 10.1038/s41598-023-49876-7. URL: https://www.nature.com/articles/s41598-023-49876-7.

[23] *Uterine fibroids - Symptoms and causes*. en. URL: https://www.mayoclinic.org/diseases-conditions/uterine-fibroids/symptoms-causes/syc-20354288.

[24] Wottawa, Christopher R., Genovese, Bradley, Nowroozi, Bryan N., Hart, Steven D., Bisley, James W., Grundfest, Warren S., and Dutson, Erik P. "Evaluating tactile feedback in robotic surgery for potential clinical application using an animal model". en. In: *Surgical Endoscopy* 30.8 (Aug. 2016), pp. 3198–3209. ISSN: 1432-2218. DOI: 10.1007/s00464-015-4602-2. URL: https://doi.org/10.1007/s00464-015-4602-2.

Appendix A

Consent Form

Samtyckesformulär till studie

Studien är en del av ett examensarbete på KTH. Arbetet handlar om hur haptisk feedback kan påverka operativ hysteroskopi. Tanken är att testa vilken nivå av haptisk feedback vore att föredra, samt att ställa frågor kring simuleringen.
Personer kopplade till arbetet:

Filip Forsberg	filfor@kth.se	Masterarbete
Alessandro Iop	aiop@kth.se	Handledare
Inga Steinberga	inga.steinberga@regionstockholm.se	Extern Handledare
Mario Romero	mario.romero@liu.se	Extern Handledare

Vi behöver spara och behandla personuppgifter om dig, såsom er:

- Arbetsplats
- Ålder
- Kön
- Erfarenhet med operationen
- Erfarenhet med simulering i allmänhet
- Erfarenhet med haptisk feedback verktyg, såsom Touch X av 3D Systems.
- Era resultat i simuleringen
- Röstinspelning av intervjun

Syftet med en sådan behandling är för att kunna analysera resultaten av simuleringen samt intervjufrågorna. Denna data kommer sedan att användas och publiceras i ett examensarbete på KTH. Informationen kommer att sparas digitalt. Röstinspelningen kommer att användas vid transkribering av vad som sades till en textfil, efteråt kommer inspelningen att bli raderad.

Vi har fått dina uppgifter från er själv. Du har när som helst rätt att återkalla ditt samtycke till behandlingen. Ett återkallande påverkar inte lagligheten av behandlingen innan samtycket återkallades. Vi tillämpar vid var tid gällande integritetslagstiftning vid all behandling av personuppgifter. Den rättsliga grunden för att behandla dina personuppgifter är samtycke. Dina uppgifter kommer att sparas till bruk för examensarbetet och kommer att vara del av arbetet som laddas upp till bland annat DIVA.

De personuppgifter vi behandlar om dig delas som allmän information. Vi kan även komma att dela dina personuppgifter med en tredje part, förutsatt att vi är skyldiga att göra så enligt lag.

Personuppgiftsansvarig är Filip Forsberg. Du har rätt att kontakta oss om du vill ha ut information om de uppgifter vi har om dig, för att begära rättelse, överföring eller för att

begära att vi begränsar behandlingen, för att göra invändningar eller begära radering av dina uppgifter. Detta gör du enklast genom att kontakta oss på: filfor@kth.se.

Om du har klagomål på vår behandling av dina personuppgifter har du rätt att inge klagomål till tillsynsmyndigheten Integritetsskydsmyndigheten, IMY.

Samtycke till att delta i en studie som ingår i ett examensarbete på KTH - temporär titel: “Enhanced Haptic Feedback in a Simulated Hysteroscopic Myomectomy”

Jag har fått information om studien och samtycker till att delta. Jag är medveten om att mitt deltagande är helt frivilligt och att jag kan avbryta deltagandet i studien utan att ange skäl för det. Genom min underskrift väljer jag att delta i studien och godkänner att Filip Forsberg behandlar mina personuppgifter i enlighet med gällande dataskyddslagstiftning och lämnad information.

Datum

Deltagarens Underskrift

_____

Namnförtydligande

_____

Intervjuarens Underskrift

_____

Namnförtydligande

_____

Appendix B

Semi-Structured Interview Questions

Semi-Structured Interview Questions

Filip Forsberg

August 2025

1 Questions: important ones

1. What did you like the most about the simulation?
2. What tool do you use currently for the procedure? Follow-up: What is the best thing about the tool?
3. In your judgment, did you think that the simulation was accurate at emulating the surgery environment? Follow-up: Why is that?
4. Did you think that the type of haptic feedback is similar to what one experiences in the operating room? Follow-up: Why is that?
5. If you had a magic want that could change the haptic experience during your procedures, would you want to use it? Follow-up: Why is that? IF YES: How would you want to change it?
6. When performing the test-simulation, you landed on these levels for the realistic haptic feedback. Do you think they came close to replicating what is normally felt during surgery? Follow-up: How so?
7. When performing the test-simulation, you landed on these levels for the preferred haptic feedback. What made you choose these levels of haptic feedback as your preferred ones?
8. Do you think that changing the way you experience haptic feedback during resection of a submucosal myoma (intramuskulär myom) would be beneficial for the procedure? Yes/No: Why? IF-YES: How would you like to change it?
9. If you had a magic wand that could change the haptic experience in the operating room to the one in the simulation room. Would you like to change it? Follow-up: Why is that?
10. After having performed the experiment, how do you think implementing your preferred level of haptic feedback into the tool for your real surgeries would affect you? Follow-up: How so?

2 Questions: less important ones

1. How many years have you worked as a surgeon?
2. If you had to estimate, how many procedures like this would you say you have performed?
3. With the tools you have access to today, do you feel confident that the average surgeon can perform well? Follow-up: How so?
4. With the technology currently available, what do you think works the best in assisting you during the procedure?
5. Are there any areas of improvement when it comes to the tool you are using? Follow-up: How so?

TRITA-EECS-EX-2026:433
Stockholm, Sverige 2026

www.kth.se