Eliciting context-mechanism-outcome configurations: Experiences from a realist evaluation investigating the impact of robotic surgery on teamwork in the operating theatre

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Abstract

This paper recounts our experience of eliciting, cataloguing and prioritising conjectured Context-Mechanism-Outcome configurations (CMOcs) at the outset of a realist evaluation, to provide new insight into how CMOcs can be generated and theorised. Our construction of CMOcs centred on how, why and in what circumstances teamwork was impacted by robotic surgery, rather than how and why this technology improved surgical outcomes as intended. We found that, as well as offering resources, robotic surgery took away resources from the theatre team, by physically reconfiguring the operating theatre and redistributing the surgical task load, essentially changing the context in which teamwork was performed. We constructed CMOcs that explain how teamwork mechanisms were both constrained by the contextual changes, and triggered in the new context through the use of informal strategies. We conclude by reflecting on our application of realist evaluation to understand the potential impacts of robotic surgery on teamwork.

Keywords: Teamwork; surgery; realist evaluation; randomised controlled trial

Introduction

The Randomised Controlled Trial (RCT) is still held up as the preferred method for assessing the impact of an intervention on outcomes in health services research (Craig et al., 2013). However, a criticism of this design is that it oversimplifies causality, especially when used to evaluate complex interventions, focusing on whether the intervention has worked or not, rather than how and why it has worked (Fletcher et al., 2016). In contrast to the RCT, realist evaluation attempts to explain what about an intervention has worked, for whom, how, why and under what conditions (Pawson and Tilley, 1997). The evaluative process involves an iterative cycle of eliciting, testing and refining programme theory, constructed as Context-Mechanism-Outcome (CMO) configurations. Evaluation by this mode is slowly becoming established in health services research, offering future implementers an explanation of where the intervention is most likely to be successful outside the study setting (Marchal et al., 2012). However, a number of challenges have been reported when applying its principles, including using the conceptual tools of Context, Mechanism and Outcome (Marchal et al., 2012).

To provide new insight into how CMO configurations can be generated and theorised for complex interventions, we recount our experience of constructing conjectured CMO configurations, as stage one of a three stage realist evaluation (see Figure 1 for study stages) that was designed to get inside the black box of an RCT, entitled RObotic versus LAparoscopic Resection for Rectal cancer (ROLARR) (Collinson et al., 2012; Randell et al., 2014).

Figure 1: Study stages

The ROLARR trial focused on surgical outcomes and the technicalities of surgery; however robotic surgery is a sociotechnical system (Healey et al., 2008). To fully understand how this system works to improve surgical outcomes requires examining the interactions between its social, and technological elements. For this reason, we used realist evaluation to investigate how robotic surgery impacted on teamwork in the OT and to what effect. In this paper, we explore how robotic surgery changed the immediate context in which surgery is performed (through physically reconfiguring the OT and redistributing the surgical task load) and examine how both this new and pre-existing contextual factors influenced the ways in which teamwork was performed.

Laparoscopic versus Robotic surgery

The benefits of minimally invasive (laparoscopic) surgery, in comparison to open surgery, are well documented and include shorter hospitalisation and less post-operative pain (Collinson et al., 2012). However, laparoscopic surgery is technically more challenging than open surgery, as the surgical instruments are passed through small ‘key hole’ incisions and have limited freedom of movement, and the operating site is viewed on a 2-dimensional screen (Randell et al., 2016). The pelvis, where rectal cancer surgery is performed, is a narrow space, and has been described as a particularly challenging environment in which to use laparoscopic surgery (Collinson et al., 2012). In comparison to other specialities, this technically challenging environment may lead to a higher rate of conversion to open surgery, which is significant due to its association with increased post-operative morbidity and mortality.

In comparison to laparoscopic surgery, robot assisted laparoscopic surgery (referred to hereafter as robotic surgery) offers a number of technological advancements including an immersive, 3-dimensional operative field, instruments with increased dexterity and freedom of movement, and a stable, operator-driven camera platform (Ficarra et al., 2007). The ROLARR trial was designed to test the hypothesis that robotic assistance facilitates the use of laparoscopic rectal cancer surgery; the primary outcome of interest was the rate of conversion to open surgery, which was used as a surrogate for the technical ease of the surgery (Collinson et al., 2012).

The implicit assumption underpinning the ROLARR trial is that the technical advances offered through robotic surgery will increase the surgeons' technical capacity and ease their use of laparoscopic techniques, such that they are less likely to convert to open surgery during the operation. The surgeons' experience was thought to be influential on this process, as the ROLARR study protocol states that participating surgeons must have performed 'at least 30 robot-assisted or standard laparoscopic rectal cancer resections, *with at least ten of each type'* (Collinson et al., 2012: 235). However, there were no criteria regarding the experience of the wider theatre team, whom, alongside the surgeon, includes Operating Department Practitioners (ODPs), nurses, and anaesthetists. These professionals work with the surgeon to implement robotic surgery, so that any technical advances can be utilised by the surgeon to impact surgical outcomes.

Teamwork in the Operating Theatre (OT)

In the healthcare setting, teamwork can be defined as two or more people who work towards a common goal through interdependent collaboration, open communication and shared decision making (Xyrichis and Ream, 2008; Xiao et al., 2013). The OT brings together a number of professionals (surgeons, ODPs, nurses and anaesthetists) who perform distinct roles, but must also work together to perform collaborative activities, such as instrument exchanges, safely and efficiently (Catchpole et al., 2008). These seemingly small tasks are said to underpin and enable the accomplishment of more complex activities and together make up the surgical procedure as a whole (Svensson et al., 2007). Table 1 describes teamwork-related behaviours that have been observed in standard surgical procedures.

Table 1: Teamwork-related behaviours (Undre et al., 2007)

These behaviours, or non-technical skills as they are referred to in the surgical literature, are used routinely in practice. Even so, breakdowns, most notably in communication, have been associated with adverse events including impaired technical performance and injury to patients (Lingard et al., 2004; Greenberg et al., 2007; Hull et al., 2012). These breakdowns have been well documented, but there has been less emphasis on understanding how and why they occur, or instances where practitioners successfully adapt their behaviour to address hazards in complex and high risk environments (Rankin et al., 2014; Patterson and Wears, 2009). Such details could be used to inform guidance for theatre teams wishing to improve their practice, which has been called for in response to the volume of communication failures reported in standard surgical procedures (Weldon et al., 2013).

Guidance to support successful teamwork may be particularly useful when novel technologies are introduced to the OT, as they have the potential to disrupt the usual patterns of teamwork (Edmondson et al., 2001). The introduction of robotic surgery, for example, physically reconfigures the OT, as the surgeon operates unscrubbed (without sterile gown and gloves) via the console, which controls the robotic arms, and provides a pseudo-3D image through a binocular viewer (see Figure 2).

Figure 2: Laparoscopic/open and robotic OT configurations

In realist terms, we can think of this physical reconfiguration as a change to the context of surgery that offers technical resources to the surgeon, but also removes resources in terms of how teamwork is performed, for example, studies of anaesthesia in the OT have highlighted how the physical environment, such as the precise alignment of team member's bodies and tools, support coordination (Goodwin, 2007; Hindmarsh and Pilnick, 2007). However, teamwork has rarely been the focus of research in robotic surgery (Randell et al., 2014; Webster and Cao, 2006). Applying realist evaluation as a study framework, we used the ROLARR trial as an opportunity to investigate how, why and in what circumstances robotic surgery impacts on teamwork in the OT, and to what effect. The CMO configurations elicited in this stage of the study, once tested and refined, will be used to inform actionable guidance for OT teams on how to ensure effective teamwork when undertaking robotic surgery (Randell et al., 2014).

Realist evaluation

Realist evaluation is rooted in scientific realism which is premised on a generative understanding of causality (Marchal et al., 2012; Pawson and Tilley, 1997). It proposes that the outcomes we observe are the result of causal processes and forces (or mechanisms) that we cannot observe directly (Pawson and Tilley, 1997). These causal processes are shaped by the social context in which they occur, thus producing a pattern of outcomes or demi-regularities (Pawson and Tilley, 1997; Westhorp, 2014). Consequently, the social world is not governed by and thus cannot be explained by universal rules or laws, but neither is it completely random. Realist research seeks to understand how context shapes the causal mechanisms through which change occurs to produce outcomes, in order to explain how and why the social world works.

Realist evaluation applies these principles to understand how interventions work using the conceptual tools of Context, Mechanism and Outcome. In realist terms, a Mechanism refers to how the resources offered by an intervention interact with individuals' reasoning to trigger a change in behaviour, as Pawson and Tilley (1997) note we cannot simply treat programs [interventions] as things, we have to follow them through into the choices made by recipients (Pawson and Tilley, 1997: 188). To help operationalise the realist mechanism, Dalkin et al. (2015) suggest 'disaggregating' the intervention resources from individuals' reasoning (see Figure 3).

Figure 3: CMO configuration, adapted from Dalkin et al. (2015)

Using this mind set, the intervention resources (the robot and console) are inserted into an existing Context (C); we have depicted what was known about the context into which robotic surgery was inserted in the ROLARR trial, however context has many layers and can include political, social, organisational and individual influences (Blamey and Mackenzie, 2007). These circumstances support or constrain individuals' responses to the intervention resources (M), to generate Outcomes (O) (intended and unintended consequences). To surface CMOs, programme or 'middle-range' theories that explain how the intervention (programme) is expected to produce the desired outcomes are first elicited (Blamey and Mackenzie, 2007). Conjectured CMO configurations are then teased out as testable elements of the programme theory, and a selection are prioritised for testing and refinement though empirical work.

Methods

Programme theory can be elicited from a number of sources including the researcher's own theorising, although they are said to 'normally flow most readily' from programme documentation that suggest how the intervention will achieve its aim and stakeholders, including programme managers and practitioners (Pawson and Sridharan, 2010: 45). The ROLARR study protocol suggested how the technical advances of robotic surgery were hypothesised to impact on conversion to open surgery. However, we wanted to understand how and why robotic surgery impacted on teamwork, and to what effect. Hence, we drew on data from a comprehensive review of the surgical literature and interviews with theatre staff with experience of implementing robotic surgery.

Literature review

The literature review explored how robotic surgery was successfully integrated into routine practice, and how it impacted on teamwork and decision-making in the OT, reflecting the broader study objectives (Randell et al., 2016; Randell et al., 2014). Here we summarise the findings regarding teamwork that were used to inform the subsequent interviews; the questions addressed by the review were how, why and in what circumstances is teamwork impacted by robotic surgery. We searched a number of electronic databases, and websites of relevant professional organisations, including the Royal College of Surgeons and the Royal College of Nursing. The review incorporated editorials, news articles and comment sections, which are noted as useful sources for theory elicitation (Pawson et al., 2004), and the discussion sections of quantitative papers of robotic surgery. For a full report of the review, including data extraction and analysis, see Randell et al. (2016).

Semi-structured interviews

A total of 44 professionals, including Surgeons, Surgical Trainees, Operating Department Practitioners (ODP) and Theatre Nurses who used robotic surgery for rectal cancer procedures in nine hospitals across the UK were interviewed. Interviews were conducted using the teacher-learner cycle, a method advocated within realist evaluation (Pawson, 1996; Manzano, 2016). The researcher first teaches the interviewee about the theories that they want to explore within the interview. The researcher then invites the interviewee to use their experience of the intervention to reflect on these theories so that the interviewee is using their experience to teach the researcher. This cycle can be used in all stages of realist evaluation. We used them to expand upon our findings from the literature review and catalogue new theories as they emerged; hence they were used for theory ‘gleaning’ as opposed to testing and refinement (Manzano, 2016).

Analysis

Analysis of the interview data was performed to draw out conjectured CMO configurations. After each interview was performed, we reflected on how the data could inform the development of CMO configurations in the emerging theory areas identified in the review or whether they revealed new areas for exploration. We recorded these reflections in a working document that traced the construction of CMO configurations. This reflective process enabled us to feedback emerging findings into data collection, and we amended our interview schedule as necessary. However, the data was also managed more formally using the Framework approach (Ritchie and Spencer, 2002). A thematic framework based on our interview schedules and our emerging CMO configurations was developed and applied to categorise the interview data, which was also summarised in data matrices (participant by theme).

Construction of CMO configurations

Robotic surgery was designed to improve surgical outcomes, as opposed to teamwork, which impacted on the theory elicitation process. Examining the interaction between the theatre team (their response to) and robotic surgery (the resources it offered) we identified two overarching theory areas, which can be summarised as: 1) Robotic surgery changes the context of the OT which may disrupt the use of teamwork-related behaviours, potentially leading to unintended surgical outcomes; and 2) In the changed context of the OT, the theatre team adapt their practice using strategies to overcome disruptions to teamwork-related behaviours to perform collaborative activities and potentially optimise surgical outcomes. We surfaced and catalogued CMO configurations in these two areas and then prioritised which configurations to test and refine; below we present these findings as follows;

1) How robotic surgery changed the context in which surgery is performed and constrained the mechanisms usually used to perform teamwork, summarised as CMO configurations.

2) The strategies used by theatre staff to overcome the constraints to teamwork identified.

3) How, why and in what circumstances the strategies work to maintain teamwork during robotic surgery, summarised as CMO configurations.

4) How conjectured CMO configurations were prioritised for testing and refinement.

How robotic surgery changed the context in which surgery was performed and constrained the mechanisms usually used to perform teamwork

Analysis of the literature review data suggested that the physical reconfiguration of the OT, necessary to implement robotic surgery, constrained teamwork mechanisms. For example, communication was constrained as hearing the surgeon's instruction may be difficult due to the distance between the surgeon and the theatre team, particularly when the surgeon's head is immersed in the console (Randell et al., 2016). Further to this, the surgeon's ability to communicate via physical gesture and to successfully use deictic instructions is also reduced. Potential outcomes associated with these impacts include reduced coordination such as 'inadvertent adjustment, movement and complete removal of an instrument that is in use' and extended operation duration (Randell et al., 2016), which is associated with inefficiency and increased cost (Gillesie et al., 2012) . This data was used to develop two propositions that were explored in the interviews:

1. **Communication constrained:** The physical separation of the surgeon from the theatre team might make it difficult to communicate instructions, resulting in longer operation duration
2. **Coordination constrained:** The physical separation might make it difficult for the theatre team to monitor the surgeon's actions, impacting on coordination and resulting in longer operation duration

These propositions were presented to interview participants who recognised the constraints, and provided further detail of their impact, for example, surgeons reported that *'they can tell, but not show'* [Surgeon 2, Site 1] the first assistant (a role performed by an ODP or surgical trainee) who assists the surgeon with retraction of the tumour, what they want to achieve, and that *'no one notices if they are struggling'* when positioned at the console [Surgeon 3, Site 1]. A theatre nurse also explained:

> *'In a robot case, because they* [the surgeons] are somewhere in the corner and we hear them through a speaker and sometimes that doe*sn't even work very well, and* we always have to ask or repeat what he said just to be absolutely sure that *whatever we're going to do is the right thing'.* [Theatre nurse 1, Site 1]

Robotic surgery provides a microphone and speaker to facilitate oral communication. However, interview respondents reported that difficulties hearing the surgeon might persist because this technology is not always effective in overcoming difficulties in hearing that are caused by the separation. The theatre nurse reported that they repeated the surgeon's instructions before they act, which may extend the time it takes to complete collaborative activities.

The literature review also highlighted that robotic surgery impacts on the division of labour in the OT, as the surgeon is able to control more instruments that have increased freedom and movement, and the laparoscopic camera (Randell et al., 2016). This change results in a reduction of task load for the scrub practitioner (a role performed by a theatre nurse or ODP) who prepares and hands instruments to the surgeon in standard procedures, and the first assistant, who usually controls the laparoscopic camera; an ODP commented; *'the exchange of instruments is massively reduced because of the dexterity of the instruments'* [ODP, site 4]. Consequently, some participants described robotic surgery as '*monotonous'* and that *'there is a lot of standing around and staring at the TV'* [ODP, Site 3]. A surgeon provided some insight into the repercussions of this change:

> *'I'm the only one working and because I'm the only one working, everyone else's* attention gets distracted, including the assistant and they start chitting chatting *away and then occasionally I'll be sitting there with a tied suture waiting for them* to cut. *I look over and they're chatting away.'* [Surgeon, Site 7]

The changes in task load appeared to impact on the theatre team's engagement in the procedure and consequently their awareness, defined as the team's 'observation and awareness of ongoing processes' (Undre et al., 2007: p1375). This impact can potentially disrupt the progress of the procedure, as the team may be less responsive to the surgeon's need for assistance.

Unlike a typical realist evaluation that attempts to explain intervention effectiveness, we identified that the intervention (robotic surgery) changed the context in which surgery was performed, by physically reconfiguring the OT and redistributing the surgical task load, taking resources away from the theatre team. Analysis of the literature and interview data was used to construct conjectured CMO configurations, presented in Table 2. These CMO configurations explain how the changed context constrained the mechanisms (communication, coordination, awareness) usually at work, which could potentially disrupt the performance of collaborative activities (outcome). These disruptions provide a potential explanation for extended operation duration, an outcome identified in the starting proposition, and may also influence the ease with which surgery is performed in the context of the ROLARR trial.

Table 2: How teamwork mechanisms are constrained by changes in context introduced to the OT by robotic surgery?

Strategies to address constraints to teamwork

The literature review also surfaced strategies that could be used to enhance communication, such as the use of agreed terms and read-back, where requests are repeated by the recipient to ensure that the information has been transferred and received correctly (Randell et al., 2016). These specific strategies were not included in the interview schedule, but participants were asked in general terms whether they used strategies to address the constraints identified. In response, participants discussed a number of informal strategies that they used to perform teamwork during robotic surgery; these are discussed below.

Communication and coordination strategies

The CMO configuration regarding communication explained how the physical separation of the surgeon from the theatre team might constrain communication. However, the majority of sites initially had consultant surgeons working in pairs as they became familiar with the technology. One surgeon described how the use of two surgeons (one operating via the robot and one positioned at the patient table) enabled their team to overcome difficulties hearing caused by the physical separation, with one surgeon making ‘many trips’ [Surgeon 2, Site 4] between the patient table and the robot console i.e. acting as a liaison to ensure that information was transferred effectively between the two. In further discussion of this constraint a surgeon commented:

> *‘If you say, suction and suck the smoke* [smoke is sometimes generated when the diathermy is used to cut and cauterise], the nurse might look at the assistant say, who is he talking to? So I think you need clear instructions, who should be doing *what. I think that’s probably a skill on its own, sort of to say things a bit more clearly and then in a sort of crisp concise manner I think.’* [Surgeon 1, Site 6]

The surgeon suggests that, rather than difficulties hearing the instruction, as the proposition suggested, there may be confusion over to whom their request is directed when they are positioned at the console. To address this problem, they explicitly announce to whom they are talking and provide ‘clear’ instruction, which may include agreed terms. We referred to this strategy as ‘explicit instruction’, which was used by the surgeon to communicate with a recipient at the patient table. Informal use of the strategy read-back was also discussed; a theatre nurse described:

> *‘I would always say, scissors coming out, Maryland [dissection instrument]* going in, whatever, so they [the surgeon] *always knew loud and clear that we’ve* [the nurses] *not only heard them but we’re actually doing it.’* [Theatre Nurse 1, Site 5].

Robotic surgery enables the surgeon to control more instruments, but they are reliant on the scrub practitioner, at the patient table, to exchange these instruments when necessary. The potential constraint on teamwork here is not the ability to hear the surgeon, but that use of the console reduces the surgeon’s awareness of activities at the patient table, which could lead to complications if they attempt to move the robotic arms before the exchange is completed. Read-back provides a strategy to address this constraint on coordination, as the theatre nurse informs the surgeon that they have heard and are acting upon their instruction.

The idea that robotic surgery reduced the theatre teams ability to monitor the surgeon's actions (Table 1, no.2), was refuted by an ODP who explained, *'If all the theatre team are watching the [...] screens, they're watching exactly what the surgeon does in the same way as they would if it was ordinary laparoscopic surgery'* [ODP 1, Site 1]. Laparoscopic and robotic procedures both use a laparoscopic camera to view the operative site, which is displayed on a 2 dimensional (2D) screen in the OT. Hence, the theatre team can anticipate and prepare for upcoming events by monitoring the images displayed on the 2D screen. An anaesthetist discussed that they strategically positioned themselves during robotic surgery 'so I have a sort of line of sight of him [the surgeon] *and also I have my own [...] screen so that I can see what stage of the operation he's at.'* [Anaesthetist, Site 7] i.e. positioning enables the anaesthetist to access information on the 2D screen (to monitor the procedure), and the surgeon (to observe physical cues), both of which can be used to anticipate and prepare for upcoming events.

Strategies to maintain engagement in the procedure

Robotic surgery was found to take resources from the scrub practitioner and the first assistant with the potential to reduce these individuals' engagement in the procedure and consequently their awareness of ongoing processes. However, interviewees discussed how they maintained an active role during robotic surgery. A theatre nurse reported that learning to use the technology had maintained their engagement when robotic surgery was introduced at their hospital, and that teaching others prevents boredom now it is established in practice. However, without these aspects (learning or teaching) they are ‘falling asleep’ during robotic procedures [Theatre nurse, Site 6]. One surgeon reported using a strategy that incorporated a teaching element:

> ‘The way I deal with my assistant, I say, oh this is the plane you would cut so that *they're not looking away somewhere else chatting or something or someone, and* then you say, well this is the normal sort of thing you see, this is the m plane you would cut, so I explain the technique and then give them sort of tips on how they can do the operation when it comes to their turn.’ [Surgeon, Site 6]

The surgeon describes providing an educational commentary so that their first assistant would listen to the information and remain focused on the task at hand. An ODP also explained how and why they remained engaged during robotic procedures:

> ‘I think because of the knowledge and the experience *I’ve gained through doing* the work, I do engage more with the surgeon and try and not advise them but just *give them some more hints and tips, and almost you’re supporting them because they’re saying, you know, what do I think…nine times out of ten they’re* always right but by agreeing with them you know, they feel better.’ [ODP, Site 5]

The ODP reported that they were viewed as a trusted source of support for the surgeon and were consequently involved in their decision-making process, hence maintained an active role in the procedure, despite a reduced task load, and remained aware of on-going processes.

The strategies to support communication, coordination and maintain awareness were used in response to the contextual constraints to teamwork discussed in the previous section. Explanation of instances where these strategies were used successfully during robotic surgery could be used to inform guidelines for future implementers, a study objective. Therefore, we clarified our outcome of interest as the successful performance of collaborative activities, and prioritised exploration of how, why and in what circumstances the strategies worked (mechanisms and contexts) to perform collaborative activities safely and successfully (the outcome) in the remaining interviews. The CMO configurations regarding unintended outcomes were catalogued for discussion in the prioritisation stage.

Teamwork strategies: what works for whom, and in what circumstances?

The previous section described strategies that individuals report using to perform teamwork in the context of robotic surgery. To summarise, communication and coordination strategies were used to provide, or access, information, which the recipients of that information could use to progress the procedure, avoid complications and anticipate upcoming events. Strategies to maintain engagement in the procedure offered recipients an opportunity to have a more active role (teacher, learner or interaction) during the procedure so that they remain focused on the task at hand and aware of ongoing processes. Figure 4 summarises who used the strategies and their recipients.

Figure 4: Strategies used to perform teamwork during robotic surgery

Applying realist principles, we also sought to understand what circumstances supported successful use of these strategies. At this point in the theory elicitation process we understood that robotic surgery had changed the context in which teamwork was performed, which had prompted the use of these strategies and that some, such as read back and explicit instruction, assume that the surgeon and theatre team can hear each other. In these circumstances experience was also highlighted as an important contextual influence; when talking about the use of explicit instruction, a surgeon commented:

> ‘With the robot you're saying, okay, pick up X and move it in such a such a *direction, and they’re having to follow you and it’s down to their experience as to* how well they follow that instruction.’ [Surgeon 3, Site 2]

The experience of the first assistant appears to enable the recipient to correctly interpret and complete the surgeon’s request. The value of experience was supported in later discussion of an occasion where the surgeon had to scrub-in (put on gown and gloves) in order to assist an inexperienced assistant at the patient side i.e. when explicit instruction had not triggered mechanisms to successfully complete a collaborative task. Experience of participating in the procedure was also necessary for use of the coordination strategies; a surgeon discussed:

> *'It all comes down to experience as well. You know, if the scrub* [nurse] is *watching the operation and they can see it's getting to the point where you're going to have to divide a vessel and you're going to* need a different instrument they will have that ready.' [Surgeon, Site 1]

Experience of participating in the procedure provides the scrub practitioner with an understanding of how and when an implement will be used, which enables them to anticipate and prepare for the instrument exchange using the information displayed on the 2D screen. The ability to anticipate action was also valued in the first assistant, 'T*hey'll* [experienced first assistant] *notice that there's something they can do to help exposure* and they will make the operation easier.*'* [Surgeon 2, Site 3]. In this example, the surgeon discusses that an experienced first assistant can improve their view of the operating site without prompting, because they understand what the surgeon is trying to achieve from monitoring the 2D screen.

In regards to maintaining awareness, a surgical trainee explained that if the recipient had no interest in the educational commentary, 'if the surgeon is still talking to me you *wouldn't be more interested* [in the procedure]*'* [Surgical Trainee, Site 7], hence this strategy may only work in contexts where the first assistant is relatively inexperienced and still learning. However, a surgeon commented that '*some of that's* [engagement in the procedure] due to experienc*e of the assistant and how much they're actively trying to help'* [Surgeon 2, Site 3], suggesting that experienced first assistants 'actively' try to help the surgeon regardless of changes in their duties and responsibilities. Here we were unsure whether a to configure an experienced first assistant as the context or strategy. We decided on the latter, to remain in line with the previous CMO configurations constructed with the intention of developing our understanding of the role of experience in the next study stages. Our findings are summarised as CMO configurations in table 3.

Table 3: What works to maintain effective teamwork?

How CMO configurations were prioristised for testing

In total we identified ten conjectured CMO configurations regarding teamwork. Three explain how contextual constraints on teamwork mechanisms potentially lead to unintended outcomes, and seven explain how strategies might trigger teamwork mechanisms to perfom collaborative activities succesfully. Prioritisation of a subset of these conjectured CMO configurations was done in collaboration with the Study Steering

Committee (SSC), which included practitioners involved in implementing robotic surgery, and a patient panel.

The decision making process was first based on what outcomes were deemed most important to explain. A study objective was to inform guidance to support effecitve teamwork, therefore it was felt appropriate to focus on the theories concerning the teamwork strategies and succesful team performance. From these seven CMO configurations, communication was highlighted as important, as it is a signifcant predictor of deviation from expected length of operation duration (Gillespie et al., 2012). The choice to focus on the strategy 'explicit instruction' was made because the practitioners consulted deemed this strategy the most significant in enabling the first assistant and scrub practitioner to undertake their roles during robotic surgery. We also wanted to interrogate the role of experience as context or strategy; hence we priotised monitoring the 2D screen and interaction with the surgeon.

Discussion

Realist evaluation typically investigates how the resources offered by an intervention introduce opportunities that may be acted upon by individuals to improve an outcome of interest, or not, depending on the context (Pawson and Tilley, 1997). Robotic surgery offers the surgeon technological advances that may be used to facilitate their use of laparoscopic surgery. However, robotic surgery also physically reconfigures the OT and redistributes the surgical task load. Our investigation of teamwork in the OT revealed that these changes take resources, available in standard surgical procedures, away from other members of the theatre team, which may constrain the mechanisms usually used in teamwork, potentially leading to unintended surgical outcomes.

Individuals make choices to utilise, adapt or work around the resources offered to them by interventions, or the changes these resources may introduce to their environment (Rankin et al., 2014; Greenhalgh et al., 2004). Realist evaluation acknowledges and investigates these interactions: in the case of robotic surgery, interviewees reported adapting their practice using strategies, which drew upon new and existing resources, to perform collaborative activities safely and efficiently. The impact of robotic surgery on teamwork, therefore, appeared to unfold in a cumulative or ripple effect – where the outcomes from an initial set of CMO configurations (constrained team performance) influence the context of a 'second generation' of CMO configurations (Jagosh et al., 2015; Byng et al., 2005). In this study, the outcomes from our second generation of conjectured CMO configurations (successful performance of collaborative activities) provide a supportive context for the potential technical advances of robotic surgery to be realised in practice, thus linking our findings regarding teamwork to the ROLARR trial.

Surfacing realist mechanisms take understanding beyond intervention description into explanation (Pawson and Manzano-Santaella, 2012; Marchal et al., 2012). However, this concept has been interpreted and applied in various ways in previous realist studies. Recent guidance has attempted to clarify a definition and how mechanisms can be operationalised in practice (Dalkin et al., 2015). We drew on this guidance, attempting to distinguish resource from reasoning when eliciting realist mechanisms. Nevertheless we experienced challenges, perhaps because robotic surgery (the intervention) was intended to improve surgical outcomes rather than impact teamwork. The mechanisms we identified, therefore, were not triggered by the resources offered by robotic surgery, as such, but constrained by the changes in context it introduced, or triggered in this changed context using informal strategies. A useful step forward was to clarify the outcomes of interest as the successful performance of collaborative activities. This clarification enabled us to surface mechanisms that explain how and why collaborative activities were successfully performed during robotic surgery using strategies.

Context is also key in realist explanation; we tried to think of context as the pre-existing circumstances into which the intervention was inserted. However, as discussed, the intervention (robotic surgery) created and was constitute of a new context into which strategies were inserted to trigger mechanisms in response to the contextual changes. In these circumstances, experience (a pre-existing context) was highlighted as important in shaping the strategies success. This finding resonates with previous studies of teamwork in the OT where experience is documented as contributing to team performance, one reason being that it is thought to cultivate a shared frame of reference between team members of the tasks required and the teamwork needed to perform these tasks (Bezemer et al., 2011; Finn and Waring, 2006).

We configured experience as context; however, in some cases we were unclear whether experience would be better placed as the strategy that triggers teamwork mechanism in the changed context. Further to this, communication is also thought to be influenced by vertical hierarchal differences, role conflict and ambiguity and interpersonal power and conflicts (Sutcliffe, Lewton et al. 2004, Salas, King et al. 2012). These can be thought of as different layers of context that may be differentially changed by the introduction of robotic surgery. The findings presented in this paper represent the first stage of a realist evaluation, therefore the next study stages provide an opportunity to interrogate the role of experience and deepen our understanding of the impact of contextual influences. However, even at this stage, eliciting contexts and mechanisms have helped surface ‘critical details’ of the strategies (or interventions) success, which are necessary in high-risk environments, such as the OT, where ineffective use can have major consequences for patient safety (Rankin et al., 2014).

Our conjectured CMO configurations demonstrate how an intervention can both offer and take resources from individuals, which may necessitate adaptations (strategies) to optimise system performance. Challenges were experienced in constructing these configurations, as the intervention's intended outcomes were not the main focus of investigation. However, clarifying the outcomes of interest in this study enabled theory elicitation to move into explanation of how, why and in what circumstances teamwork was successfully performed in the context of robotic surgery. The conjectured CMO configurations prioritised for testing provide a theoretically informed basis to focus data collection and analysis in the next study stages. Once tested and refined they will be used to inform guidance to support successful teamwork practice during robotic surgery.

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