Exploring the Social-technological Gap in Telesurgery: Collaboration within Distributed OR Teams

Pieter Duysburgh
iMinds-SMIT-VUB
Pleinlaan 2,
1050 Brussels, Belgium
pieter.duysburgh@vub.ac.be

Shirley Elprama
iMinds-SMIT-VUB
Pleinlaan 2,
1050 Brussels, Belgium
shirley.elprama@vub.ac.be

An Jacobs
iMinds-SMIT-VUB
Pleinlaan 2,
1050 Brussels, Belgium
an.jacobs@vub.ac.be

ABSTRACT
While its technical feasibility has been illustrated over a decade ago, today, robot-assisted telesurgery is not a part of everyday surgical practice. The thresholds for adoption of telesurgery are mostly seen as technical, legal and financial challenges. However, the aim of this paper is to understand collaboration within distributed OR teams, which seems to be under examined in research on telesurgery. By means of a proxy-technology assessment and a series of interviews, collaborative challenges for telesurgery have been identified. These include the unfamiliarity of the remote surgeon with the practices of the local operating room team and the patient. In addition, verbal and non-verbal communication have to be mediated in a telesurgery setting, making it difficult for the remote surgeon to have an overview and stay in control during surgery. With this research, we illustrate how trust issues in distributed teams manifest in OR teams in a telesurgery setting.

Author Keywords
Telesurgery; distributed teams; robot-assisted surgery; robot-assisted telesurgery; team work; surgical teams.

ACM Classification Keywords
H.5.3. **[Group and Organization Interfaces]**: Computer-supported cooperative work; I.2.9. **[Robotics]**: Manipulators; J.3. **[Life and medical sciences]**: Health.

INTRODUCTION
Today, telesurgery is no longer a hot topic. The technical feasibility of telesurgery has been shown in 2001 by Dr Marescaux [15] by operating on a patient in Strasbourg (France) from New York (U.S.). However, since then, telesurgery has not become a part of common surgical practice, and the few publications dedicated to telesurgery in recent years still regard it as a future practice (e.g. [8]). The main issues for adoption of telesurgery practices are considered to be cost efficacy, technical challenges (especially video latency), training, patient outcomes, and the legal and regulatory framework [14].

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Telesurgery can be understood as a type of robot-assisted surgery where the surgeon (while manipulating a robot with a controller) is not in the same operating room as the rest of the operating room team (OR team) members and the patient (see Figure 1). When using a surgical robot, the surgeon is outside the sterile area, and operates on the patient from a controller, manipulating one or more robot arms that are connected to surgical tools, and inserted in the patient through 'trocars' (small tubes) that are fitted in body ports [11]. Here, a surgical robot is "*a powered, computer-controlled manipulator with artificial sensing that can be programmed to move and position tools to carry out a wide range of surgical tasks*." [5:71].

In robot-assisted surgery, the surgeon operates from a controller and does not stand next to the patient. As such, all forms of robot-assisted surgery can be understood as a kind of '*remote*' surgery when compared to open surgery or minimally invasive surgery: using surgical robots increases the distance between the surgeon and the rest of the OR team and the patient (see Figure 1).

However, in telesurgery, the distance between the surgeon and the patient is further increased since the surgeon is not located in the same room as the rest of the operating team and the patient. In other words: the OR team is no longer collocated but distributed. As a result, not only the actions of the surgeon on the patient are mediated through technology but all communication between the surgeon and the OR team is mediated.

While all telesurgery is 'robot-assisted', we will not repeat this explicitly throughout the paper. We will use the term 'robot-assisted surgery' when talking about collocated OR teams and both the surgeon(s) and the rest of the OR team find themselves in the same room. When we use the term 'telesurgery', this will always imply that a surgical robot is used and the OR team is distributed.

Advantages of robot-assisted surgery
The importance of robotics in surgical practice has substantially increased and have found their way into everyday surgical practice [4]. Theoretically, a surgical

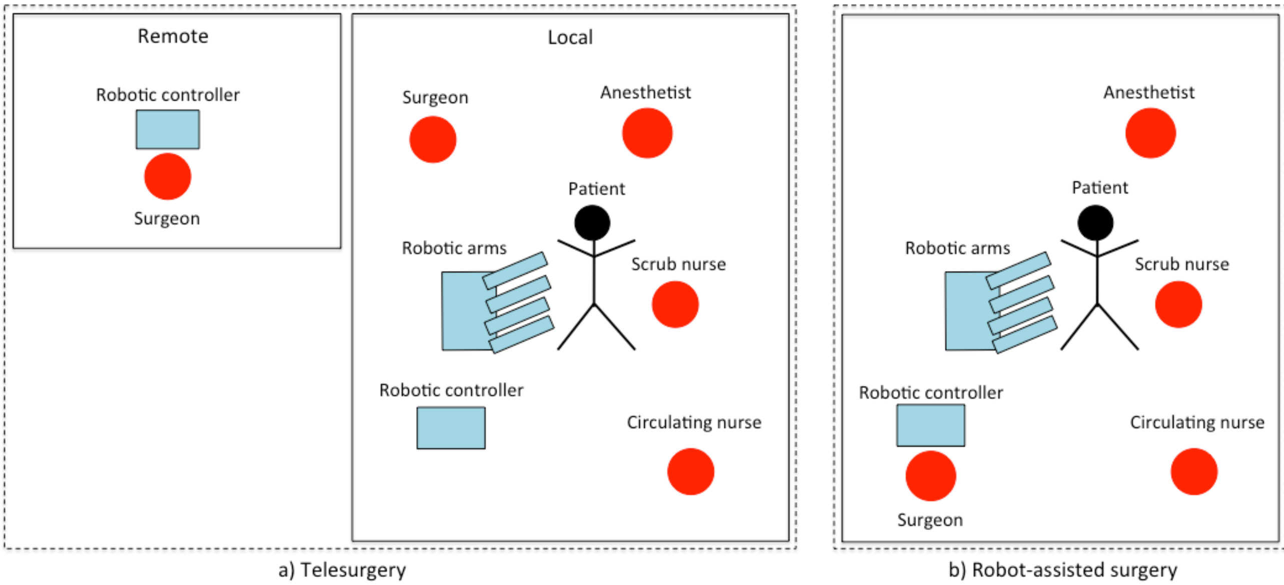

Figure 1: Operating room (a) during telesurgery with distributed teams; (b) during robot-assisted surgery with collocated teams.

robot allows a surgeon to work with more precision than in minimally invasive surgery. The surgeon has a 3D visualization of the body of the patient, and can make use of six to seven degrees of freedom of manipulation and scaled movements (micromotion). However, the acquisition of a surgical robot still is a substantial economical investment for a hospital, and it remains controversial if and to what extent the surgical robots offers medical advantages compared to minimally invasive surgery (e.g. [4, 22]). Still, surgical robots are increasingly being used for procedures in a wide range of medical fields (such as abdominal surgery, pediatric surgery, gynecology, urology, cardiothoracic surgery, and otorhinolaryngology [11]). Especially in Belgium, many hospitals have acquired surgical robots to position themselves as technological front-runners: this country has considerably more surgical robots available than its neighboring countries [4].

With surgical robots becoming more and more commonplace, the question what issues are at play for adoption of telesurgery becomes pertinent. In theory, telesurgery has potentially some clear advantages: the technology can bring the expertise of a surgeon to hospitals in rural areas or extreme locations, such as underwater stations or even space stations [9]. Other application domains are remote areas, warzones, rare interventions or interventions that require a high specialized or skilled surgeon, etc. [8]. However, we have not found any publications detailing to what extent, if at all, telesurgery is being practiced today. Also, none of the surgeons involved in this research were aware of such telesurgery procedures taking place. This paper will look at what issues might be at play with regard to supporting the collaborative practices within OR teams.

The highly collaborative nature of OR teams

An OR team in its basic form consists of a surgeon, an anesthetist, a scrub nurse and a circulating nurse. In some cases, an assisting surgeon and one or more additional nurses are also present in the OR. The role of the circular nurse can be taken up by several people during a single operation. In general, medical personal tends to walk in and out the operating room during interventions. As such, an operation room should not be regarded as a closed environment.

In telesurgery this basic OR team is typically extended with an additional surgeon, who is located at a remote location (see Figure 1). Having a remote surgeon does not change the composition of the local OR team: a second surgeon still needs to be present with the patient, for the start-up of the intervention (e.g. placement of surgical ports) and the end of the operation, or in case the surgery needs to be reverted to open surgery (which may be necessary when complications occur during the intervention). As such, a distributed OR team will usually be larger than a collocated OR team. The local surgeon could at times assist the remote surgeon, or could operate on the patient as well from the local controller. Since both scenarios are possible, we did not decide upon a specific task for the local surgeon while the remote surgeon is operating.

An OR team can be considered as a highly hierarchical and strictly organized collaborative group of medical professionals. The roles in an OR team are strictly defined and often, the members of the OR team have been working together for many years. In any type of surgical intervention, the surgeon is always 'leading' the operation. During robot-assisted surgery, the surgeon is most of the time sitting behind the controller, away from both the rest of the OR team and the patient. The surgeon is required to do complex actions, operating the three or four arms of the surgical robot simultaneously, while being less able to communicate with the rest of the OR team in a non-verbal manner, since the OR team cannot see the surgeon during the operation. As such, in robot-assisted surgery, the complexity of the tasks of the surgeon seems to have increased compared to minimally invasive surgery, which already caused more pressure on the surgeon to perform [2].

Hence, surgical robots pose a challenge for collaboration in the operating room. This might be problematic, since several authors have pointed out the importance of good collaboration in surgery [21, 22, 25]. It is clear that errors resulting from miscommunication can result in grave consequences for patients and all others involved. As such, it is our opinion that collaborative practices should be a focal point in research on robot-assisted surgery and telesurgery. We should also investigate how the introduction of additional technology in the operating room and the increased working distance between the OR team members will influence collaboration. We think that a good understanding of the collaborative challenges related to telesurgery will provide additional insights into why the technology has not (yet) been adopted and how the technology might be improved.

Closing the socio-technical gap in telesurgery

This collaborative element in the OR team has been under examined in publications on telesurgery. The barriers for telesurgery are usually seen as technological, financial, legal, or safety issues. For instance, quite some research effort goes to minimal degradation of the picture, minimal latency, high data quality and a robust communication system [5]. Another focal point is the lack of tactile feedback for the surgeon when using surgical robots, which omits an important source of information for surgeons during the operation [20]. The costs (of the robotic systems, telecommunication, training and research and development) are another important threshold. Finally, having a surgeon working on a patient remotely increases the complexity of the legal framework considerably (e.g., national differences in privacy legislation or surgical accountability in case of a medical error) [5].

While these issues are certainly pertinent, we feel that the issue of collaboration also deserves specific attention. Telesurgery requires a geographically distributed OR team, which may result in new collaborative practices. Studies have shown that technical advances can imply new forms of collaborations in OR teams, since technology may change the tasks and responsibilities [15, 23]. Understanding these changes is crucial to avoid medical errors due to miscommunication.

As such, this paper wishes to explore what Ackerman [1] has described as 'the social-technical gap' to understand how this might impede the adoption of telesurgery. The social-technical gap is "*the great divide between what we know we must support socially and what we can support technically*" [1:180]. According to Ackerman, what is a central intellectual challenge in CSCW is precisely exploring, understanding and ameliorating this social-technical gap. Even though this gap will most probably not go away, it can perhaps be approached better and taken into account.

When applied to telesurgery, we need to understand how the staff in the operation room interacts and communicates, and how these patterns of collaboration occur in telesurgery settings, and where they are problematic. Typically, a process of *mutual shaping* occurs between a technology and users: the users adjust themselves to a new ecology and product, and adjust their working practices to the new conditions [23]. As such, it is to be expected that the new technology in the operating room, and different setup of the people and tools will cause changes in the workflow and how information is accessed in the OR [27]. But a distributed OR team will also adjust itself to this surgical setup and appropriates the technological tools. However, a social-technical gap will remain, and a close examination and good understanding of it, can either steer future developments in telesurgery, or help explaining why telesurgery remains a rare practice.

METHOD

This research consisted of two phases. A first step was an exploratory phase, where a series of interviews and unstructured observations were held to get a better understanding of surgical practices. These observations slowly developed into more structured observations to find specific answers to our research goals. Secondly, a series of interviews were organized with surgeons and scrub nurses to legitimize, adjust and nuance the results of the analysis of the structured observations. As such, this paper elaborates on the results described in prior work [6], but the additional research allowed us to identify central themes in the initial results. Also, this research presents additional insights and more nuanced understandings.

As stipulated in the preceding paper [6], we wanted to verify the findings of this first research phase further with some additional data collection. We called this second phase 'further verification' since we agree with Morse et al. [16] that reliability but also validation cannot simply be limited to a kind of post hoc evaluation. Verification strategies are to be used and kept in mind throughout the whole research process. However, after the first research phase, we found that additional interviews were required, both with some of the medical personal that had participated in the research already, as with some new people. To the medical personnel involved before, we wanted to present the abstractions we had made of their activities and those of others. To interviewees we had not talked to before, we wanted to present the full research, and ask for their opinions. As such, by collecting more data, we wished to continue following the principles of qualitative research, by being self-corrective and working iteratively rather than linearly.

In what follows, we will describe both phases in more detail.

Phase 1: Identifying the barriers

To the best of our knowledge, and according to the surgeons we have encountered during the research, telesurgery interventions have been executed rarely, and mainly for research purposes. We have not found any examples or figures about telesurgery taking place. As a result, we were unable to observe telesurgery.

Consequently, it was decided that robot-assisted surgeries where both the master-side (the controller) and the slave-side (the robotic arms) of the robot are located in the same room would be studied (see Figure 1). By observing how a collocated OR team interacted with and around the robot, we wanted to identify those interactions that potentially could be problematic in a distributed OR team when the main operating surgeon would be in another location.

Such an analysis can be described as a proxy technology assessment (or ‘PTA’) [13]. Proxy technology assessment is a research method where the users are given a ‘future’ experience by making use of technology that already exists. PTA has been defined as “*a method for emulating everyday life practices with future technologies and applications by confronting selected user groups with existing similar tools and applications*”[13]. As such, the technology used in the research has some strong similarities with the technology under development, but also misses some key features. In our case, it could be argued that ‘local’ robot-assisted surgery can be understood as the best proxy available for telesurgery. Key differences between the two technologies are the location of the main operating surgeon and any additional, currently unspecified technical features that would be required to make telesurgery a common practice.

By choosing this method, ‘product use’ (the surgical robot) is central in our analysis and we regard it as a starting point to understand collaboration in the OR team. We decided to concentrate mainly on the (collaborative) user experience and we do not depart from a general understanding of how OR teams collaborate. While this focus on the product use might be considered as a weakness, we think this approach is useful for understanding how collaboration evolves as a result of using surgical robots. As Olson and Olson [20] have pointed out: if technology is useful, then the constrains of that technology are going to change the way how people will collaborate. Practices will evolve that will fit the tools in the flow of collaborative activity. Therefore, we decided to focus on the use of the product, rather than researching OR team collaboration in general.

In the first phase, we collected data by observing 7 interviews and observing 14 surgical procedures in various hospitals in Belgium.

Interviews

As previously explained, a series of interviews was done at the start of the research project, in order to gain a general understanding of surgical practices and the working procedures. With these interviews, the researchers (who do not have a medical background), wanted to increase their understanding of the general practices and procedures of an OR team involved in minimally invasive surgery and robot-assisted surgery. The researchers interviewed two surgeons, two assistants, one scrub nurse, one bio technician and IT support for the operating room across three different hospitals in Belgium. Both types of surgery were looked at, in order to establish how robot-assisted surgery and minimally invasive surgery are different.

Observation

Next, 14 surgical procedures (9 robot-assisted surgeries and 5 minimally invasive procedures) were examined in four different hospitals in Belgium. Here too, both minimally invasive procedures and robot-assisted surgeries were observed, in order to gain a better understanding how the introduction of the surgical robot in the operating room changed the collaborative practices of the OR team, and as such, be able to understand how telesurgery might further change collaborative practices.

The researchers have observed minimally invasive procedures done by surgeons specialized in gastrointestinal surgery or general surgery. The robot-assisted surgeries (executed with the Da Vinci Surgical System from Intuitive Surgical) were urological interventions and included procedures such as robot-assisted radical prostatectomy and robot-assisted partial nephrectomy.

These observations were done in a structured manner. Based on Forlizzi’s product ecology framework [7] an observation scheme was worked out. The framework identified the several components that define product use, in order to describe and investigate how people relate to products and how their relationships change over time. Hence, the scheme included themes such as personnel in the operating theater, the atmosphere in the OR, the interactions amongst the personnel, and other topics. The researchers stopped observing when they reached a point of data saturation and no new information could be observed. During the observations, notes were made and pictures were taken. Also, maps of the OR were drafted, including the positioning and movement of the material and personnel in the operating room. This resulted in one observation report per observed intervention.

Analysis

The analysis of the reports was done using NVIVO software. There were two iterations of coding. In the first iterations, all the actions and interactions between the staff in the operating room were coded. This included any type of communication (questions, agreeing, commenting, instructing, requesting...). These codes were then visualized: the interactions between the members of the OR team were mapped per member of the OR team. This gave the research team a schematized representation of the interactions in the team, allowing for a more direct and visual understanding of the types of interactions and their frequency. These visual representations served as a first point of discussion in identifying potential thresholds for collaboration in a distributed OR team.

Based on this discussion, we returned to the data and the coded interactions were screened in more detail and recoded. During the coding, we now departed from the discussion based on the visual representations of the interactions. Next, they used this to focus on the identification of interactions that are currently challenging, and on the identification of interactions that may become problematic in a telesurgery setting.

This analysis resulted in a first report and paper [6], describing 13 barriers that might impede collaboration in a distributed OR team.

Phase 2: Further verification of the barriers

As detailed before, an additional phase of data gathering was organized after the first part of this research. Not only did the researchers want to validate the findings of the first research phase further, in addition, they wished to move more towards theory building and make a further abstraction of our findings in the first phase.

Participants

For these interviews, the researchers decided to recruit surgeons and scrub nurses. They chose not to include the other OR personnel, since the first phase of the research made clear that it is precisely the relationship between the surgeon and the scrub nurse that is of utmost importance in surgical interventions, and it is this relationship that would change substantially in a telesurgery setting. Most of our initial findings pointed towards barriers related to the collaboration between scrub nurses and surgeons. Therefore, we decided to restrict our additional interviews to this profile. We contacted two surgeons that had already participated in the research (their surgeries were observed) and several others who had experience with robot-assisted surgery, using the Da Vinci robot. Eleven surgeons (working in Belgium) were asked to participate. In the end, 5 of those 14 surgeons agreed to collaborate with the researchers. All 5 surgeons were male, their mean age was 47.2 years (range 40 – 54). On average, they had 21.5 years of experience in general surgery and 7.2 years of experience in robot-assisted surgery. Their specializations included urology, gynecology and digestive surgery. We also contacted 5 scrub nurses, of which 3 agreed to participate in an interview, who worked at two different hospitals. Two scrub nurses were female and one was male; their mean age was 49.3 years (range 45 – 54). All nurses were specialized in assisting at urologic surgeries. Two nurses had no prior experience in being a scrub nurse, while one nurse had 27 years of experience as a scrub nurse. On average, the nurses had 6.5 years experience assisting during robot-assisted surgery (range 1 – 12.5 years).

Interview

During the interviews, the researchers wanted to go over all barriers identified in the previous research, and discuss these with the interviewees. Therefore, the surgeons were sent the report beforehand and were asked to read it in preparation of the interview. The report was not sent to the scrub nurses, because the researchers were concerned that the use of (academic) English in the report would discourage the nurses from participating (English was not the mother tongue of the nurses). In addition, a summary of the results was made, that could be used during the interviews to give them a quick insight in the preliminary results. This summary proved to be useful for the interviews with both the scrub nurses and the surgeons, since not all surgeons had read the report beforehand.

The surgeons that were interviewed had very busy time schedules and several interviews were numerously interrupted by colleagues (the interviews were held during working hours). Hence, it was not possible to discuss all barriers in detail with each interviewee. Also, some participants simply did not want to discuss each barrier separately and gave a more generic feedback on the analysis, while others focused on certain elements in the report or summary they found particularly interesting relevant or, in contrast, did not agree with at all. Nevertheless, despite the fact that the semi-structured setup of the interviews could not always be entirely executed as planned, the researchers felt that these interviews were insightful and substantially enriched the original analysis.

Each interview consisted of three parts. The first set of questions was about personal information such as age, experience with surgery and experience with robot-assisted surgery. Furthermore, we asked the participants about their views on telesurgery. Finally, we presented them with the several challenges to telesurgery and we asked them to which extent they viewed them as legitimate. Each surgeon and scrub nurse was interviewed individually and the interviews lasted on average for 33 minutes (range 15 min - 1 hour).

Analysis

The researchers had originally planned to code the interviews using a structured codebook based on the barriers that were identified in the research. However, since the interviews had to be done in a less structured way than planned beforehand, the analysis of the resulting data also required another approach.

The researchers chose to analyze the data using the affinity diagramming method [3]. For this purpose, the researchers went through the transcribed interviews and identified all potentially relevant and interesting feedback. These were listed per interviewee. Then, the researchers reorganized and categorized these according to similarity of contents. Next, a second categorization was done; now also including the barriers identified in the original report. This final categorization regrouped some of the original barriers into central themes. As such, we made further abstraction of our original findings and decided to describe some of the barriers on a more general level.

In this process, we kept in mind that our participants did not necessary need to judge the analysis to be correct. As clarified by e.g. [16], a simplistic interpretation of the reactions of the interviewees on the first results could in fact be a thread to validity rather than guaranteeing it. Since our data was synthesized, decontextualized and abstracted from individual participants and situations, it might well be possible that our interviewees might not recognize themselves in their data. This is especially true for those participants we had seen and talked to before (which can be understood as a form of 'member check') but also for the interviewees that were new to the research. For instance, a surgeon operating in a commercial hospital might be reluctant to confirm certain barriers specific to robot-surgery given the high investments required by the hospital management for surgical robots, and the strategically importance of the robots in the hospital in attracting certain patients. Research pointing out difficulties with surgical robots (whether or not in a telesurgery setting) might ultimately jeopardize the income stream of the hospital in general and the position of the surgeon specifically. Therefore, during the analysis and interpretation of the results, the background of the interviewees was taken into account, and they remained identifiable in all stages of the data analysis, enabling us to contextualize their answers by relating them to their personal and professional interests, and their working environment.

This research phase allowed the researchers to add more details and nuances to barriers that already described. While none of the results of the original paper were necessarily seen as erroneous, they felt that these additional insights added sufficient information to the original paper for another publication.

RESULTS

When presented with the possible challenges towards conducting telesurgery [6] most interviewees found the results interesting and they recognized their everyday work practices conducting robot-assisted surgery as the researchers described them in the paper. Some challenges for telesurgery were considered trivial by several interviewees (such as planning or language barriers), and most regarded these as easy to overcome. However, at the same time they emphasized that working from a distance is far from ideal, can be stressful and might never be as efficient as working together in the same operating room.

Some interviewees were somewhat surprised by the focus on team collaboration. When contacted beforehand, they were inclined to think of technical or legal barriers with regard to telesurgery. Nonetheless, they acknowledged the 'social' challenges as identified in the previous paper. Also, one of the surgeons explained that although these identified challenges are appropriate, they are not necessary specific to robot-assisted surgery.

A. Remote surgeon as a new member of the local surgical team

A first challenge follows from the hypothesis that in a telesurgery setting a remote surgeon will sometimes have to work together with an OR team that might be unfamiliar with his or her working methods. This is challenging since we observed very close working relationships amongst the OR team, especially between the surgeon and the scrub nurse. Getting familiar with each other's professional preferences results in additional communication flows.

Close working relationship

During the observations and exploratory interviews, we noticed a very tight working relationship between surgeons and their surgical team in minimally invasive surgery and in robot-assisted surgery. Some surgeons compared the relationship they have with the OR team with their marriage. For instance, one surgeon noted *"with some staff members, you have been [working] longer together than with your wife"*. This close working relationship could also clearly be observed in the operating room during interventions: the team members continuously anticipated each other's actions and communicated non-verbally. The whole OR team knows the procedure and the next steps that need to be taken in the intervention.

For instance, we frequently noticed how the scrub nurse anticipates the surgeon's actions and already had the tools ready, before the surgeon requested or needed it. One scrub nurse said: *"I always know what they are going to think.*" In an interview, a surgeon confirms this by saying: *"It would be exhausting [to have a new team composition each day]. You would have to ask [for instruments], while now we are used to each other, the nurse knows what we are doing, [she] gives the default instruments and has prepared the things that you need. You just have to reach out with your hand without [verbally] asking for it. And this will be difficult if you would have a new team or changing teams"*.

OR team members do of course change over time, and personnel does leave a team or joins a new team. But (scrub) nurses usually stay longer than assisting surgeons: they are in training and after that will change teams and hospitals. As such, surgeons often invest more time and effort in building up a good professional relationship with scrub nurses than with their assistants.

Professional preferences and increased operating time

Working with a new OR team can have considerable impact on the surgical intervention. Besides having to communicate more when new team members are introduced, the operating time will also increase. A surgeon estimated that the operation time of a surgical intervention increases with more or less 30 minutes when a new nurse or assistant is added to the team.

This has to do with the professional preferences of the surgeon. Even though procedures are roughly the same, there are still some degrees of freedom for each surgeon. All surgeons have their own way of approaching a medical problem, and while the aims of similar surgical interventions are the same, the way to attain that goal can differ amongst surgeons. For instance, one of the surgeons explained the importance of using tools that he is familiar with. In general, he reported to be extremely dependent on his instruments. The choice for the tools he is using now is the result of years of testing to find out which tools work well and which do not. Having to use tools he is not used to, can be an extra element of stress, on top of working with nurses he is not familiar with. A scrub nurse confirms this: *"All surgeons have their preferences. [...] They appreciate it if take these into account."* Therefore, it is for instance very important to communicate the remote surgeons' preferences for specific instruments to the local team so they can prepare the right tools.

Implications for telesurgery

Keeping the above in mind, a surgeon in a telesurgery setting faces several challenges. Having to work with an OR team the surgeon is not familiar is, means the new team members need to get to know each other. Part of this has to do with the professional preferences of the surgeon involved, the way in which the surgeon approaches the medical problem, and the preferred tools and working methods. The combination of these elements makes a telesurgical intervention considerably more challenging for a surgeon. Initially, this will lead to a higher need for communication, both before and during surgery, which results in a higher likelihood of misunderstandings and longer surgeries.

B. Trust between remote surgeon and local surgical team

In a telesurgery setting, a remote surgeon will have to collaborate very closely since a local surgeon will always be needed for the startup and the end of the operation, and has to be stand-by in case the operation needs to be converted to open surgery. However, we learned that collaboration between surgeons is relatively rare. Depending on each other for the placement the trocars, relying on each other's capacities, and trusting other surgeons for referring patients to them might be challenging.

Working with fellow surgeons

Telesurgery forces surgeons to collaborate closely before, during and after surgery. Especially during surgery, usually only one surgeon is present. If another person with surgical training is present, this person is usually the surgeon's assistant. This is important with regard to the hierarchy in the operating room: the operating surgeon is the person in charge, and the rest of the personnel in the operating room mainly follows the surgeon's activities.

When surgeons do collaborate during surgery, this is mostly across medical disciplines, namely, when two types of interventions are done during one operation. Here, surgeons often collaborate smoothly since the surgeons have different expertise and have to rely on each other.

It can be expected that, when both surgeons have similar knowledge, their diverging ideas might be a cause for conflict. Unless when know each other thoroughly and trust each other's judgment. A scrub remembers an operation where two surgeons operated together: *"This went relatively smooth. They talked and discussed a lot, but the operation went well. I have to add that these surgeons have been working together for many years. Together, they started doing robot-assisted surgery at this hospital."*

Relying on the skills of the other surgeon

For certain phases of a telesurgery procedure, a surgeon will have to rely fully on the actions of another surgeon. This is most manifest in when the local surgeon will have to make the incisions to place the trocars in the body of the patient, through which the robot arms would enter the body of the patient. To a large extent, the placement of the trocars at the beginning of the surgery determines the success of a surgery. This requires a high degree of trust and several surgeons confirmed that they definitely prefer to place these trocars themselves, or by an assistant they have trained themselves.

A surgeon detailed that such a trust relationship is something that needs to grow over time. A scrub nurse thought it would be essential for the surgeons to have met and preferably worked in real life before. All interviewees agreed that the surgeon working remotely should be able to have great confidence in the skills of the local operating team. Especially since in case of a medical error, having two surgeons in charge will complicate the question of who is to be held responsible.

Trusting referrals

In this regard, it is important to mention that it is unusual as well for surgeons to operate on patients referred to them by other surgeons. While one of the surgeons commented that he regularly operates on patients he has never seen before and that he can fully rely on the medical record of the patient, the other surgeons never did so. All surgeons had a reserved attitude towards operating on patients from other doctors when reflecting on telesurgery.

For instance, one of the surgeons said he was sometimes "*suspicious*" when other surgeons referred one of their patients to him. He figured that if these surgeons could operate on the patient themselves, there would be no reason to refer the patient to him. The surgical intervention probably would be highly complicated and thus very stressful for the surgeon.

Implications for telesurgery

In the context of telesurgery, the complexity caused by having to work with another surgeon might add considerable stress to the working conditions of a surgeon. The remote surgeon needs to work together with a colleague with similar skills, and has to put a lot of trust in the operating team he or she might not have met before. In addition, they have to execute a surgical intervention that is more likely to be more complicated (since this patient was referred) on a patient they might only know through the medical records. These working conditions make telesurgery a less appealing way of working for the surgeons involved.

C. Keeping overview of OR during procedure

We wonder how in a telesurgery setting, the remote surgeon will be able to have a good overview of all activities and events occurring the OR. We saw that during minimally invasive surgery or open surgery, surgeons are usually aware of all activities going on in the OR. The introduction of the surgical robot, however, has changed this to some extent. One surgeon described the situation as follows: *"When doing open surgery or laparoscopy, you can see the monitors of the anesthetist, you can see who is entering and leaving the OR. (...) You can tell if there is a problem or a discussion is going on. You have a good overview of what is going on. But when sitting at the console, you're unable to see things like that, you cannot even see the patient.*"

Stepping away from the controller

We observed during multiple robot-assisted surgeries that the surgeon frequently steps away from the console to see what was going in the operating room. During one surgery, a surgeon was not aware that an assistant was struggling to attach a new instrument to a robotic arm. After a while, the surgeon left the controller, and walked up to the patient, to then notice that the assistant was having some problems. After walking back to the console, the surgeon asked repeatedly if he could continue operating while the assistant was actually still working on the problem. Similarly, sometimes the robotic arms get entwined and the scrub nurse needs to stop the surgeon from operating further until she has repositioned the robotic arms.

Also, for the OR team it is difficult to see what a surgeon, hidden behind the controller, is doing. He or she can be texting or making phone calls, keeping the rest of the OR team unaware and confused about a seemingly inexplicable stop of activities from the surgeon.

Shortcomings of the setup

Tools are available for both the surgeon and the rest of the OR team to create more contextual awareness: the robot has a communication system installed that allows the surgeon and the rest of the OR team to talk with each other. But what is being said often is incomprehensible due to the noise. One surgeon commented that he often turned off the sound coming from the OR inside his console: "*When I sit behind the console (...) and someone passes the microphone (...) you hear noise, buzzing, and humming through the [speakers]. (...) It drives me crazy. So I shut down the volume (....) so [the surgical team] should speak loud [enough so I can hear it]*".

This example, and the example of the surgeon stepping away from the controller and walking through the operating room may illustrate that the surgeon has a lack of overview and develops coping strategies to compensate for the shortcomings of the setup.

Implications for telesurgery

The problems the surgeons encounter during robotic surgery to keep overview of activities and events, will most likely only increase in telesurgery. The surgeon will not have the opportunity to step away from the console and walk to the patient to see what is going on. If camera views from the operating room are available, he might at most be able to switch views and no longer look through the endoscope. Equally, the others in the OR team will have even more difficulty to know what the surgeon is doing when not operating. The surgeon will have to rely even more on the local OR team when troubles occur with tools or robotic arms. Even though surgeons cannot approach the patient too closely during robotic surgery (since they are not scrubbed in), they are still able to evaluate the situation from a certain distance. The OR team will not be able to rely on the current coping strategies currently used and additional displays and communication tools will have to be provided in order to give both the remote surgeon and the local OR team a better understanding and overview of the activities of all people involved in the intervention.

D. Mediated communication

As we have argued, the introduction of the surgical robot in the operating room has physically moved the surgeon further away from the patient compared to open or minimally invasive surgery. When conducting telesurgery, the remote surgeon will be even further removed from the surgical team and the patient. This distance will most likely increase the difficulty of communication between the surgeon and surgical team, and the surgeon and the patient.

(In)formal communication in the OR

From the observations and the interviews, we learned that besides work-related communication, there is also a lot of informal communication taking place in the operating room. A surgeon says: "*We talk about everything, not only about work [related topics], also about what people did* *during the weekend...*" As mentioned in the previous section, the surgical robot hampers the surgeon from having an overview of what is going on in the operating room. Similarly, the robot also hinders informal or work related communication and nonverbal communication between the whole surgical team including the surgeon.

Being able to talk about private life during work, also during surgery, was considered to be important for enjoying work. A scrub nurse mentions: *"You like to know what someone did over the weekend. It's important for the team spirit."*

Patient contact

In addition to informal communication during surgery, a surgeon usually frequently talks to the patient both before and after surgery. With the exception of one surgeon we interviewed, all surgeons always encountered their patients and discussed the intervention at hand with them. Most surgeons wish to keep it as such. Patients frequently want a specific surgeon to operate on them. Often, surgeons and patients have a personal relationship.

One surgeon was explicitly worried about surgeons not meeting their patients outside of surgery. According to him, there have been indications that these patients suffer more frequently from complications after surgery. He explained this by the fact that the surgeon is probably unable in these situations to follow up the medical condition of these patients as carefully as is required.

Implications for telesurgery

In telesurgery, all communications between the remote surgeon and the local OR team will be mediated. As becomes clear of the situations described above, this inevitably changes the nature of the interactions. Current teleconferencing systems are becoming more advanced and increasingly give their users a sense of 'presence'. The communication tools should ideally allow the members of the OR team to enjoy each other's company and allow surgeons to communicate with their patients.

E. Incremental changes in effort

To conclude, we discuss two challenges that most surgeons did not see as problematic, but in the end could be a hassle for surgeons and their team or for patients. These have to do with the planning of the operation and the differences in language. In isolation, these challenges might have a minimal impact, but in combination with the previous issues, their impact might be substantial.

Planning

Telesurgery would require planning and coordination between the schedules of two hospitals. Some surgeons considered this to be a minor detail, however, planning might complicate regular activities in hospitals. As one scrub nurse explains: *"Hospitals all work in their own way, and operations do not take place every day. Different hospitals often have different operating days, so you need to take that into account."*

A surgeon added how telesurgery might affect the planning of the hospital where the remote surgeon resides. Patients from the local hospital might have to be on the waiting list longer, because their surgeon first needs to perform some surgeries on patients in other hospitals through telesurgery. This surgeon therefore would not consider telesurgery, as there is already insufficient operation in the hospital he works now.

Language differences

A similar issue is the language difference. For instance in Europe, when doing remote surgery, chances increase that the personnel in the operating room might speak another language. One of the surgeons considered language differences as an extra complication, but expected it to be overcome easily. Another surgeon, however, did not seem to be worried about language issues, since he reported to speak multiple (European) languages and gave as an example that even in the Middle East they speak English in the operating room.

However, a scrub nurse mentioned a lot of communication problems when working with a Dutch surgeon. While his mother tongue is Dutch and hers Flemish (which is a regional variation of Dutch), there were a lot of misunderstandings during the operation. The Dutch surgeon used other names for some of the instruments than she did, and she mentioned frequently *"having to guess"* what instrument he meant.

Implications for telesurgery

Planning might be relatively easy to organize, but hospitals are often organized in different ways, and it may imply that the patients of the remote surgeons will have to wait longer in order to be treated. Similarly, all medical personnel in the operating room might have sufficient knowledge of a language all are familiar with to some extent. However, language differences in addition to unfamiliarity between the surgeon and the OR team, might be a hurdle for successful telesurgery. Keeping in mind that in telesurgery the amount of communication between the members of the OR will probably increase substantially and members of the OR team will often speak different languages, this can further increase the likelihood that misunderstandings will occur.

DISCUSSION AND CONCLUSION

As we have argued, most research on telesurgery is focused on technical, financial and legal barriers, and in our opinion, the collaborative side of telesurgery has been under examined in the research on telesurgery. In this paper, we aimed to explore the socio-technical gap in telesurgery by asking ourselves how the introduction of a surgical robot and a geographical distribution of an OR team might change collaboration between OR teams. As a result of this exercise, we have identified challenges for collaboration between the remote surgeon and the local surgical team during telesurgery. These challenges were discussed with several surgeons and scrub nurses familiar with robotic surgery, and the analysis of these interviews served as a basis to restructure, nuance and correct the original barriers that were identified before [6]. In comparison, the central themes in this paper are formulated on a more general level. Some additional insights were gained in the second research phase. For instance, we highlighted the conflicts that might potentially arise from two surgeons working together, we further explored the relationship between the scrub nurse and the surgeon, and considerable attention was given to the trust issue in OR teams.

This study has a number of limitations. The small sample size is a limitation of any type ethnographical work. As HCI researchers familiar with dealing with recruitment of participants, we found it particularly difficult to find surgeons willing to participate in interviews. The surgeons that agreed to participate were usually under high time pressure and could not go through our results in as much detail as we hoped for. However, we believe these surgeons with different backgrounds still allowed us to present different views on the challenges in telesurgery. Another shortcoming is that we were not able to observe any real telesurgery, which might have given us even more insight in how OR teams collaborate when geographically distributed. Our approach to use robotic surgery as a proxy-technology has its merits, but it is also a pragmatic solution to the fact that we could not give our participants the actual experience of telesurgery.

Since our main interest was to understand how future collaborative experiences of distributed OR teams might differ from current experiences of collocated teams using surgical robots, we decided to concentrate mainly on the (collaborative) user experience and did not depart from a general understanding of how OR teams collaborate. However, as a result of this choice, we are reluctant to state that our research has resulted in what Ackerman [1] has called 'social requirements' of OR teams. But we did identify some challenges for telesurgery that may serve as input for developers and designers working on surgical robots to improve their systems for telesurgery purposes; or will need to be taken into account by the OR team when the technology is implemented in the hospital. The main challenges as described in the results section are:

- making the remote surgeon and the local OR team familiar with each other's working practices and procedures;
- creating trust between the remote surgeon and the local OR team;
- allowing the surgeon to keep control over the operation and allowing all OR team members to keep an overview of the activities of all personnel involved in the intervention;
- allow for supportive mediated communication between both the remote surgeon and the rest of the OR team and the remote surgeon and the patient; and
- finding ways to decrease the complexity created by combined planning and language differences.

Trust is a reoccuring issue in many of these challenges: being able to trust a member of the OR team was an important element brought up by many of the surgeons and scrub nurses at several occasions. This is not really surprising, since trust has been identified as the main component of functional virtual teams [10]. The key components of trust have been understood as 'risk' and 'reliance' (or 'interdependence') [19], or the fact that group members of teams could experience negative outcomes and that the fate of a member of the OR team can be determined by other members of the group. This helps understanding why trust is of such high importance in a telesurgery setting: the members of the OR team heavily have to rely on each other and the risks are high when their reliance on this other person would be unjustified.

In their list of characteristics of collaboration over distance that will be largely resistant to technological support, Olson and Olson mentioned 'trust' [18]. They wonder if the same level of trust can ever be achieved through for instance video chat. However, more recent research seems to show that this is indeed a possibility: Wilson et al [28] have used Walther's Social Information Processing theory [26] for an empirical study in which they demonstrated that initial levels of trust are indeed higher in collocated teams than in distributed teams, but that there is an interaction effect of time, which neutralizes the effect of communication media. The Social Information Processing theory states that people strive for human relationships in any mode of interaction. But since computer-mediated communication affects the rate of information change (there are e.g. no or less nonverbal cues) it takes longer for trust to develop in distributed teams.

This type of research seems to illustrate that it is possible for distributed OR teams to grow a trusted relationship amongst the members. However, it also seems to illustrate that the distributed OR team also needs to have a certain fixed form, since it takes time to grow a trusted relationship, and probably more time than in collocated teams. Thus, most of the measures that will be required to create trust will be non-technological. Perhaps structural collaborations with a limited team of surgeons will be required, perhaps it is better for the remote surgeon and the rest of the OR team to occasionally have a face-to-face meeting, or OR team members will see it necessary to have an easier understanding of the reputation and skills of the other members of the OR team. Also, Hinds et al [12] have illustrated how informal communication (they call it 'spontaneous communication') helps to create a shared identity and context in distributed teams, which helps to reduce the amount of conflicts (both interpersonal and task-related). As they clarify, conflicts typically result from distrust, and they hypothesize that spontaneous communication also results in more trust. How growing a trusted relationship amongst OR team members should be operationalized, and the implications this will have for the telesurgery setup and the distributed OR team, will have to be the focus of future research.

Increasing trust in the team, can involve more communication amongst the team members for collaboration. Ultimately it will be the OR team that decides whether telesurgery brings added value for them to make the additional efforts in order to grow a trusted relationship within a distributed team. Perhaps other forms of remote interactions that require less trust (are less risky and allow the surgeons to rely less on each other) are more likely to become part of surgical practices in the near future. Future research might for instance focus on telementoring (a remote surgeon guides a procedure where the operating surgeon has limited experience with), teleproctoring (remote assessments of skills surgeons performing live surgeries), teleconsultation (a surgeon remote assessing a patient), telestration (a remote surgeon guiding an operating surgeon using live annotations on the video stream coming from the robot) and others [8].

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