Title: **The impact of robotic assisted surgery on team performance: A systematic mixed studies review**

Manuscript type: Review

Word count manuscript: 3,400

Word count references: 1815

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PRÉCIS/SHORT ABSTRACT

This review describes the impact of robotic assisted surgery on team performance in the operating room. The addition of the robot alters team dynamics and potentially influences team members' ability to read and respond to adverse events. Unintended consequences of robotic technologies need to be identified and understood relative to team behaviour, performance, and safety.

KEY POINTS

- The presence of the robot changes the way information is distributed among team members, with much of the responsibility falling on the console surgeon to communicate critical information.
- In robotic-assisted surgery, there is a need for increased and deliberate communication, particularly when there is reduced visual access to information when using robotic equipment. Other challenges specifically related to robotic-assisted surgery include distance, obstacles, and physical barriers.
- An experienced surgeon who controls the information flow can compensate for an inexperienced team.
- Disruptions caused by changing equipment and personnel during the procedure can be minimised through standardisation of surgical steps and processes.

The impact of robotic assisted surgery on team performance: A systematic mixed studies review

ABSTRACT

Objective: To describe the impact of robotic assisted surgery on team performance in the operating room.

Background: The introduction of surgical robots has improved the technical performance of surgical procedures but has also contributed to unexpected interactions in surgical teams, leading to new types of errors.

Method: A systematic literature search of CINAHL, PubMed, ProQuest, Cochrane, Web of Science, PsycINFO and Scopus databases using key words and MeSH terms was conducted. Screening identified studies employing qualitative and quantitative methods published between January 2000 and September 2019. Two reviewers independently appraised the methodological quality of the articles using the *Mixed Methods Appraisal Tool* (2018). Discussions were held among authors to examine quality scores of the studies and emergent themes, and agreement was reached through consensus. Themes were derived using inductive content analysis.

Results: Combined searches identified 1065 citations. Of these, 19 articles, 16 quantitative and 3 qualitative, were included. Robotic-assisted surgeries included urology, gynaecology, cardiac, and general procedures involving surgeons, anaesthetists, nurses and technicians. Three themes emerged: *Negotiating the altered physical environs and adapting team communications to manage task and technology; Managing the robotic system to optimise workflow efficiency; and, Technical proficiency depends on experience, team familiarity, and case complexity.*

Conclusion: Inclusion of a robot as a team member adds further complexity to the work of surgery.

Application: These review findings will inform training programs specifically designed to optimise teamwork, workflow efficiency, and learning needs.

Key words: non-technical skills, ergonomics, operating room, workflow, patient safety.

Precis

This review describes the impact of robotic assisted surgery on team performance in the operating room. The addition of the robot alters team dynamics and potentially impacts on team members' ability to read and respond to adverse events. Unintended consequences of robotic technologies need to be identified and understood relative to team behaviour, performance, and safety.

Background

Robotic and laparoscopic techniques came into use around the same time. However, in the late 1990s, robotic technology allowed continuous input of the surgeon's actions to be translated into real-time movements (Bric et al., 2016; Cunningham & Cao, 2012). Robotic assisted surgery (RAS) is a complex intervention because it aims to produce change in the delivery and organisation of healthcare services, and includes several separate components that act both independently and interdependently (Campbell et al., 2000; Moore et al., 2012). These components are not only technological but are also social and organisational, and they may affect the successful integration of the robotic technology in surgical practice. The effective performance of the operation relies on collaboration among different professional groups including surgeons, anaesthetists, nursing staff, and ancillary personnel (Bric et al, 2016; Cunningham et al., 2013; Uslu et al., 2019). Throughout this process, a complex division of labour requires team members to use their skills collaboratively to accomplish a single, primary activity.

The dynamic and complex technical environment of surgery requires each team member to perform a multitude of tasks aligned to their individual expertise. Studies of team performance have suggested that preventable medical errors are related not only to technical performance, but also to interpersonal aspects of operating room (OR) team functioning and work practices (Campbell et al., 2000; Catchpole, 2011; Flin et al., 2008). This is especially critical in addressing the extended learning time and high error rates while adapting to the new technology or personnel in the OR (Gjeraa et al., 2016).

RAS, while safe, requires different skills. When compared with open and laparoscopic surgery, the duration of surgery is longer, team sizes are larger, the equipment

used is more complicated and visual coordination is essential (Gjeraa et al., 2016). These inherent differences heighten the imperative for increased vigilance, anticipation, and collaboration compared with open surgery (Zheng et al., 2015). Thus, the nuances surgical teamwork associated with RAS likely contributes to increasing cognitive load, causing stress, culminating in reducing team members' situational awareness. Arguably, the introduction of robotics-assisted technologies in surgery also increases the need for team training, although training programs need to be tailored to account for these discrete complexities (Graafland et al., 2015). In this systematic review, our objective was to determine the ways in which team communications and workflow efficiencies are influenced following the introduction of robotic technology. The findings of this review will inform further research and the design of training programs in this area that specifically address the nuances of RAS.

Review methods

Design

We chose a systematic mixed methods review as it is a broad research review approach that can guide the identification and integration of experimental and non-experimental research methodologies. In this systematic review, we followed the method described by Pluye and Hong (2014). The diversity and inclusivity of the method allows an in-depth understanding of the topic area; it nevertheless increases the complexity of data synthesis. To ensure a systematic and rigorous approach, we followed seven stages of conducting a mixed studies review (Pluye & Hong, 2014). Based on a priori criteria, this review is registered with PROSPERO. We used the *Preferred Reporting Items for Systematic Reviews and Meta-Analysis* (PRISMA: Moher et al., 2009) statement to report findings.

Stage 1: Formulate a Review Question

The objective of this mixed methods review was to describe the impact of RAS on teams' non-technical skills performance and workflow efficiencies. **Table 1** details the conceptual definitions based on the literatures in this area that we used to inform eligibility criteria and literature search strategies.

Table 1

Concepts/Constructs, Their Definitions and Exemplars from the Literature

Concept/construct	Definition	Example from literature
<p><i>Robotic-assisted surgery (RAS).</i> Systems listed below include:</p> <ul style="list-style-type: none"> • da Vinci Surgical System • da Vinci Si system • Senhance surgical robotic system • Sensei X Robotic Catheter System, • FreeHand 1.2, invendoscopy E200 system, Flex® Robotic System • Robotic Einstein • LaproTek • Zeus system 	<p>Surgical techniques using a robotic system to provide 3D magnified views of the surgical field using an endoscopic camera. The system includes multi-articulated instruments that provide the operator with greater dexterity, reduce tremor, and increase precise dissection. The surgeon is located away from the patient and other members of the surgical team, in an ergonomically comfortable position.</p>	<p>Blavier and Nyssen (2014), Randell et al. (2016), Scarpinata and Aly (2013)</p>
<p><i>Non-technical skills (NTS):</i></p> <ul style="list-style-type: none"> • Teamwork • Communication • Situational awareness • Leadership • Decision making • Coordination 	<p>NTS include the interpersonal (i.e., communication, leadership, teamwork) and cognitive (i.e., decision making, situational awareness).</p>	<p>Gillespie, Harbeck, Kang, Steel, Fairweather and Chaboyer (2017); Gillespie, Harbeck, Kang, Steel, Fairweather, Panuwatwanich, et al. (2017), McCulloch et al. (2009), Hull et al. (2012), Sevdalis et al. (2008)</p>

<i>Workflow efficiencies</i>	Work performance that results in cost reduction without compromising quality and productivity. In the OR context, efficiency measures focus on reductions in time and depend on minimising wasted and/or unused time to meet surgical targets.	NSW Agency for Clinical Innovation (2014), Healthcare Improvement Unit (2017)
<ul style="list-style-type: none"> • Room set up time • Operative time • Robotic arm positioning time • Robotic operative time • Turnover time 		

Stage 2: Define Eligibility Criteria

We considered studies published in English, including all procedures involving the use of RAS, and all members of the interprofessional team. Articles were excluded if they were not based on primary research data, were undertaken in other clinical contexts, were not inclusive of all professional groups, focussed exclusively on clinical or cost outcomes or articles that featured exclusively on other types of surgical technologies. **Table 2** details the inclusion and exclusion criteria we used to guide study selection for this review.

Table 2

Inclusion/Exclusion Criteria

No.	Criteria
1	<p>Included: Papers based on primary research (i.e., empirical data), including qualitative, quantitative and mixed methods research.</p> <p>Excluded: Quality improvement studies, research protocols, meta-analyses, systematic review and literature reviews, articles based on consensus or expert opinion and case studies.</p>
2	<p>Included: Studies undertaken during the intraoperative period of the perioperative journey.</p> <p>Excluded: Articles based on robotics and automation conducted in other acute specialty areas such as radiology, intensive care or emergency department.</p>
3	<p>Included: Articles that specifically focus on some aspect of team performance (e.g. non-technical skills, e.g., communication, teamwork, situational awareness), and/or clinical efficiencies, (e.g., case turnover times, procedural delays and interruptions, case set up time and length of procedure).</p> <p>Excluded: Articles that focus exclusively on cost and clinical outcomes (e.g., surgical complications, hospital readmission/return to surgery, 30-day mortality).</p>

- 4 **Included:** Articles that specifically focus on robotic surgery but may also include comparisons with other types of technologies.
Excluded: Articles that examine the impact of laparoscopic/minimally invasive surgery in the absence of a robotic element.

 - 5 **Included:** Articles that examine the impact of robotic surgery on *all* team members including nurses, surgeons, anaesthetists and ancillary team members.
Excluded: Studies that focus on the impact of robotic surgery from the perspective of only *one* or *two* disciplines and/or technical aspect of the work, e.g., surgical technique in using the robotic technology.
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Stage 3: Apply an Extensive Search Strategy

A systematic literature search in September 2019 was undertaken. The search period covered 1 January 2000 to 16 September 2019. Database searches using search terms and Medical Subject Headings (MeSH) were used to execute searches. Boolean connectors AND, OR and NOT were used to combine search terms. The databases used included; CINAHL (Cumulative Index to Nursing and Allied Health Literature; via EBSCOhost), PubMed (Medline), ProQuest central, Cochrane central, Web of Science, and Scopus databases. Search terms in article titles and abstracts included robotic surgery OR robotic surgical procedures OR robotic technologies AND communication OR teamwork OR team performance AND intraoperative OR surgical team OR human factors. As the Google Scholar database does not have similar Boolean operator functions, this was only used for retrieving information from the full text of an article when we could not identify its original source. We used criteria such as language and publication type to reduce the number of irrelevant records. Since computerised searches identify only 50% of eligible studies (Hopewell et al., 2007), ancestry searching and journal hand-searching of included articles were also conducted. With the assistance of a health librarian, one author undertook the literature searches. All database results were imported into an Endnote (v X9, Clarivate Analytics) reference manager program prior to screening of titles and abstracts.

Stages 4 and 5: Identify and Select Relevant Studies

We identified empirical studies about the use of robotics technologies in surgery based on quantitative, qualitative and mixed methodologies. Two review authors independently reviewed the titles and abstracts based on predetermined eligibility criteria. Once full texts were identified, articles meeting eligibility criteria were reviewed independently by the same two authors. Review authors held regular discussions and the lead author adjudicated over discrepancies. One review author extracted data using a table specially developed. Some of the included studies examined clinical outcomes related to patients; however, only data that answered the review objective were extracted. The lead author verified the extracted data directly from the results/findings as reported in the primary papers. Data extracted included author, year, country, aim, research design, sample, participants (nurses, surgeons, anaesthetists, adult and/or paediatric patients undergoing robotic surgery), and limitations.

Stage 6: Appraise Methodological Quality

Critical appraisal of the data was conducted by two independent reviewers using the *Mixed Methods Appraisal Tool* (MMAT, version 2018: Hong et al., 2018). We assessed articles against the MMAT criteria based on the chosen category. The latest version of the MMAT encourages a descriptive quality appraisal rather than a summative numerical score. Response options across all study categories include 'yes', 'no' and 'can't tell'. The 'can't tell' response indicates that there was insufficient information reported in the paper to answer

either 'yes' or 'no'. Rating 'can't tell' may also indicate the need to look for companion papers or contact the study authors for more information (Hong et al., 2018).

Stage 7: Thematic Analysis

Thematic synthesis as described by Thomas et al. (2004) was undertaken in three phases. Two authors independently analysed the textual data and immersed themselves in the data by reading and re-reading the 'results' and 'findings' section of each article. Next, line-by-line coding was used to identify similar words and concepts within and across studies. To ensure authenticity in the findings of included studies, inductive codes were compared and grouped based on their similarities and subsequently organised into 'descriptive' categories, and then development of higher order 'analytical' themes (Thomas et al., 2004). A data-based convergent qualitative synthesis design (Pluye & Hong, 2014) was used to transform quantitative and mixed methods studies into qualitative findings and were subsequently combined using a qualitative narrative synthesis. Review authors held regular meetings to discuss emergent subcategories and themes. All team members met to discuss themes across studies and decisions were based on consensus.

Rigour

We followed a systematic review process that is widely accepted (Pluye & Hong, 2014). A comprehensive systematic search strategy including detailed documentation of search decisions ensured accuracy of the data. Credibility of interpretation was maintained through recording memos about analysis decisions made during interpretation and participating in regular team meetings to discuss interpretation. Interpretive validity to

ensure representation of the primary researchers' interpretation maintained by having two reviewers independently extracting data and undertaking quality appraisal to avoid overstating of conclusions (Thomas et al., 2004). Transferability of synthesised findings was enacted using data extraction tables, allowing readers to judge the applicability of findings to their contexts.

Results

Our electronic database searches yielded 1065 documents after removal of duplicates. Of these, we considered 61 for full text screening, and 42 were excluded during data leaving 19 documents. The PRISMA (Moher et al., 2009) flow diagram (**Figure 1**) illustrates the complete selection process based on the database searches.

[insert Figure 1.]

Figure 1 *PRISMA Flow Diagram*

Table 3 details the characteristics of the 19 included studies, published between 2004 and 2019. Of these, 15 were published in the USA and 4 in Europe. Sixteen used quantitative methodologies based on structured observations (Ahmad et al., 2016; Allers et al., 2016; Catchpole et al., 2018; Catchpole et al., 2016; Dru et al., 2017; Jain et al., 2016; Sexton et al., 2018; Souders et al., 2019; Tiferes et al., 2019; Tiferes et al., 2016; Weber et al., 2018; Weigl et al., 2018), electronic health record (Schiff et al., 2016) and self-report survey (Allers et al., 2016; Schiff et al., 2016; Weber et al., 2018; Weigl et al., 2018) methods. One quantitative study was reported as a randomised controlled trial (Müller et al., 2018) while another used a case-control design (Sorensen et al., 2010). Three qualitative

studies (Cao & Taylor, 2004; Lai & Entin, 2005; Randell et al., 2015) used either observations or in-depth semi-structured interviews. Across observational studies, the number of robotic procedures ranged from 1 to 89 procedures. Fourteen studies (Ahmad et al., 2016; Allers et al., 2016; Almeras & Almeras, 2019; Cao & Taylor, 2004; Catchpole et al., 2018; Catchpole et al., 2016; Lai & Entin, 2005; Randell et al., 2015; Schiff et al., 2016; Sexton et al., 2018; Tiferes et al., 2019; Tiferes et al., 2016; Weber et al., 2018; Weigl et al., 2018) described the impact of robotic technologies on communication and teamwork performance in surgery, while 11 studies (Ahmad et al., 2016; Catchpole et al., 2016; Dru et al., 2017; Jain et al., 2016; Müller-Stich et al., 2007; Schiff et al., 2016; Sexton et al., 2018; Sorensen et al., 2010; Souders et al., 2019; Weber et al., 2018; Weigl et al., 2018) also described clinical efficiencies relative to set up and operative times, and workflow processes. Only three studies involved more than one type of surgery (Catchpole et al., 2018; Catchpole et al., 2016; Jain et al., 2016). Notably, 12 observational studies (either video-taped or coded) analysed data collected in three individual projects and represented surgeries conducted in three medical facilities (5 x Techno-Fields, 5 x Cedars-Sinai, 2 x Munich). Funding was reported in 15 studies, with the predominant sources being universities, foundations, government and research bodies.

Table 3*Characteristics of Quantitative Studies (n=16) and Qualitative Studies (n=3)*

Lead author (year) location	Design & sampling	Aim	Measures / interventions	Key findings
Ahmad <i>et al.</i> (2016) USA	<ul style="list-style-type: none"> Retrospective analysis of 10 recorded videos of RAS radical prostatectomies Tracked 3 surgeons, 3 surgical fellows, 11 circulating nurses, 7 scrub nurses, 3 physician assistants, 13 anaesthesiologists <i>Techno-Fields' Project 2013</i> 	Analyse ambulatory movements and team dynamics during RAS, and investigate congestion of the physical space	<ul style="list-style-type: none"> da Vinci system OR divided into 8 zones based on traffic areas, supplies and equipment Movements tracked: zones, duration, purpose Movements classified as avoidable (with improved setting) or unavoidable 	<ul style="list-style-type: none"> Mean ambulation time per procedure = 16%, mean 290 movements per procedure 31% of movements were procedure-related 50% of movements were avoidable and could be eliminated with improved OR setting
Allers <i>et al.</i> (2016) USA	<ul style="list-style-type: none"> Retrospective analysis of 10 recorded videos of RAS radical prostatectomies Tracked 3 surgeons, 3 surgical fellows, 12 circulating nurses, 7 scrub nurses, 3 physician assistants <i>Techno-Fields' Project 2013</i> 	Identify non-technical obstacles to optimal team performance during RAS	<ul style="list-style-type: none"> da Vinci system Questionnaires: 1) team familiarity; 2) NASA Task Load Index (NASA-TLX) Interruption: start, end, duration, surgery stage, personnel involved, and topic of interruption. Surgical flow Miscommunications and/or repetitions Unavoidable/ avoidable 	<ul style="list-style-type: none"> 252 interruptions (163 min) during 1848 min operative time On average, each case was interrupted 16 times Most interruptions related to Equipment/Technology (69%), followed by Supervision/ Training (37%), & other (19%): can be more than one topic per interruption 14% of interruptions potentially avoidable (46% of all interruption time), and associated with low team familiarity ($r = -0.63$, $p = .05$)

Almeras & Almeras (2019) France	<ul style="list-style-type: none"> • Questionnaire • Multiple sites • Convenience sample recruited by mail invitations addressed to surgeon operators (O), operator assistants (OA), and scrub nurses (SN) involved in robot-assisted surgery in surgical centres 	Evaluate the feelings and expectations of participants in robot-assisted laparoscopic surgery and specify potential modalities for improved interaction and cooperation	<ul style="list-style-type: none"> • da Vinci system • 32-item questionnaire assessing experience, training received, and aspects of communication during robotic surgery. 	<ul style="list-style-type: none"> • 69 responses, 130 invitations • 40 SN, 10 OA and 19 O. • Most SN & OA did not work with the same team (88 & 90%), O sig different (53%), $p = .002$ • OA vs SN/O more likely to rate communication as more difficult during robotic vs traditional surgery ($p = 0.02$) • Communication difficulties ascribed to: Surgeon 'total immersion' by OA & SN > O ($p = .002$); Remote telesurgery by OA > SN & O ($p = .045$); Environmental noise by OA & SN > O ($p = .019$) • Participants agreed: better communication would reduce interruptions; noisy personnel should be quietened by OA/SN; communication changes during training, but verbal control was useful; communication improves with experience; systematic descriptions useful.
Cao & Taylor (2004) USA	<ul style="list-style-type: none"> • Observational study using video and digital recordings • Single hospital site • 2 cholecystectomy procedures with the same surgeon, 1 conventional and 1 RAS • Videotapes annotated and verbal communication transcribed 	Examine changes in performance and communication patterns in the OR team with the introduction of a remote-master-slave surgical robot	<ul style="list-style-type: none"> • LaproTek robotic system • Time and motion analyses of surgical events were based on beginnings and endings of events 	<ul style="list-style-type: none"> • Surgeon required more and different type of information in RAS vs conventional • OR team relied heavily on verbal exchanges to coordinate the RAS procedure, more communication errors in RAS • RAS added complexity in the flow and sharing of information • Surgeon more responsible for distributing information during RAS vs conventional, increasing communication load on team • Increased multitasking for surgeon in RAS

Catchpole <i>et al.</i> (2018) USA	<ul style="list-style-type: none"> • Sub-analysis of Catchpole <i>et al.</i> (2016) data • Single hospital site • Convenience sample of 89 robotic-assisted surgeries: Urology, Gynaecology, Nephrology and Cardiac Surgery • <i>Cedars-Sinai project</i> 	Sub-classify the four most frequent FD categories in Catchpole <i>et al.</i> (2016) data to provide insight into system functions and problems across the various operative phases.	<ul style="list-style-type: none"> • da Vinci S & da Vinci Si systems • FD types: Communication, Coordination, Equipment, Training • FDs identified across 4 operative phases: <ol style="list-style-type: none"> 1. Pre-robot 2. Robot docking 3. Main surgical intervention 4. Procedure completion 	<ul style="list-style-type: none"> • 89 retrospective surgeries • 4229 total FDs: <ol style="list-style-type: none"> 1. Pre-robot: 339 (11.3%) 2. Robot docking: 406 (13.6%) 3. Main surgical: 1964 (65.4%) 4. Completion: FD (9.8%) • Co-ordination (890) and Equipment (880) FDs most frequent, then Training (700) and Communication (533) • Most Communication (72%), Equipment (76%), Training (70%) and Coordination (48%) FDs occurred in phase 3 • Repeating utterances = 60% of Communication FDs • Supplies retrieval most frequent Coordination FD (20-25%). Training support (15-17%) and Human error (13-14%) more frequent in phases 3/4 than 1/2. • Equipment FDs varied across phases: Unfamiliarity dominated phase 1 (33%), Visual Problems dominated phases 2, 3, 4 (33%, 31%, 29%) 89% of the Training-related FDs occurred in the 50 training cases (56% of the 89 cases studied). Instrument training highest in phase 1 (45%) compared to phases 2, 3, 4 (13%, 16%, 21%). Phase 2 dominated by Port Placement (29%) and Robotic Technical (32%) FDs. Procedure Specific training highest in phase 4 (46%), and phase 3 (27%).
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Catchpole <i>et al.</i> (2016) USA	<ul style="list-style-type: none"> • Direct observation study • Single hospital site • Convenience sample of 102 surgeries observed (urologic, gynaecology, and cardiac), 13 discarded due to incomplete data • <i>Cedars-Sinai project</i> 	Describe the duration of surgery and flow disruptions associated with RAS.	<ul style="list-style-type: none"> • da Vinci & da Vinci Si systems • Intraoperative duration • FD rates • FDs identified across four operative phases: <ol style="list-style-type: none"> 1. Pre-robot 2. Robot docking 3. Main surgical intervention 4. Procedure completion 	<ul style="list-style-type: none"> • 89 surgeries, 4229 FDs observed • Average phase 1 was 53.2 min (95 % CI 50.0–57.0), phase 2 was 20.7 min (95 % CI 17.6–23.9), phase 3 155.9 min (95 % CI 143.0–168.8) and phase 4 68.7 min (95 % CI 60.6–76.9). • Mean FD rates were higher in phases 2 (16.4 FD/h, 95 % CI 13.6–19.1) & 3 (13.4 FD/h, 95 % CI 12.1–14.7) with higher rates than phases 1 (5.58, 95 % CI 4.78–6.3) & 4 (3.47, 95 % CI 2.71–4.24). • Low rates of FDs associated with surgeons of high experience vs moderate or low exp. ($p < 0.001$)
Dru <i>et al.</i> (2017) USA	<ul style="list-style-type: none"> • Direct observation study • Single site • 34 RAS radical prostatectomies over a 20 week period • 6 urologists • <i>Cedars-Sinai project</i> 	Identify and quantify FDs during RAS prostatectomies and characterise barriers to robotic operating efficiency	<ul style="list-style-type: none"> • da Vinci & da Vinci Si systems • FDs identified across four operative phases: <ol style="list-style-type: none"> 1. Pre-robot 2. Robot docking 3. Main surgical intervention 4. Procedure completion • Physician experience (low, high) • Operative duration, FDs, FD rates, FD categories 	<ul style="list-style-type: none"> • Mean case duration 302 m ($SD=76$), mean 9.2 ($SD=3.7$) FDs/h • Highest FDs/h during robot docking phase 14.7 ($SD=4.3$) • Highest FDs/case were Coordination involving equipment (1.4), equipment malfunction (1.3), and communication breakdown (1.0) • High experience physicians ($n=3$) spent sig less time in phase 1 ($p=.028$) & phase 2 ($p=.003$) than low experience physicians ($n=3$); and had fewer FDs in phase 4 ($p=.038$) • More FDs in training cases ($p<.0001$) and in da Vinci Si vs S ($p=.002$), but no effect of training or robotic model on operative duration

Jain <i>et al.</i> (2016) USA	<ul style="list-style-type: none"> • Direct observation study • Single site • 32 RAS: 21 prostatectomies, 8 sacrocolpopexies, 3 nephrectomies over a 6 week period • <i>Cedars-Sinai project</i> 	Investigate the effects of resident involvement on RAS, as measured by FDs and operative duration.	<ul style="list-style-type: none"> • da Vinci & da Vinci Si systems • Presence of resident • FDs identified across four operative phases: <ol style="list-style-type: none"> 1. Pre-robot 2. Robot docking 3. Main surgical intervention 4. Procedure completion • Operative duration, FDs, FD rates 	<ul style="list-style-type: none"> • 32 RAS (146 h 52 m), 19 involved resident training • 1542 FDs; mean 48.2 per RAS (95% CI 28.6-54.8), 10.4 per hour (95% CI 8.55-12.31) • Resident comparison in prostatectomies only (21 cases) • Mean # FDs 60.8 (95% CI 47.8-73.8) with resident, 29.8 without (95% CI 22.1-37.4; $p=.0012$) • Mean FD rate 12.7 FDs/h with resident (95% CI 10.4-15.2), 7.0 without (95% CI 4.4-9.3) • Mean operative duration 285 m with resident (95% CI 263-306), 260 without (95% CI 229-291) • Sig longer duration for resident vs no resident, in Robot docking phase only ($p=.026$) • Each FD added 2.4 m to total operative duration, no sig effect of resident involvement
Lai & Entin (2005) USA	<ul style="list-style-type: none"> • In-depth interviews • Purposive sampling • 24 participants: 7 academic researchers, 4 developers. Also included 13 end users (8 surgeons, 2 anaesthesiologists, 2 nurses, one administrator). • Interviews conducted on an individual basis, face-to-face or telephone 	Describe the relationship between significant human factors and the integration of robotic and other computer-assisted technologies in future ORs.	<ul style="list-style-type: none"> • Researcher and data triangulation • Consensus approach to data coding / analysis 	<p>Role modifications in surgery:</p> <ul style="list-style-type: none"> • Nurses perceived RAS increased number & complexity of tasks including robot sterilisation, tool changes, communicating status, and patient protection • Surgeons have increased cognitive, perceptual, collaborative demands <p>Team coordination:</p> <ul style="list-style-type: none"> • Surgical teams must adapt & accommodate the robot (interactions,

				<p>decision-making, team coordination strategies, movements)</p> <ul style="list-style-type: none"> • Need to understand others' tasks to allow anticipation • Surgeon isolated, increased reliance on team, increased emphasis on explicit communication and predefined protocols
<p>Müller-Stich <i>et al.</i> (2007) Germany</p>	<ul style="list-style-type: none"> • Pilot RCT • Single hospital site • 52 patients screened, 12 excluded BMI >40kg/m² • Patients randomised to robot-assisted (RALF) or conventional (CLF) laparoscopic fundoplication groups 	<p>Compare surgical outcomes between robotic-assisted and conventional techniques.</p>	<ul style="list-style-type: none"> • da Vinci system • Total operative time • Effective operative time • Set-up time 	<ul style="list-style-type: none"> • Robotic-assisted surgery time was lower: RALF = 88 mins, CLF = 102 mins ($p = 0.033$) • Effective operative times were lower for RALF = 65 mins than CLF = 82 mins ($p = 0.006$) • Total setup times: RALF = 23 mins, CLF = 20 mins ($p = 0.050$)
<p>Randell <i>et al.</i> (2015) USA</p>	<ul style="list-style-type: none"> • Semi-structured, teacher-learner cycle interviews • Snowball sampling of personnel using robot for colorectal surgery • 9 English hospitals • 44 participants: 12 surgeons, 5 trainee surgeons, 1 manager, 6 anaesthesiologists, 13 OR nurses, 7 OR practitioners. • Interviews conducted face-to-face or telephone 	<p>Gather perspectives of OR personnel on how robotic surgery impacts surgeon decision making.</p>	<ul style="list-style-type: none"> • Literature review to generate 'theories' of how robotic surgery impacts surgeon decision making • Theories presented to interviewees for reflection on their own experience • Theories redefined through interview data • Framework analysis, matrix display of data • Consensus approach to data coding / analysis 	<ul style="list-style-type: none"> • Situation awareness (SA): Surgeons & team perceived reduction in surgeons' SA. SA increased through good communication and trust. • Lack of tactile information: Not a significant problem, visual cues. • Immersion: Robot produces sense of immersion for surgeons; increased concentration due to less experience, may reduce; isolation reduces distractions, enhances concentration. • Impact of ergonomics: Learning RAS increased stress; RAS physically less tiring but mentally more so. • Revised theories: In the context of a positive relationship between surgeon and team or experienced surgeon + good

communication or ergonomic console = complications avoided, increased concentration, reduced stress/tiredness, reduced conversion to open surgery.

Schiff <i>et al.</i> (2016) USA	<ul style="list-style-type: none"> • Questionnaire-based study using self-reported surveys and electronic health records • Single hospital site • 40 RAS performed • Convenience sample of 32 participants – surgeons, circulating nurses and surgical technicians – completed the survey at the end of each surgery 	Investigate the association between quality of communication in RAS and surgical outcomes.	<ul style="list-style-type: none"> • 13-item Composite quality of communication survey tool (cQOC) developed based on Safety Attitudes Questionnaire (SAQ) & psychometric testing of interpersonal communication skills questionnaire • da Vinci system • Collected data of patients' medical and surgical history, operative details and outcomes including operative times 	<ul style="list-style-type: none"> • 32 participants responded to survey 108 times across 40 cases: RR 60%, highest rate in circulating nurses (79%), lowest in fellows (41%) • Operative times: $M = 277.78\text{m}$ (92.9) • Poorer communication (cQOC) associated with longer operative time ($p = 0.045$) and cut-to-close time ($p = 0.045$) • Surgeons rated communication more poorly than nurses or technicians ($p < .001$) • Most common factors effecting communication: noise level 78%, microphone problems 64%, unfamiliarity with procedure 61% (% = yes/no responses for 36 surgeries)
Sexton <i>et al.</i> (2018) USA	<ul style="list-style-type: none"> • Prospective observational study of 12 RAS radical prostatectomies • Single hospital site • Convenience sample including 3 surgeons, 3 assistant surgeons, 11 circulating nurses, 7 scrub nurses, 3 physician assistants • <i>Techno-Fields' Project 2013</i> (data Nov2014 – Apr2015) 	Investigate how surgical teams' anticipation of each other's actions and needs as well as familiarity between team members impacts efficiency in RAS.	<ul style="list-style-type: none"> • Non-verbal requests • Anticipated requests and non-anticipated requests • Anticipated ratio (ratio of anticipated to total requests) • Request duration (mins) • Inconvenience/disruptions • Surgeon & Team NASA Task Load Index (NASA-TLX) 	<ul style="list-style-type: none"> • 1335 requests during 36 h (2147 m) of console time • On average, 111 requests per procedure, 37 anticipated and 18 associated with inconvenience. • Anticipated averaged 5 s to complete, non-anticipated 26 s • Higher surgeon task load associated with higher % of requests duration x surgery time ($r=0.70$, $p=0.02$), and higher anticipation ratio ($r=0.74$, $p=0.01$)

				<ul style="list-style-type: none"> • Higher familiarity associated with fewer inconveniences ($r=-0.67$, $p=0.02$) • More requests associated with longer operative time: $\beta=0.79$, $p<0.001$ • Higher anticipation ratio associated with shorter operative time: $\beta=0.44$, $p=0.01$
Sorensen <i>et al.</i> (2010) USA	<ul style="list-style-type: none"> • Case-control (1:2 ratio) comparative analysis between RAS and open surgery • Single hospital site • Consecutive sample of 50 children undergoing robotic-assisted laparoscopic (RAL) from Apr 2006 (20 month study) involving 4 surgeons (2 general, 2 urologic) 	Evaluate the introduction of robotic surgery in a paediatric cohort relative to operative efficiencies and surgical outcome complications.	<ul style="list-style-type: none"> • da Vinci system • Total operative time • Mechanical failures • Comparison data for ureteral reimplantation surgeries only (RAL cases = 13, open control = 26) • Open surgery data from a period preceding robotics cases 	<ul style="list-style-type: none"> • 5 RAL cases required conversion to open • Average operative time was 53% higher for RAL vs open (279 ± 82 vs. 162 ± 50 min, $p < 0.001$) • Surgical time for RAL averaged almost 2 h longer than open (279 ± 82 vs. 162 ± 50 min, $p < 0.001$) but had similar peripheral times (82 ± 17 vs. 73 ± 18 min, $p = 0.19$) • Bilateral repair added an average of 21 min in an open case but added an average of more than 2 hours for RAL cases. • Mechanical failures = 5 (10%)
Souders <i>et al.</i> (2019) USA	<ul style="list-style-type: none"> • Direct observation study • Single hospital site • 24 robotic-assisted abdominal sacrocolpopexies surgeries (RASCs) observed for flow disruptions (FDs) • Cedars-Sinai project 	Identify and characterise flow disruptions in RASCs to develop interventions to improve safety and efficiency	<ul style="list-style-type: none"> • da Vinci S & da Vinci Si systems • FDs identified across four operative phases: <ol style="list-style-type: none"> 1. Pre-robot 2. Robot docking 3. Main surgical intervention 4. Procedure completion 	<ul style="list-style-type: none"> • 1195 FDs, 49.8 per RASC ($SD=21.7$), 10.9 per hr ($SD=5.1$) • Most frequent were training (24%), equipment (20%), coordination-related (19%) • More FDs in Phase 2 vs P1 (M diff = 13.7, $p < .001$), vs P4 (M diff = 14.4, $p < .001$), vs P3 not reported

				<ul style="list-style-type: none"> • More FDs in Phase 3 vs P1 (M diff = 9.5, $p < .001$), vs 4 (M diff = 10.3, $p < .001$), no diff P1 vs P4 • Higher experienced surgeons had FD rate 1.8/h < low experience and were faster. Negative correlation between FD and length of surgery. • da Vinci S slower than Si • 22 trainee cases, increased surgery time in Phase 1 only (+40 m)
Tiferes <i>et al.</i> (2019) USA	<ul style="list-style-type: none"> • Observational study consisting of 11 RAS radical prostatectomies • Main 'triad' = 1 surgeon, 1 scrub nurse, 1 PA • Single hospital site • <i>Techno-Fields' Project 2013</i> 	To characterise team verbal and nonverbal interactions, thereby increasing knowledge of how teams communicate during RAS.	<ul style="list-style-type: none"> • Da Vinci Si • Modality (verbal/nonverbal communication) • Topic • Pair (sender/receiver) 	<ul style="list-style-type: none"> • 11 cases: 13,873 unique interaction events (41% verbal and 59% verbal) over 37.1 console hrs. • 9300 events between surgeon & PA (S-PA), 3639 between PA and scrub nurse (PA-SN), 934 between surgeon and SN (S-SN) • Verbal vs nonverbal interactions differed by pairs ($p < 0.001$): S-PA verbal 34%, PA-SN 50%, S-SN verbal 75%. • Topics differed by pairs: S-PA procedural, S-SN technology-related, PA-SN mixed. • Higher familiarity between pairs was associated with less explicit instructions for only S-SN pair, not for S-PA or PA-SN.
Tiferes <i>et al.</i> (2016) USA	<ul style="list-style-type: none"> • Single sample case study as pilot test • Video analysis techniques to observe surgical workflow & communication during RAS • 1 RAS radical prostatectomy 	<p>Design a methodology to allow analysis of team activity during RAS.</p> <p>Determine feasibility of the methodology, by evaluating a single surgical procedure in</p>	<ul style="list-style-type: none"> • da Vinci system • OR divided into 8 zones based on traffic areas, supplies and equipment • Movements tracked: zones, duration, personnel, pathway, 	<ul style="list-style-type: none"> • Console time 132 m • Communication: 35 m (27%). Mostly surgeon/PA (22 min; 62%), followed by PA/nurse (7min, 21%), and nurse/surgeon (5 min, 14%).

	<ul style="list-style-type: none"> • Surgical triad: 1 console surgeon, 1 PA, and 1 scrub nurse • <i>Techno-Fields' Project 2013</i> 	communication events, physical movements, and procedural interruptions.	<p>purpose, avoidable/unavoidable</p> <ul style="list-style-type: none"> • Interruptions (instances when console activity halted) tracked: duration, personnel, cause, mode of communication • Pilot procedure communication tracked: information flow, mode (verbal vs. nonverbal), topic 	<ul style="list-style-type: none"> • Ambulatory movements related to: procedure 24%, technology 23%, communication 21%, layout 12%, miscellaneous 20%. Approx 50% avoidable. • Communication between surgeon & PA procedural: surgeon-PA 48% not-verbal, 37% verbal, 15% mixed; PA-surgeon 91% non-verbal. • Communication between PA & nurse mostly procedural; PA-nurse 32% verbal, 42% non-verbal, 26% mixed. Nurse-PA 31% verbal, 41% non-verbal, 28% mixed. • Communication between surgeon & nurse mostly technology-related, mostly verbal from surgeon (87%) and non-verbal from nurse (69%). • Interruptions: 28 (421 s), 11 procedural, 7 technology, 10 training.
<p>Weber <i>et al.</i> (2018) Germany</p>	<ul style="list-style-type: none"> • Prospective multi-method design • Structured observations • 40 prostatectomies conducted in one large German hospital • 239 surgeons, nurses, anaesthetists observed & surveyed • <i>Munich study</i> 	Identify different types and severity of workflow disruptions (FDs) during robotic surgery cases	<ul style="list-style-type: none"> • da Vinci Si robot • One observer coded workflow disruptions relative to communication, coordination, visitors to the OR, phone calls, training, equipment, environment, procedure, instruments, surgeon decision making & patient factors • Each distraction rated for its severity of interference (1-9) • Surgery Task Load Index (SURGTLX) survey completed by OR personnel after procedure 	<ul style="list-style-type: none"> • 2285 FDs, average 15.8 per hour • Highest proportion of FDs due to personnel entering & exiting OR (20%: n = 456), followed by case-irrelevant communication (14%, n = 308), procedural (13%, n = 287) • Equipment FDs were the most severe (range 5.44-6.95) • Survey response rate 90% (216/239) • Anaesthetists reported highest mental demands compared to surgeons ($p < .001$) and nurses ($p = .011$) & more distractions than surgeons ($p < .001$)

Weigl <i>et al.</i> (2018) Germany	<ul style="list-style-type: none"> • Multi-methods observational study • 40 prostatectomies conducted in one large German hospital at one large hospital in Germany • Structured observations and survey • Convenience sample of surgeons, anaesthetists and nurses • <i>Munich study</i> 	Identify type and severity of flow disruptions (FDs) and measure impact of FDs on perceptions of intraoperative teamwork	<ul style="list-style-type: none"> • Da Vinci Si robot • Surgical Flow Disruption Source & Severity tool • Intraoperative Teamwork survey • Procedure divided into 3 phases: P1 prerobot, P2 robot docking, P3 console time. • Patient data 	<ul style="list-style-type: none"> • Severity of equipment FDs assoc with higher mental demands for nurses and anaesthetists ($p<.05$) • Higher severities assoc with increased distractions ratings by the OR team ($r=.34$, $p=.030$) <p>Sources of FD:</p> <ul style="list-style-type: none"> • 2012 FDs observed, with a mean rate of 16.27 ± 2.19 per hour (95% CI 15.57, 16.97) • FDs varied across phases: P1 = external 29%, communication 28%; P2 = coordination 32%, external 30%, communication 22%, P3 = external 30%, communication 22% • 607 (30.2%) evaluated as high impact FDs, highest proportion during P2 37% (P1 26% & P3 30%) • High impact FDs due to: P1 mostly communication (46%) & coordination issues (29%); P2 mostly coordination (52%) & communication issues(28%); P 3 mostly communication (28%) & equipment problems (23%).
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Note: RAS = robot-assisted surgery; OR = operating room; FD = flow disruption, SA = situation awareness

Quality Assessment

Table 4 shows the quality assessments of each study against MMAT (Hong et al., 2018) quantitative (descriptive, RCT) and qualitative criteria. Agreement between raters was high, demonstrating excellent reliability (ICC = .945, 95% CI .831 – .983, $p < 0.0001$). Overall, the methodological quality of studies varied. Among all included studies, there were inherent methodological limitations. Most included studies were single site, therefore the ability to generalise beyond the study setting is limited. All studies, except for one (Müller-Stich et al., 2007), were descriptive with no comparators to act as referents. Further, most studies used observational methods, which may have given rise to performance bias (i.e., Hawthorne effect). A common limitation among the quantitative studies was the limited explanation about operationalisation of the variables used to define the measures used (Müller-Stich et al., 2007; Sorensen et al., 2010). The types of surgeries observed in individual studies were homogeneous; however, most included studies used convenience sampling (Allers et al., 2016; Almeras & Almeras; 2019; Catchpole et al., 2018; Catchpole et al., 2016; Dru et al, 2017; Jain et al, 2016; Sexton et al., 2018; Schiff et al, 2016; Souder et al, 2019; Tiferes et al., 2019; Tiferes et al., 2016; Weigl et al, 2018). In the three qualitative studies, there was variation in data collection methods (i.e., face-to-face, telephone). Additionally, the lack of a reproducible audit trail and reflexivity were notable omissions (Cao & Taylor, 2004; Lai & Entin, 2005; Randell et al., 2015).

Table 4*Quality Assessment of Included Studies Using the MMAT Criteria*

Quantitative Descriptive	Is the sampling strategy relevant to address the RQs?	Is the sample representative of the target population?	Are the measurements appropriate?	Is the risk of nonresponse bias low?	Is the statistical analysis appropriate to answer the RQ?	Limitations
Ahmad et al., 2016	Y	CT	Y	CT	Y	<ul style="list-style-type: none"> • Possible selection bias of surgical cases, sampling selection not reported • Retrospective data from single hospital site • Small sample, single surgery type • Video blind spots resulted in some loss of tracking data
Allers et al., 2016	Y	CT	Y	CT	Y	<ul style="list-style-type: none"> • Possible selection bias of surgical cases, sampling selection not reported • Single hospital site, single surgery type • Small sample • Interruptions may have been missed due to technical disruptions or when taping ceased as non-consenting staff entered OR
Almeras & Almeras, 2019	Y	N	Y	N	Y	<ul style="list-style-type: none"> • Convenience sampling, possible selection bias • 53% response rate; 58% nurses, 27.5% surgeons, 14.5% assistants; 130 surveys posted, response rate not stratified by professional category
Catchpole et al., 2018	Y	CT	Y	Y	Y	<ul style="list-style-type: none"> • Retrospective data from single hospital site • Possible variability amongst observers • FD standards not specified

Catchpole et al., 2016	Y	CT	Y	Y	Y	<ul style="list-style-type: none"> • Single hospital site • Possible Hawthorne Effect • Possible variability among observers
Dru et al., 2017	Y	CT	Y	Y	Y	<ul style="list-style-type: none"> • Single hospital site, single surgery type • Possible Hawthorne Effect • Possible variability among observers
Jain et al., 2016	Y	CT	Y	Y	Y	<ul style="list-style-type: none"> • Number of prostatectomy cases with/without residents that were used in comparison analysis not reported • Imbalances in data; no nephrectomies involved residents, all sacrocolpopexies involved residents • Single hospital site • Possible Hawthorne effect
Schiff et al. 2016	Y	N	Y	N	Y	<ul style="list-style-type: none"> • 60% response rate, lower rate for fellows 41%, higher rate for nurses 79%) • Convenience sample, selection bias • Single hospital site, small sample
Sexton et al. 2018	Y	N	Y	Y	Y	<ul style="list-style-type: none"> • Single hospital site, single surgery type • Possible variability amongst observers • Small sample
Sounders et al., 2019	Y	CT	Y	Y	Y	<ul style="list-style-type: none"> • Only 2 high experienced surgeons vs 22 low, low power for experience analysis • 22/24 were training cases, possible confound • Single hospital site, single surgery type • Small sample
Tiferes et al., 2016	Y	CT	Y	Y	Y	<ul style="list-style-type: none"> • Single sample case study as pilot test • Video blind spots resulted in some loss of tracking data • Possible Hawthorne effect

Tiferes et al., 2019	Y	CT	Y	CT	Y	<ul style="list-style-type: none"> Possible selection bias of surgical cases, sampling election not reported Single hospital site, single surgery type Small sample
Weber et al., 2018	Y	CT	Y	Y	Y	<ul style="list-style-type: none"> Potential performance, observer and recall biases Single hospital site, single surgery type Did not control for variability in experience in using robotic technologies or team familiarity which may decrease interruption rates
Weigl et al., 2018	Y	CT	Y	Y	Y	<ul style="list-style-type: none"> Single hospital site, single surgery type Variability in experience in using robotic technologies or team familiarity not controlled for.
Quantitative RCT	Is randomisation appropriately performed?	Are the groups comparable at baseline?	Are there complete outcome data?	Are outcome assessors blinded to the intervention provided?	Did the participants adhere to the assigned intervention?	Limitations
Muller-Stich et al., 2007	CT	Y	Y	N	Y	<ul style="list-style-type: none"> Single hospital site, single surgery type Randomisation process not explained Single-blinded RCT – patients were blinded, but clinicians were not Possible performance bias
Quantitative Non-randomised Controlled trial	Are the participants representative of the target population?	Are measurements appropriate regarding both the outcome and exposure/intervention?	Are there complete outcome data?	Are the confounders accounted for in the design and analysis?	During the study period, is the intervention/exposure administered as intended?	Limitations

Sorensen et al., 2010	Y	Y	Y	Y	Y	<ul style="list-style-type: none"> • Surgical selection not randomised, based on surgeons' preference • Confound related to surgeons' experience, compared new operative technique to established technique • Single hospital site, single surgery type
Qualitative Descriptive	Is the approach appropriate to answer the RQ?	Are the data collection methods adequate to address the RQ?	Are the findings adequately derived from the data?	Is the interpretation of results sufficiently substantiated by data?	Is there coherence between data sources, collection, analysis, and interpretation?	Limitations
Cao & Taylor, 2004	Y	Y	CT	CT	CT	<ul style="list-style-type: none"> • Only 2 case comparisons • Audit trail of study processes unclear • Impacts of team unfamiliarity and RAS a new technology for OR staff difficult to ascertain
Lai & Entin, 2005	Y	Y	CT	CT	CT	<ul style="list-style-type: none"> • Over representation of some professional groups (surgeons) within the sample and under representation of other groups (nurses and anaesthesiologists) • Variation in methods of interview – either telephone or in-person
Randell et al., 2015	Y	Y	CT	CT	CT	<ul style="list-style-type: none"> • Specific focus on single surgical procedure type • No description of participants' RAS experience • Variation in methods of interview – either telephone or in-person

Note. RQ = Research question; RAS = robot-assisted surgery; FD = flow disruption; CT = Can't tell

Thematic Synthesis

Inductive analysis of the textual data derived from the 'Results' and 'Discussion' sections of the 19 studies revealed three themes: *Negotiating the altered physical environs and adapting team communications to manage task and technology*; *Managing the robotic system to optimise workflow efficiency*; and, *Technical proficiency depends on experience, team familiarity, and case complexity*. Each theme, while distinct, was not mutually exclusive, and overlapped with the others. **Table 5** details three themes, their associated categories, and the contributing studies. The following section presents a narrative analysis of the review findings.

Table 5

Themes and their supporting categories, and contributing studies

Theme	Category	Contributing studies
Negotiating the altered physical environs and adapting team communications to manage task and technology	<ul style="list-style-type: none"> • Understanding task and technology • Adapting to ergonomic and spatial constraints • Managing noise and interruptions • Protecting the patient • Flow of information, shared access 	Ahmad et al. (2016); Allers et al. (2016); Almeras and Almeras (2019); Catchpole et al. (2018); Randell et al. (2015); Sexton et al. (2018); Tiferes et al. (2019); Tiferes et al. (2016); Weber et al. (2018); Cao and Taylor (2004); Lai and Entin (2005); Schiff et al. (2016); Weigl et al. (2018)
Managing the robotic system to optimise workflow efficiency	<ul style="list-style-type: none"> • Having the right people, at the right place, at the right time • Equipment and procedural delays • Changes in personnel • Avoidable and unavoidable movements • Docking the robot 	Ahmad et al. (2016); Allers et al. (2016); Almeras and Almeras (2019); Catchpole et al. (2018); Catchpole et al. (2016); Dru et al. (2017); Jain et al. (2016); Müller-Stich et al. (2007); Schiff et al. (2016); Sexton et al. (2018); Souders et al. (2019); Sorensen et al. (2010); Tiferes et al. (2016); Tiferes et al. (2019); Weber et al.

(2018); Weigl et al. (2018); Cao and Taylor (2004); Lai and Entin (2005)

Technical proficiency depends on experience, team familiarity, and case complexity

- Prolonging length of surgery
- Patient acuity and anatomy
- Team experience and training
- Procedural familiarity
- Supporting and teaching

Allers et al. (2016); Catchpole et al. (2018); Catchpole et al. (2016); Dru et al. (2017); Jain et al. (2016); Schiff et al. (2016); Sexton et al. (2018); Souders et al. (2019); Tiferes et al. (2019)

Negotiating the Altered Physical Environs and Adapting Team Communications to Manage

Task and Technology

This theme, supported by five categories, described environmental factors associated with ergonomics, increased cognitive load, and noise and distractions, imposed by the presence of the robotic system. The room layout, including positioning of furniture, screens and equipment altered workflow (Ahmad et al., 2016; Allers et al., 2016), with team members having to adapt to the separation of the operating surgeon, who was physically “immersed” in the surgery (Almeras & Almeras, 2019; Randell et al., 2015), isolated from the team, away from the patient’s side and seated at a console (Almeras & Almeras, 2019; Cao & Taylor, 2004; Lai & Entin, 2005; Randell et al., 2015). Circulating and instrument nurses relied on the deliberate and purposeful procedure-specific communications between the console surgeon and their assistant who was positioned at the operating table (Cao & Taylor, 2004; Catchpole et al., 2018; Lai & Entin, 2005; Tiferes et al., 2019). There were vast disparities in the type of information required by team members to complete the procedure (Cao & Taylor, 2004; Tiferes et al., 2019). Flow disruptions related to communication processes impeded surgical progress, with three studies (Catchpole et al., 2018; Weber et al., 2018; Schiff et al., 2016) describing associations between the quality of communication

and duration of surgery. Sexton et al. (2018) reported 1335 requests during 36 hours of console time, while Catchpole et al. (2018) described the impact of miscommunications on length of procedure, with increased repetitions occurring on average 3 to 4 times per procedure.

Depending on the phase of the procedure, RAS teams combined verbal and non-verbal cues, and different roles (e.g., console surgeon, anaesthetist, circulating nurse) used different communication strategies (Lai & Entin, 2005; Tiferes et al., 2019). Surgical flow disruptions relative to communication, coordination, and noise had variable impacts on the progress and length of surgical procedures (Ahmad et al., 2016; Catchpole et al., 2018; Schiff et al., 2016; Sexton et al., 2018; Tiferes et al., 2019; Tiferes et al., 2016; Weber et al., 2018; Weigl et al., 2018). For example, the number of disruptions observed in each study varied, ranging from 28 (Tifferes et al., 2016) to 4,229 (Allers et al., 2016; Catchpole et al., 2018; Catchpole et al., 2016) and averaging around 16 per hour (Weber et al., 2018; Catchpole et al., 2018; Weigl et al., 2017). The presence of the robot also increased the need to protect the patient relative to positioning, ensuring the risk of pressure injuries was minimised, and maintaining airway integrity during anaesthesia (Cao & Taylor, 2004; Lai & Entin, 2005).

Managing the Robotic System to Optimise Workflow Efficiency

This theme encompassed five categories, describing the impact of the robotic system on coordination of clinical activities and workflow processes. In RAS, work processes cover four phases; prerobot, docking, console time, and undocking (Catchpole et al., 2018; Catchpole et al., 2016; Dru et al., 2017; Jain et al., 2016; Weigl et al., 2018). Nine studies (Allers et al., 2016; Cao & Taylor, 2004; Catchpole et al., 2018; Catchpole et al., 2016; Lai & Entin, 2005; Souders et al., 2019; Tiferes et al., 2019; Weber et al., 2018; Weigl et al., 2018)

described the different ways in which a robotic system disrupts or prolongs existing work processes. For instance, Catchpole et al. (2018) observed that waiting on staff to complete a task associated with docking the robot accounted for 10% of coordination disruptions, occurring at least once per procedure. Coordination of team activities associated with task, technology and teamwork processes requires 'the right people, the right equipment, at the right place and the right time' (Catchpole et al., 2018). Thus, team members had to learn how their tasks related to those of others, and how this relatedness affects overall team performance and efficiency (Almeras & Almeras, 2019; Cao & Taylor, 2004; Catchpole et al., 2016; Lai & Entin, 2005). Instrument changes, equipment-related problems and ambulatory movements over the four phases varied, reflected different procedural tasks undertaken over the course of the surgery (Ahmad et al., 2016; Allers et al., 2016; Catchpole et al., 2018; Catchpole et al., 2016; Dru et al., 2017; Souders et al., 2019; Weber et al., 2018; Weigl et al., 2018).

Procedural delays were attributed to breaking sutures from over-tension due to limited tactile information, problems with a robotic arm, a lack of awareness of its location relative to the position of other team members or equipment and fogging or blood on the camera (Allers et al., 2016; Catchpole et al., 2018; Catchpole et al., 2016). In some cases, the impacts of procedural delays were quantified: Allers *et al.* (2016) observed that of 252 interruptions, 69% were related to equipment/technology. Several studies (Allers et al., 2016; Catchpole et al., 2018; Weigl et al., 2018) described procedural delays because of the need to frequently leave the theatre to fetch sterile supplies/equipment, which in one study accounted for up to 25% of all workflow disruptions (Catchpole et al., 2018).

Technical Proficiency Depends on Experience, Team Familiarity, and Case Complexity

This theme included five categories describing team and patient related factors that influenced technical proficiency in performing RAS. Several studies described the salience of the physician's robotic experience and team familiarity in minimising the impact of flow disruptions and length of procedure (Dru et al., 2017; Jain et al., 2016; Sexton et al., 2018; Souders et al., 2019; Tiferes et al., 2019). The effects of limited team and procedural familiarity often culminated in repeated utterances, missed information and case-irrelevant communications. Surgeons' level of robotic experience and time needed to train junior doctors had variable impacts on flow disruptions and length of surgery (Dru et al., 2017; Jain et al., 2016; Souders et al., 2019). At the console, the operating surgeon creates synergy between the visual information and the motions carried out by the hands, and haptics (i.e., receiving tactile information), increasing the surgeon's cognitive load (Catchpole et al., 2018; Sexton et al., 2018; Tiferes et al., 2019). Nonetheless, surgeons necessarily made adaptations to compensate for altered ergonomics and the lack of team familiarity (Allers et al., 2016; Catchpole et al., 2018; Catchpole et al., 2016; Tiferes et al., 2016; Weigl et al., 2018). In several review studies (Dru et al., 2017; Jain et al., 2016; Souders et al., 2019), patient related factors such as age, BMI and ASA had limited effect on overall procedural performance and length of procedure.

Discussion

This mixed methods systematic review presented a thematic synthesis of the findings of 19 studies. The review findings highlight the challenges surgical teams face in adapting to robotic technologies. Clearly, the presence of the robot changes the way

information is distributed among team members, with much of the responsibility falling on the console surgeon to communicate critical information. Surgeons make adaptations while at the console to compensate for altered ergonomics and the lack of team familiarity (Allers et al., 2016; Catchpole et al., 2018; Catchpole et al., 2016; Tiferes et al., 2016; Weigl et al., 2018). Nevertheless, a more experienced assistant surgeon functions as a communication “bridge” between the console surgeon and the rest of the team, negating the effect of physical separation and decreasing the risk of surgical flow disruptions. Additionally, properly placed viewing screens enhance visual access throughout the entire procedure and increase shared situational awareness (SA). However, team members (e.g., instrument nurses) sometimes have limited viewing access because of the stage of the procedure and where they are positioned (Ahmad et al., 2016). Often, the console surgeon assumes that everyone can see what they see as it is shown on the screens but this is not always the case. Consequently, this influences the extent to which team members develop and maintain shared SA.

There is evidence that deficits in SA are associated with misinterpretation and miscommunication leading to surgical errors (Mishra et al., 2008; Rogers et al., 2006). SA occurs on both individual and team levels, together creating a shared SA. Factors such as perceptions, understanding one’s own limitations, team collaboration, mutual trust and communication influence SA and thus the assessment of risk and decision-making (Endsley, 1995). In RAS, surgeons’ perception of the full situation is restricted. Team members around the patient are the ‘eyes’ of the console surgeon and have greater awareness of what is happening in the broader physical environment. This includes the position of the patient, and the activities occurring around the patient and in the room. Clearly, the quality and timing of case-related communication can either hasten or impede the progress of an

operation (Freischlag, 2012) and influence the safety of the patient. Team members need to communicate in a detailed and explicit way, making decisions about what is necessary to communicate to the surgeon, and *when* to communicate this information and vice versa. An experienced team around the patient is more likely to be able to judge what information to communicate, and when. An inexperienced team around the patient to some extent can be balanced by an experienced surgeon who can control the information flow by being more active in asking the team for continuous updates. This differs from conventional laparoscopic surgery when all team members are close to the patient and have an immediate awareness of what is going on around them (Mathew et al., 2018).

The findings of this review highlight the salience of using standardised workflow processes in the execution of all phases of RAS to maximise clinical efficiency. Earlier experimental research in the use of automation in surgery suggests that repeated disruptions in workflow distract team members, diverting their attention to a secondary activity thus reducing their ability to respond to the primary task (Manzey et al., 2011). Some suggest that minimising disruptions caused by changing equipment and personnel during the procedure can be achieved through training team members to standardise moments during robotic surgery (Mathew et al., 2018; van der Vliet et al., 2019). For example, standardising the positioning of the robot when not docked to the patient, and placing surgical equipment in relation to the robot (Ng et al., 2019). Standardisation increases team members' ability to work fast in emergency situations when the robot needs to be removed quickly, such as conversion to open surgery. Standardisation will also, to some extent, make up for lack of experience in the team as a standardised procedure is easier and quicker to master. Arguably, this will not only increase efficiency, it will also increase patient safety during the procedure.

Some surgeons estimate the learning curve to perform procedures in RAS without the need for potential backup is between 20 to 40 surgeries, depending on the procedure. However, even with improved oncological and functional results, the learning curve for the console surgeon may be up to several hundred cases (Lim, 2010, 2013; Zhu et al., 2018). The learning curve for the rest of the surgical team encompasses the technology itself, mastering a new vocabulary to communicate, and adjusting to new tasks and responsibilities (Randell et al., 2016). Yet, in contrast to the literature on surgeons' learning curve when introducing new surgical methods and techniques (Palagonia et al., 2019), there is a paucity of research on learning curve at a team level. Although many factors affect the duration of an operation, interprofessional miscommunication is a significant predictor of deviation from expected length of operation (Gillespie et al., 2012).

The introduction of RAS increases the demand for multitasking as well as technical and instrumental knowledge. Moreover, physical distances among team members dramatically changes the structure of the task and mode of cooperation, particularly between the surgeon and their first assistant, who becomes less part of the procedure and whose tasks become more of a supportive nature (Nyssen & Blavier, 2010). For other team members, there is an increased sense of responsibility due to the level of task difficulty and the imperative to protect the patient (Lai & Entin, 2005). When the rest of the team is more experienced in RAS, they understand that the surgeon's SA is dependent on them orally communicating information about the patient's condition and vice versa. Graafland et al. (2015) highlight the lack of SA training in surgical curricula and the need to implement and evaluate SA training programs on team level, suggesting that training strategies from other areas such as aviation, could be tested.

Limitations

There are several limitations to this systematic review: First, as the review includes only research articles written in English, it may be subject to language bias. Second, although we carried out comprehensive searches based on a rigorous search strategy, some articles may have been missed. Third, in terms of the included studies, no review is better than the included studies: Most studies were single site, and 12 articles drew on the same data sets. Arguably, this may call into question the independence of these 12 studies. Yet these studies had different research aims, and focussed on specific types of surgeries (e.g., urology) and personnel (e.g., surgical residents), so their results were sufficiently different. We acknowledge that generalisability of the findings may be limited due to the paucity of independent data available at this time. Fourth, given the narrow focus of these studies, the development of themes that emerged during qualitative analysis may have been constrained by the results of these studies. Therefore, conceptual transference of thematic findings may be limited. Nonetheless, the process we used is clearly articulated in the methodology and was grounded in data directly derived from the primary research papers. Themes generated from both types of data were cross checked independently by two authors to enhance rigour. Finally, the lack of randomised controlled trials in this area makes comparisons impossible to draw. Given the fluidity of surgical teams, it is logistically challenging to make paired comparisons (of team performance) based on an experimental design. Clearly, flow disruptions such as retrieving supplies and equipment are also common in conventional surgery, as are miscommunication and technology/instruments problems (Zheng et al., 2008; Wiegmann et al., 2007). Therefore, there are limitations in relation to

the extent to which comparisons can be drawn between robotic versus conventional surgeries.

Implications

The findings of this review illustrate the adaptations team members must make to optimise team performance in RAS. Review findings highlight the importance of increased and deliberate communication, particularly when there is reduced visual access to information when using robotic equipment. Other challenges that are more pertinent to RAS specifically relate to distance, obstacles, and physical barriers. Team members need to train together in programs that respond to the added complexity associated with robotic technologies. To fully appreciate and implement RAS safely, all team members, including the console and assistant surgeon, need to be educated on all roles within it (Taylor, 2016). Teams that train together learning to use the same vocabulary and identifying new tasks, goals and responsibilities develop shared mental models during training sessions. To gain proficiency in this specialised technology, stable dedicated teams are needed. The unintended consequences of robotic technologies need to be identified and understood relative to team behaviour, performance, and safety from the “work as done” perspective. These understandings may provide further insights into systems-related and workflow issues that impact on safety and thus inform future interventions.

Conclusions

RAS is in its infancy, but the numbers of surgical robots are increasing around the world. While robotic technologies have innovated and revolutionised surgery, they also

impose challenges in the way surgical teams work. The addition of the robot alters team dynamics and potentially impacts on teams' ability to read and respond to adverse events. As such, understanding the adaptations teams must make will help to inform training programs specifically designed to respond to environmental and non-technical factors that influence team behaviour, clinical performance and safety standards.

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