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Impact of Robotic Surgery on Decision Making: Perspectives of Surgical Teams

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Abstract

There has been rapid growth in the purchase of surgical robots in both North America and Europe in recent years. Whilst this technology promises many benefits for patients, the introduction of such a complex interactive system into healthcare practice often results in unintended consequences that are difficult to predict. Decision making by surgeons during an operation is affected by variables including tactile perception, visual perception, motor skill, and instrument complexity, all of which are changed by robotic surgery, yet the impact of robotic surgery on decision making has not been previously studied. Drawing on the approach of realist evaluation, we conducted a multi-site interview study across nine hospitals, interviewing 44 operating room personnel with experience of robotic surgery to gather their perspectives on how robotic surgery impacts surgeon decision making. The findings reveal both potential benefits and challenges of robotic surgery for decision making.

Introduction

Technological innovation has led to great advances in surgical practice over the past two decades, resulting in improvements in patient outcomes[1]. In the 1990s, traditional open surgery was challenged by the introduction of minimally invasive surgery (MIS). With MIS, the surgeon performs operations using small 'key-hole' incisions, through which cameras and laparoscopic instruments are passed. This removes much of the abdominal access trauma, resulting in numerous benefits for patients, including less postoperative pain, shorter hospitalisation, quicker return to normal function, and improved cosmetic effect[2-4]. In addition to patient benefits, laparoscopic surgery is also cost-effective for healthcare providers[5], due to shorter inpatient stay and decreased wound care costs[4]. However, laparoscopic surgery can be technically challenging to perform, as a result of the 2-dimensional operative image and instruments that have limited freedom of movement and require awkward and non-intuitive handling. As a consequence, uptake of laparoscopic surgery has been slow[6].

Robotic surgery overcomes some of the limitations of laparoscopic surgery, potentially making the benefits of MIS available to a greater number of patients. The Da Vinci surgical robot (Intuitive Surgical, California, USA) is currently the only commercially available robot for soft tissue surgery. The surgeon sits unscrubbed at a console that provides them with a magnified pseudo 3-dimensional (3D) view of the surgical site. From the console, the surgeon is able to control the robot arms that hold the laparoscopic instruments inserted into the patient. Robotic surgery enables the surgeon to achieve increased precision through intuitive instrument handling, tremor elimination, and motion scaling. There has been rapid growth in the purchase of Da Vinci robots in North America, despite the cost of the latest model being almost $2 million and annual maintenance costs of $125,000, and Europe is quickly following suit. Between 2007 and 2011, the number of Da Vinci robots installed in the United States increased from 800 to 1,400[7], while the number of Da Vinci robots installed worldwide had reached 2300 in 2011[8]. Whilst robotic surgery is primarily used in urology, its use is expanding across the surgical specialties, also being used in gynecology, ear nose and throat, colorectal, cardiology, and pediatrics.

Decision making is an important component of surgical expertise[9], yet there is a paucity of research on decision making in the operating room (OR)[10, 11]. Theories of decision making highlight the importance of previous experience with particular situations, to enable the development of patterns or mental models which draw attention to relevant cues, provide expectations, determine plausible goals, and suggest typical responses to the situation[12]. In the OR, factors that impact surgeons' decision making include tactile perception, visual perception, motor skill, and instrument complexity[11], all of which are affected by robotic surgery, and may therefore impact on the surgeons' ability to use their experience (mental models) to inform decision making. Similarly, the separation of the surgeon from the rest of the OR personnel may also be significant, as there is strong evidence, both in the OR and in other contexts, that physical proximity of team members and technology influence the gathering of information that is used to inform decision making[13-15]. Again, disruption of these patterns of information seeking may impact if and how surgeons are able to use their experience to inform their decision making. However, evaluation of robotic surgery to date has understandably focused on patient outcomes and the impact of robotic surgery on decision making has not previously been studied.

This is the first study to explore how robotic surgery impacts decision making, through interviews with surgeons and OR personnel. Interviews were conducted using the teacher-learner cycle, where interviewees are presented with ideas from the literature and asked to reflect on the extent to which those ideas fit with their experience[16]. We first review relevant literature on decision making before describing the methods of our study and presenting the results. We conclude by discussing the implications of the findings for the implementation of robotic surgery.

Background

Klein, in his recognition primed decision (RPD) model, highlights the importance of context or situation in 'triggering' mental models that guide decision making in numerous complex decision situations[12]. This situation awareness is defined as the perception of elements in the environment, the comprehension of their meaning, and the projection of their status in the near future[17]. Situation awareness is also an important factor in understanding information behavior, the manner in which decision makers seek and use information to guide their choices[18]. As highlighted in the RPD model, situation awareness is an important component of surgeons' intra-operative decision making[2,3] and better situation awareness of the surgeon is associated with fewer surgical errors[19, 20]. One model of intra-operative decision making suggests a continuous cycle where, with the preoperative plan in mind, the surgeon assesses the situation, reconciles new information with existing information, and subsequently implements a revised course of action[21]. In this cycle, through the use of existing mental models, information may be actively sought or, by remaining observant of what is happening in the OR, perceived without active seeking. Robotic surgery potentially changes the nature of the information that the surgeon has available to them. The magnified, surgeon-controlled, 3D view of the surgical site may support the surgeon in visually perceiving anatomic information. However, because the surgeon sits at a console away from the patient and the rest of the OR team, they may not be able to see the patient or the robot arms directly and access to auditory information is also likely to be reduced. One report of the introduction of robotic surgery described a tendency for surgeons to 'bury themselves in the console,' thereby blocking out the OR[22]. Consequently, the surgeon is dependent on the rest of the OR team communicating information that they previously obtained through visual perception[1, 23]. This has led some to argue that intra-operative decision making in robotic surgery is more collaborative than open or laparoscopic surgery[1].

Robotic surgery also changes the ability of the surgeon to use tactile perception to determine anatomic information. In open surgery, surgeons work primarily with visual and tactile information. In laparoscopic surgery, tactile information is reduced but, by touching with the instruments, surgeons are still able to determine features of objects such as shape, texture, and consistency[24, 25]. In robotic surgery, the surgeon receives no tactile information and this is considered to be a major limitation of robotic surgery[26]. Some surgeons have suggested that the lack of tactile information means that surgeons move more slowly because they have to rely on visual information only[27]. However, research suggests that, as experience of robotic surgery increases, surgeons find visual information sufficient for informing their intra-operative decision making[28], and this is supported by surgeons' own reports[29].

While robotic surgery changes the visual and tactile information that is available to the surgeon, potentially reducing their situation awareness, it has been argued that the surgeon's position inside the console and the 3D image create a sense of immersion[30] and that the subsequent reduced 'distractibility' of the surgeon could be a benefit of robotic surgery[31]. Certainly, if robotic surgery does reduce the number of distractions that the surgeon experiences, this could have positive impacts on decision making and subsequent patient outcomes; research reveals that distractions in the form of case-irrelevant communication are linked to an increase in surgeons' mental fatigue and intra-operative stress[32] and excessive levels of intra-operative stress compromise not only technical skills but also non-technical skills such as decision making[33]. However, it has also been found that equipment and work environment distractions are more frequent in laparoscopic operations than in open operations, due to the more complex technology, suggesting that robotic surgery may also introduce new distractions[34].

The ergonomic benefits of robotic surgery may also impact surgeons' stress and fatigue. Robotic surgery removes the awkward and unnatural movements required during laparoscopy and the surgeon is able to sit down comfortably at the console, potentially reducing physical stress and associated fatigue. This has led some surgeons to argue that, with stress arising from a difficult operation being an indirect cause of conversion to open surgery, robotic surgery may result in a lower rate of conversion[35]. However, results from experimental studies are inconclusive; while two studies found robotic surgery to result in lower mental and physical stress than laparoscopic surgery[36, 37], in another study the difference was not statistically significant[38].

Methods

This study was undertaken as part of a process evaluation, running alongside ROLARR, a multicenter randomized controlled trial comparing laparoscopic and robotic surgery for the curative treatment of rectal cancer[39]. Realist evaluation, an approach that is increasingly popular for the evaluation of complex interventions in healthcare[40], provides an overall framework for the process evaluation. Realist evaluation involves building, refining, and testing users' ideas and assumptions, or 'theories', of how an intervention produces its outcomes[41]. From a realist perspective, interventions in and of themselves do not produce outcomes. Rather, interventions offer resources to users; outcomes depend on how users choose to respond to those resources, which will vary according to the situation or 'context'. Thus, rather than just asking 'what works?', realist evaluation seeks to answer the question of 'what works, for whom, in what circumstances, and how?'. Realist evaluation involves gathering data in order to explain how different contexts trigger particular changes in the reasoning and responses of users ('mechanisms') which, in turn, give rise to a particular pattern of outcomes. While general qualitative approaches can only provide a catalogue of possible contextual factors thought to impact the process and outcomes of interest, the advantage of realist evaluation is that it increases the specificity of our understanding of the relationship between context, mechanisms and outcomes. As part of the first phase of the process evaluation, we undertook a multi-site interview study, interviewing OR teams to elicit their theories of how robotic surgery impacts decision making during surgical operations.

Participants

All English hospitals participating in the ROLARR trial were invited to participate in the interview study. English hospitals not participating in the trial but using the robot for colorectal surgery were identified by the trial team and through personal contacts of one of the team members (DJ), and all were invited to participate in the interview study. In this way, geographic spread and variation in level of experience of robotic surgery was achieved. A snowball sampling strategy was used[42]; at each hospital, one of the surgeons was interviewed first, who then assisted in identifying other members of the OR personnel to interview (surgeons, trainee surgeons, anesthesiologists, OR nurses, and OR practitioners).

National Health Service (NHS) study-wide ethical approval was granted and research governance permissions were obtained from each hospital. All participants gave informed consent.

Data collection

Interviews were conducted, either face-to-face or by telephone, using the teacher-learner cycle[16, 41]. Teacher-learner cycle interviews are advocated within realist evaluation as a way to uncover users' ideas and assumptions (theories) about how an intervention works and thus understand how user responses (mechanisms) are triggered in different circumstances (contexts) and produce certain outcomes. These theories can then be expressed as context-mechanism-outcome configurations (CMOs). In contrast to standard qualitative interviews, in teacher-learner cycle interviews, the researcher's theories are the subject matter and the purpose of the interview is to confirm, falsify, or refine that theory[16]. Using a semi-structured interview schedule, the interviewer presented the interviewee with theories from the literature concerning how robotic surgery is thought to impact surgeons' decision making. Interviewees were asked to reflect on whether or not, and in which ways, these theories fitted with their experience.

From our review of the literature, we started with the following theories:

1. When the team is more experienced in robotic surgery, they understand that the surgeon's situation awareness is dependent on them orally communicating information and they respond by using more oral communication about the patient's state which in turn improves the surgeon's situation awareness.
2. Surgeons progress more slowly through a robotic procedure because they do not have tactile information to inform their assessment of the situation and to determine whether to persist with or revise their course of action, but this effect becomes less pronounced as experience with robotic surgery increases.
3. The sense of immersion that the robot provides means that the surgeon is more focused, resulting in improved decision making and patient outcomes.
4. The ergonomics of the robot mean that the surgeon is less stressed and tired, resulting in better decision making and reduced conversion to open surgery.

As the literature provided limited information on the contexts in which robotic surgery impacts decision making, and the mechanisms through which those impacts are achieved, the interviews sought to elicit further detail about this. An iterative approach to data collection and analysis was taken, with the theories being revised as the interviews progressed. Interviews were audio recorded and transcribed verbatim.

Analysis

The interview transcripts were anonymized and entered into NVivo 10. Framework analysis, an approach developed for analyzing qualitative data for applied policy research, was used[43]. Informed by the interview schedule and reading of preliminary interviews, codes for indexing the data were identified and agreed by three members of the research team (RR, NA, SH). They then indexed four transcripts to test the applicability of the codes and assess agreement. Where there was variation in the indexing, the codes were refined and definitions were clarified. The refined codes were applied to all transcripts. The indexed data was summarized in a matrix display to build up a picture of the data as a whole[44]. In the final stage, mapping and interpretation, the matrix was used to identify similarities and differences in participants' responses.

Results

Forty-four interviews were conducted across nine hospitals between January and August 2014. Interviews ranged from 29 minutes to1 hour 40 minutes, with an average (mean) length of interview of 53 minutes. Table 1 provides a summary of participants and settings. The findings are organized around the main theories discussed.

Table 1. Participants by professional group and hospital type.

N = 44	N (% of sample)
Professional group	
Surgeon	12 (27)
Trainee surgeon	5 (11)
Manager	1 (2)
Anesthesiologist	6 (14)
OR Nurse	13 (30)
OR Practitioner	7 (16)
Hospital type	
Teaching	21 (48)
District general	17 (39)
Cancer center	6 (13)

Theory 1: Situation awareness

The majority of surgeons perceived that their situation awareness is potentially reduced during robotic surgery, stating that they are focused on a small area and therefore are less aware of their environment; they have 'tunnel vision'. One surgeon provided the example of 'sucking fluid'; the surgeon can request that their assistant provide suction, but they are unaware if the assistant experiences difficulties fulfilling their request or the reasons why. Attitudes to the seriousness of this varied. One surgeon described operating with a second surgeon as a 'wing man' to counteract the problem of reduced situation awareness and stated that he would be very concerned about reduced situation awareness if he operated without a second surgeon present. Another surgeon described being 'vastly less aware' of what is going on in the OR but he had not been 'hindered' by this and did not think it made any difference to the operation. Only two surgeons felt that their situation awareness is not reduced. One described still listening to the 'banter' amongst the team in the OR, while the other surgeon made a conscious effort to intermittently ask the team about the patient's status.

Team members also perceived that the surgeon's situation awareness is reduced due to their position in the console e.g. the surgeons do not have lateral vision and their sensory feedback, which can indicate problems, is reduced. Consequences of the surgeon's reduced situation awareness described by the team include the robotic arms impinging upon each other, which could damage the robot or prevent the surgeon achieving their aim. Respondents explained that the surgeon only realizes that the robot arms are clashing when they are unable to maneuver the instruments as desired. On one occasion the robot arms nearly collided with a patient's head; this problem was averted by the OR nurse who intervened.

The overarching strategy described by the surgeons to increase situation awareness, in line with our initial theory, was to establish good communication links between the surgeon and the team. Good communication was seen as an essential part of robotic surgery. Trust between the surgeon and the team was also emphasized, as the surgeon has to rely on the rest of the team to communicate information outside of their field of vision to avoid complications. If the surgeon trusts their team to communicate problems to them, their concern over their reduced situation awareness is lessened. One surgeon commented that a more experienced team might be better able to communicate the necessary information to them.

Communication was also described by the OR teams as the main strategy to increase situation awareness, who saw it as their responsibility to act as the 'surgeon's eyes and ears'. In contrast to our initial theory, the information that they described communicating to the surgeon was less about the patient state and more often about the robot, as in the examples described above. Some noted that they just 'tell the surgeon' when there are problems and that everyone in their team knows to do this whether it is themselves or the robot that is struggling. Others described that it is important, because of the physical separation of the surgeon from the team, that team members have voices that are 'strong enough for the surgeon to hear'. Good communication was seen as dependent on the relationship between the surgeon and team. While this is dependent on individual personalities and approaches, training together as a team and having a dedicated team were strategies that were considered by interviewees to increase team members' confidence to speak up. As one nurse said about training as a team:

'I just think having been away, just you got to know the surgeons better and […] you're just that much happier saying, can we start, can we slow down a bit, can we do this or we need to get that, it just sort of levels the hierarchy *so much, which made it much easier to work with people.'*

Another strategy described by the OR teams was positioning the console so that the surgeon has a direct view of the patient and the assistant when they look up from the robot, i.e. they are 'not hidden in a corner.'

Theory 2: Lack of tactile information

Several surgeons described initial experiences with the robot where, due to the absence of tactile information, they had not realized how much force they were applying and consequently had, for example, snapped a suture. However, none of the surgeons considered the lack of tactile information a significant problem. While a couple of the surgeons described being 'a bit more careful', 'a bit more hesitant', the surgeons we interviewed did not consider that the lack of tactile information led to a longer operation duration. They felt that they had adapted quickly to relying on visual cues, learning to look for tension. Several surgeons related this to their experience of laparoscopic surgery; with laparoscopic surgery, they had already learnt to work with reduced tactile information. As one surgeon described, 'from previous experience you know what you're looking for, so you know the tension that you're putting on the tissues from what you can actually see.' Interviewees contrasted this with the experience of urology surgeons who had moved straight from doing open prostatectomies to doing them robotically.

Theory 3: Immersion

The majority of the surgeons we interviewed agreed that the robot produces a sense of immersion. One surgeon described how they can 'lose themselves' during the operation and, referring to level of concentration, he described this feeling as 'quite intense'. Other surgeons commented that it is not that the robot creates a sense of immersion but just that they have to concentrate more because they have less experience with robotic surgery than with laparoscopic surgery. Two surgeons refuted the idea that the robot produces a sense of immersion, commenting that they are immersed in the procedure regardless of whether it is laparoscopic or robotic and that technology should not determine whether the surgeon is immersed.

A number of theories about the contexts in which a sense of immersion occurs were suggested by the participants. One surgeon anticipated that, while he already experiences a sense of immersion when using the robot, the feeling will probably increase when the 'mundane' and routine tasks related to using the robot, e.g. port positioning, have been mastered. In contrast, another surgeon commented that he feels immersed using the console, particularly during complex cases, but that this feeling would probably lessen over time, i.e. that it was a feature of his limited experience with the robot. One surgeon described immersion as being dependent on who he has assisting i.e. if he trusts the assistant he can be immersed as the assistant fulfils requests with 'silver service', whereas otherwise he is 'constantly looking' as there is anxiety about where the assistant is 'pointing the instrument'. The creation of trust was also associated with training as a team, as one surgeon described:

‘We learned to trust each other. We came back from [the training] with that certain knowledge that between us we knew what we knew and *[…]* we would each remember something and we would be able to pull it off.*’*

Some surgeons described the OR as quiet during robotic surgery, enhancing their concentration, and that there are no distractions. In comparison, in open and laparoscopic cases, the surgeon can chat with the assistant and team.

Perceptions of the impact of the sense of immersion varied. Some respondents commented that heightened concentration might lead to better decision making, but how or why was not articulated. One surgeon described the sense of immersion as making him more focused, which should enable a more precise dissection. Others felt unable to comment on whether immersion would be reflected in patient outcomes. One surgeon said he felt the sense of immersion would not impact his decision making, except that he may persevere longer with an operation because he is less aware of time. However, this could cause concern if the patient is operated on for an ‘excess amount of time’.

Theory 4: Impact of ergonomics

The surgeons discussed their experiences of using the robot and the extent to which ergonomics affected their levels of stress and tiredness in comparison to laparoscopic surgery. Some surgeons discussed that, for them, performing operations using the robot is more stressful than laparoscopic surgery because they are in the early stages of implementation i.e. have not used the robot on many occasions. In this context the surgeons stated that they shared the operation with a colleague. They explained that sharing the operation reduced their levels of stress, as opposed to the ergonomics of the robot. Other surgeons felt that the robot was an improvement on laparoscopic surgery (ergonomically); how and why it was an improvement was not fully explored although one surgeon described that they were in a ‘less awkward position’. The surgeons also discussed that using the robot might be physically less tiring than laparoscopic surgery, but it is mentally more so because they have less experience of robotic surgery than laparoscopic surgery. For this reason, they have a higher level of concentration for a longer time using the robot; in comparison, they could relax on occasion during laparoscopic cases.

Two surgeons described how the level of stress is affected by the how the team acts; as one surgeon described it:

‘I think it probably makes you physically less tired. I think you’re probably mentally more tired […] We’ve all done less robotics than we have laparoscopic, so you’re carrying more of a burden I think robotically. And sometimes you feel like you’re only the person in theatre that knows what’s going on. […] Because you’re there, and you’re the only one there looking.’

The extent to which the robot reduces surgeons’ stress levels was also described as dependent on the stage of the procedure. For example, talking about suturing, one surgeon said:

‘If I was doing that laparoscopically, it would be a nightmare. It’s just a joy to do it robotically because of the ergonomics.’

In contrast, this surgeon described how with dissection his ‘fear’ of bleeding is increased, because the magnified image means that he notices tiny blood vessels that he would not notice otherwise. It was also noted that stress can be dependent on the type of operation performed e.g. a low anterior resection is stressful using both approaches, whereas operations that do not go down to the pelvic floor are less stressful and demanding. However, being able to take breaks when using the robot was noted as a benefit.

The extent to which the ergonomics of the robot impacted on decision making, particularly the decision to convert to open surgery, was difficult to ascertain. It was suggested by some respondents that if the surgeon is more comfortable during surgery he or she might persevere with a difficult operation rather than convert to open surgery. It was also noted that the surgeon can ‘take five minutes’ to consider their decisions during robotic surgery, whereas they might feel more pressure in decision making during laparoscopic surgery. However, it was also acknowledged that the decision to convert to open surgery is often due to circumstances outside the surgeon’s control, e.g. conversion was described as a ‘technical’ matter that was not linked to ergonomics or how stressed the surgeon was. One surgeon stated that, if anything, he would persevere longer with laparoscopic surgery because that is the technique with which he has more experience and so feels more confident.

How and why the ergonomics of the robot reduced surgeons’ stress levels was also postulated by the wider surgical team. Team members discussed a number of ergonomic benefits of the robot, e.g. because the surgeon is sat down must mean that they are more relaxed, the surgeon can adjust the console’s head piece, the console is padded, and it is easier to have coffee breaks as no scrubbing or de-scrubbing is required to step away from the console. However, it was also suggested that stress might be dependent on the surgeon’s experience i.e. those learning how to use the robot do not seem as relaxed using the console. Participants also noted that if a surgeon found a stage of the procedure difficult, this would cause stress regardless of the ergonomics of the robot. The difference between mental and physical tiredness was also highlighted by the team; some described that the surgeon gets tired looking at the 3D image, that robotic surgery is stressful for their eyes and requires more mental concentration. It was also noted that the surgeon can be hunched in the same position for hours.

Discussion

Robotic surgery is a complex interactive system. Whilst this technology promises many benefits for patients, the introduction of interactive systems into healthcare practice often results in unintended consequences that are difficult to predict[45]. We have drawn on the experience of OR teams to understand the impact that robotic surgery has on surgeons' intra-operative decision making. Using the approach of realist evaluation, we have not only identified some of the consequences of robotic surgery for the processes and outcomes of surgeon decision making but have also begun to unpack how these impacts are achieved and the contexts in which these impacts are likely to occur.

The findings suggest a number of revisions to the theories discussed in the interviews. They highlight the role of the team in maintaining the surgeon's situation awareness, fitting with ideas previously postulated in the literature. We anticipated this would involve teams providing surgeons with information about the patient state but the state of the robot also needs to be communicated. However, the findings also suggest that, for this to occur, there needs to be a positive relationship between surgeon and team. That relationship may be impacted by the way in which robotic surgery is introduced, with training as a team and having a dedicated robotic team being associated with positive relationships between the surgeon and team so that team members feel confident to speak up. The findings also reveal the intertwined nature of surgeon situation awareness and the surgeon's level of concentration when undertaking robotic surgery; when the surgeon trusts the team to make him aware of changes outside of his field of view, he feels confident to remain in the console, resulting in reduced distraction and increased concentration. What is less clear is how this impacts patient outcomes. The ergonomic console can reduce stress and tiredness, enabling the surgeon to persist longer with the operation and potentially reducing the number of conversions to open surgery, but this is only when the surgeon is experienced in robotic surgery. Interestingly, in contrast to some of the literature, lack of tactile information did not present a concern for the surgeons in our study. A revised set of theories, formulated as CMO configurations, is presented in Table 2. Given realist evaluation's concern with identifying what works, for whom, in what circumstances, these theories describe what is needed to produce a positive outcome. The implication is that, in the absence of the necessary contextual factors, the mechanism that produces the desire outcome will not be triggered. For example, if there is not a positive relationship between the surgeon and the OR team so that the team communicate information to the surgeon, this could lead to complications and increased distraction for the surgeon.

Table 2. Revised theories presented as CMO configurations.

CONTEXT	+	MECHANISM		=	OUTCOME
		RESOURCE	RESPONSE		
Positive relationship between surgeon and OR team	+	Team communicates to surgeon information about patient and robot	Surgeon adjusts their course of action based on the information	=	Complications avoided
			Surgeon feels confident to remain in console	=	Reduced distraction and increased concentration
Surgeon experienced in robotic surgery	+	Ergonomic console	Surgeon feels comfortable to persist longer with the operation	=	Reduced levels of stress and tiredness Reduced conversion to open surgery

These findings have a number of implications for the design and implementation of surgical robots. While there is recent research exploring how to provide haptic feedback in robotic surgery[46, 47], from the perspective of the users the lack of tactile information does not, after a short learning period, hinder their ability to assess the situation and determine the appropriate course of action. Concerns that are more persistent relate to the impact on the surgeon's situation awareness and, where this is not addressed, potential benefits of robotic surgery in terms of reduced distraction and increased concentration will not be obtained. We suggest that, to realize the benefits of robotic surgery for surgeon decision making and avoid any negative consequences, implementation of robotic surgery should involve (a) training for teams that acknowledges the need for the team to maintain the surgeon's situation awareness, and (b) whole team training and/or a dedicated robotic team to establish positive strategies of communication between the surgeon and the team.

Limitations

A limitation of this research is that, although conducted over nine different hospitals, it has been concerned with one surgical specialty, colorectal surgery. However, informal discussions with urology and gynecology surgeons suggest that they experience similar impacts of robotic surgery. In future research, we will be conducting interviews across a range of surgical specialties to assess the extent to which are findings are specific to colorectal surgery and to revise our CMO configurations to reflect the experience of a broader range of surgical specialties.

Another limitation of this research relates to the challenges associated with conducting interviews to understand decision making. Decision making in the OR has predominantly been studied through interviews[11, 21, 48-50] but to develop a rich, nuanced understand of the complexity of clinical decision making requires comprehensive data, gathered through multiple methods[51]. Consequently, in the next phase of this research, we will be testing our revised theories through a multi-method multi-site case study[52]. We will be conducting structured observations of both robotic and laparoscopic operations using OTAS (Observational Teamwork Assessment for Surgery)[53], which will provide a quantitative measure of the situation awareness of the different sub-teams in the OR. Post-operation, we will ask participants to complete questionnaires to gather their perceptions of the mental and physical demand and the extent of distractions[54]. This will be complemented by detailed analysis of video data that allows us to understand how these impacts are achieved, interviews with participants to understand their reasoning, and ethnographic observations to understand the contexts that influences these mechanisms.

Conclusion

This is the first study to explore how robotic surgery impacts decision making. It reveals both potential benefits and challenges of robotic surgery for decision making, which could have consequences for patient outcomes. While the assumption underlying the introduction of robotic surgery is that the increased precision provided by the robot results in improved patient outcomes, our findings suggest a more complex picture. This is a topic that needs to be considered and addressed by healthcare providers when implementing robotic surgery into their organization.

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