Published in final edited form as:

BMJ Qual Saf. 2018 February ; 27(2): 148–154. doi:10.1136/bmjqs-2017-006701.

Anticipation, Teamwork, and Cognitive Load: Chasing Efficiency during Robot-Assisted Surgery

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Abstract

Introduction—Robot-assisted surgery (RAS) has changed the traditional operating room, occupying more space with equipment and isolating console surgeons away from the patients and their team. We aimed to evaluate how anticipation of surgical steps and familiarity between team members impacted efficiency and safety.

Methods—We analyzed recordings (video and audio) of 12 robot-assisted radical prostatectomies. Any requests between surgeon and the team members were documented and classified by personnel, equipment type, mode of communication, level of inconvenience in fulfilling the request, and anticipation. Surgical team members completed questionnaires assessing team familiarity and cognitive load (NASA-TLX). Predictors of team efficiency were assessed using Pearson correlation and stepwise linear regression.

Results—1330 requests were documented of which 413 (31%) were anticipated. Anticipation correlated negatively with operative time resulting in overall 8% reduction of OR time. Team familiarity negatively correlated with inconveniences. Anticipation ratio, percent of requests that were nonverbal, and total request duration were significantly correlated with the console surgeons' cognitive load ($r=0.77$, $p=0.006$; $r=0.63$, $p=0.04$; and $r=0.70$, $p=0.02$, respectively).

Conclusions—Anticipation and active engagement by the surgical team resulted in shorter operative time; and higher familiarity scores were associated with fewer inconveniences. Less anticipation and nonverbal requests were also associated with lower cognitive load for the console surgeon. Training efforts to increase anticipation and team familiarity can improve team efficiency during RAS.

Keywords

Anticipation; efficiency; Non-technical skills; communication; teamwork; robot-assisted surgery; quality; adverse; sentinel

Introduction

Communication, team co-ordination, and other non-technical skills are crucial for patient safety in a high-stress environment like the operating room (OR) ¹. In 2014, The Joint Commission on Accreditation of Healthcare Organizations identified human factors and communication errors as the leading root causes for operative and post-operative sentinel events ². New technology, including robot-assisted surgery (RAS), is constantly being introduced in the OR to refine surgical technique and therefore, improve patient outcomes. RAS has been associated with reduced blood loss, transfusions, quicker recovery and enhanced convalescence ³. However, introduction of relatively new technology into the surgical armamentarium may be associated with newer forms of errors or near-miss events ⁴. Additionally, compared to the traditional open approach, RAS may be more demanding in terms of OR staff technical and nontechnical skills ⁵. The OR layout is modified to accommodate the robot and ancillary equipment obstructing views and physically isolating members of the team—most notably the surgeon, who is no longer located beside the patient and the bedside assistants ⁶. This arrangement of the team may inhibit the interpersonal cues and micro-communications that a traditional arrangement allows, which may increase the potential for minor incidents and susceptibility to errors that have been associated with sentinel events ⁷.

Another notable factor related to surgical performance and team effectiveness is cognitive workload. Individuals have a finite amount of mental resources that can be devoted to a task at any given time ^{8,9}. Higher complexity of a given task correspondingly increases the amount of mental resources used. When complexity and dedicated mental resources are high, there are fewer resources available to address unexpected events and the error rate can increase ¹⁰. Procedure duration and surgical errors have been found to be directly related to cognitive workload in surgery ^{11,12}.

In the RAS setting, where the technical demands and the surgical environment can be obstacles to effective communication, it may be advantageous to address the effectiveness of the team's communication and co-ordination strategies for this purpose. Previous research has suggested that almost half of adverse events during surgery are related to provider error and are avoidable ¹³. In this context, the Department of Defense developed teamwork training program—evaluated across 68 facilities nationwide—that addressed efficiency and performance in healthcare through team-training and emphasis on a willfully-coordinated approach to patient care. The results of this study and others have demonstrated that team training improved communication and created a safer environment for patients ^{14–16}. Additional studies have shown improved patient outcomes with increased team familiarity ¹⁷.

Anticipation has been previously established as behavioral indicator of the quality of teamwork ^{18,19}. Human factors research has indicated that highly-effective teams anticipate each other's actions and needs, which allows for more efficient coordination ¹⁹. These skills allow the team to adjust their communication strategies in response to high pressure situations ^{18,19}. While other studies have looked at team dynamics in the surgical setting and demonstrated a connection to patient outcomes, this has not been undertaken in during RAS.

In this study, we aimed to investigate the impact of anticipation as a measure of efficiency in the setting of RAS. We hypothesize that higher team anticipation would be associated with improved OR efficiency.

Methods

The Applied Technology Laboratory for Advanced Surgery (ATLAS) program at Roswell Park Cancer Institute initiated the “Techno-Fields” Project in 2013 (I 244113) to analyze and optimize team interactions in the OR environment. Data was collected from: (1) three video cameras positioned for optimal coverage of the OR, (2) the video feed from the surgical console, and (3) up to 8 individual microphones assigned to members of the team. The three video cameras were positioned to record: (1) the OR table recording interaction between the physician’s assistant (PA) on the right and the scrub nurse on the left of the patient, (2) the console surgeon and the nurses station, and (3) the left bedside assistant, anesthesia station, and the OR door. Recording began once the patient’s face was covered and time out ended (to ensure anonymity of patients) and stopped after the undocking of the robot. Recordings were stopped temporarily if OR staff that had not yet consented were in the OR. The video and audio data from each surgery was synchronized using Adobe Premier Pro CS6. Custom-programmed, multi-video software was used to play the synchronized files simultaneously and permit isolation of individual microphone channels. This permitted observational analysis of the actions and interactions of the team within the surgical environment⁵. Data was collected by two trained medical students supervised by a Urology fellow and a Human Factors engineering expert. Our methodology has been previously detailed⁵. All patients and team members that were recorded gave informed consent to participate in the study.

OR efficiency was defined in terms of anticipation index, proportion of surgery duration for requests, and inconveniences (Table 1). All requests between the console surgeon and other team members during each surgery were documented. Requests were classified based on personnel involved, equipment type, and mode of communication (Table 2). Detailed time-analysis of each request was preformed including: start, end, duration, and anticipation. In human factors analysis, the anticipation ratio describes the ratio of total exchanges of information, to exchanges where information is requested²⁰. We adapted the term for our study purpose to describe the ratio of total requests (whether inquired by the console surgeon or not) in a procedure to anticipated requests (where execution occurred only after inquiry). The cognitive load was quantified using the National Aeronautics and Space Administration – Task Load Index (NASA-TLX) administered at the end of each procedure²¹. Multiple studies in the surgical domain have established NASA-TLX as a sensitive and effective tool for evaluating cognitive workload in the OR^{21–23}. This self-assessment incorporates 6 variables: mental demand, physical demand, temporal demand, perceived performance, effort, and frustration. NASA-TLX scores from individuals were combined to calculate composite scores for the entire team. The inconvenience index was defined to reflect disruptions in team efficiency within the context of cataloged requests. It is a sum total of the cataloged events when one of the following criteria was met: communication breakdowns, multiple requests were made for an item, or an item was not readily available and had to be retrieved. In addition to NASA-TLX, participants completed questionnaires about their demographics and team familiarity at the end of each procedure. Composite

familiarity scores were calculated for the entire team and for the “key triad” consisting of the Console Surgeon, Bedside Assistant, and Scrub Nurse^{5,24}.

Descriptive statistics consisted of relative frequencies for the categorical variables and means and standard deviations for the continuous variables. Inter-rater reliability (IRR) between the two raters was assessed using intraclass correlation for the measured durations of each action during one surgery. The relationships between predictors of team efficiency were assessed using Pearson correlation. Forward stepwise linear regression was then used to identify which factors were significant predictors of the clinical outcome of surgical duration. All correlations were two-sided, with statistical significance defined as p-value

0.05. The entry criteria for the stepwise regression was $p = 0.05$, and the exit criteria was $p = 0.15$. Data was analyzed utilizing the Statistical Package for the Social Sciences (SPSS, v 24).

Results

Our study included data from 12 robot-assisted radical prostatectomies (RARPs) enrolled in Techno-Fields between November 2014 and April 2015. Participants across the 12 surgeries included: 3 lead surgeons, 3 assistant surgeons, 3 physician assistants, 7 scrub nurses, and 11 circulating nurses. Acceptable agreement has been achieved between both raters (IRR 0.74). A total of 1,330 requests were documented during 36 hours (2,147 minutes) of console time across the 12 procedures. Mean console time was 179 minutes (range 111–330) and mean requests' duration was 36 minutes (20% of overall operative time). On average, 111 requests were documented per procedure, of which 37 were anticipated and 18 were associated with inconvenience. Anticipated requests averaged 5.3 seconds to complete, while non-anticipated requests took 25.6 seconds. This was translated into an overall 8% reduction of OR time (Tables 3).

Several significant correlations were observed when comparing measures of team efficiency with familiarity assessments completed by the team members and cognitive load assessments. There was a significant positive correlation between anticipation ratio and surgeon NASA-TLX ($r=0.77$, $p = 0.05$), overall Team NASA-TLX ($r=0.64$, $p = 0.05$) and nonverbal requests ($r=0.74$, $p = 0.001$). There was a significant positive correlation between requests' duration and surgeon NASA-TLX ($r=0.70$, $p = 0.05$). (Table 4).

On stepwise linear regression analysis, larger number of requests ($r=0.76$, $p = 0.01$) and was significantly associated with longer operative time. There was a shorter operative time with higher anticipation ratio ($r=-0.46$, $p=0.008$) (Figure 1; Table 5).

Discussion

Teamwork, communication, and familiarity have been associated with better team performance and improved clinical outcomes in surgery^{15,17}. Inversely, deficiencies in these areas have been implicated in surgical error, increased surgery times, and less favorable clinical outcomes²⁵. There is a paucity of literature regarding the potential impact of these factors on teamwork and clinical outcomes in RAS. Prior studies were limited by the utilization of simulated surgical scenarios rather than the real operative environment. While

simulations can provide an insight about the possible consequences of such factors, studying the real operative environment would offer more accurate depictions of the workload and challenges that face the OR staff during RAS. Our methodology allowed for detailed analysis of anticipation and inconvenience events in a real RAS setting and assessed the impact on team performance.

The results of the current study support the impact of these factors on measures of team efficiency. Anticipation has been found to be related to team effectiveness and the ability for a team to respond to high stress situations^{18–20}. This study demonstrated that anticipation in RAS is both measurable and quantifiable with the use of the anticipation ratio. It also establishes the importance of anticipation in the RAS setting where more non-verbal communication may be necessary due to the unique environment of the RAS OR. Anticipated requests were 5 times shorter than non-anticipated ones. The significant difference in average time to complete anticipated vs. non-anticipated requests and the corresponding reduction in console time illustrates the potential importance of this finding.

Another example was the influence of team familiarity on inconveniences, where higher familiarity scores were associated with fewer inconvenience events. Inconvenience events lead to prolongation of surgery times which are associated with higher costs and less favorable clinical outcomes^{5,25–27}. This goes in hand with prior studies that demonstrated the benefit of both surgical experience and team familiarity¹⁷. This establishes the potential importance of considering these factors when the aim is to improve surgical efficiency and patient safety, and also opens new opportunities and creates new challenges for quality improvement strategies for RAS. While it seems beneficial to increase the frequency that a surgical team, whose members are familiar with each other, to work together, both scheduling and staff retention in the OR can be a challenge²⁸.

Higher task load of the console surgeon was associated with both increased time spent by other team members fulfilling requests, whereas higher task load of the whole team (driven by increased load on the assistant surgeon) was associated with higher anticipation ratios. More complicated surgeries require more focus and in turn, are likely related to an increased cognitive workload on the surgeon and team. This increased workload may require more nonverbal communication and anticipation from the team. Complicated surgeries are often unavoidable and this finding highlights the importance of efficient communication and teamwork during surgery. Improvements in teamwork and communication may potentially help to reduce the increased surgical times associated with complex procedures and improve patient safety. High cognitive and physical demands have been linked to occurrence of errors, inadvertent injuries and adverse patient outcomes^{29,30}. Consequences relate to staff stress, safety and career satisfaction have been also reported³¹.

Better understanding of the surgical team interactions and behavior during RAS can lead to substantial improvement in team “culture”, help minimize errors and improve efficiency³². Interventions targeting team interactions was associated with reduction in errors, job stress, sick leaves, better job satisfaction and patient outcomes^{33,34}.

This study has several limitations. First, those related to the nature of observational studies, which may cause some participants to change their behavior. However, we believe this effect to be small as video data has been collected in this OR for an extended period of time and the novelty has diminished. As the data was collected via video, there were technical challenges in addition to issues related to “blind spots” in the videos. These were minimized by having multiple cameras that were strategically positioned. The nature of video and audio data required time consuming data analyses but provided very rich data. Participants were asked to complete the questionnaires at the end of the procedure and therefore may be subject to recall bias. However, this was inevitable to minimize interference with patient care.

Conclusion

This study utilized an effective means to measure anticipation in the OR. Anticipation and team familiarity correlated with requests and surgical times, as well as workload. It highlights the importance of non-technical factors in improving OR efficiency and ultimately, patient safety.

Acknowledgments

Source of Funding: This research was supported in part by funding from the National Cancer Institute of the National Institutes of Health under award number: R25CA181003, and Roswell Park Alliance Foundation.

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Figure 1.
Regression model showing association between console time and anticipation ratio.

Table 1

Definitions of OR efficiency measures: anticipation index, proportion of requests' time, and inconveniences

Parameter	Description
Equipment Request	Interaction between team members to provide or manipulate a tool/item
Nonverbal request	Request in the form of bodily gestures, camera movement, or on-screen tool guidance
Anticipation	Actions/tasks initiated prior to or without requesting them
Anticipation Ratio	Number of anticipated requests/number of all requests
Request Duration	Time from the request until the response is executed to completion
Inconvenience Index	Any hindrance or difficulty associated with completing a task.

Table 2

Classification and frequency of requests

Request Type	Description	Frequency
Camera-related	Lens clean, lens change, lens focus	91
Suture/Staple/Clip Application	Provide the surgeon with suture, stapler, clip, or lap-tie via laparoscopic port	251
Suture/Staple/Clip Load	Provide the bedside assistant with a loaded needle driver, stapler, clip applicator, or lap-tie applicator	262
Suture/Staple/Clip Supply	Provide the scrub nurse with additional sutures, stapler loads, clip bars, or lap-tie packs	36
Insufflation-related	Rectal test, pneumoperitoneum adjustments	36
Robotic Instruments	Round-tip scissors, permanent cautery hook, precise bipolar forceps, needle driver, fenestrated bipolar forceps, curved mono-polar scissors	217
Laparoscopic Instruments	Scissors, grasper, needle driver (when used for item retrieval), suction wand, hydro-dissection needle	266
Other Laparoscopic Supplies	Specimen bag, mini-lap, surgical	54
Miscellaneous	Towel, syringe, saline, local anesthetic, bucket, IV dye, dish, clamp, derma-bond, ruler, gowns, gloves, robotic seals, trocars, lighting adjustments	117
Total		1330

Table 3

Analysis of requests (duration, anticipation and workload)

Procedure #	Console Time, mean (min)	Total requests, n	Requests Duration (min)	Non-Verbal requests (%)	Anticipated requests (%)	Anticip ratio	Inconv (n)	Surgeon TLX (Average of Console + Assistant Surgeons)	Team TLX
1	130.73	92	35.3	33.7%	28.3%	1.39	12	26.0	24.9
2	170.37	121	34.4	39.7%	41.3%	1.70	5	47.9	39.9
3	111.47	101	21.6	51.5%	51.5%	1.98	14	46.9	37.4
4	143.47	104	15.8	40.4%	39.4%	1.65	11	25.4	32.8
5	246.60	92	33.3	41.3%	27.2%	1.37	11	49.4	46.8
6	330.37	203	92.8	22.7%	20.7%	1.26	44	44.4	38.8
7	274.28	194	70.0	30.4%	35.6%	1.55	50	54.2	40
8	167.87	69	19.5	29.0%	23.2%	1.30	13	11.3	21.5
9	139.57	75	23.3	34.7%	24.0%	1.32	25	23.5	25.1
10	125.60	87	49.7	33.3%	33.3%	1.5	10	43.3	40.5
11	166.58	87	19.6	33.3%	33.3%	1.5	15	30.0	30.0
12	139.95	105	17.2	41.0%	42.9%	1.75	8	53.8	38.1
Average	178.9 (68.1)	111.7 (43.6)	36.0 (23.9)	35.9 (7.4)	33.4 (9.2)	1.49 (0.23)	18.3 (14.3)	38.0 (14.1)	34.6 (7.7)

Anticip, anticipation; Inconv, inconveniences; TLX, Task Load Index

Table 4

Partial Correlations for NASA-TLX Scores when Controlling for Console Time (p value is provided in parentheses, bold values indicate a significant correlation)

	# of Requests	% Surgery Duration	Anticipation Ratio	Inconvenience
Surgeon TLX	0.48 (0.13)	0.70 (.017)	0.32 (0.34)	0.16 (0.64)
Assistant Surgeon TLX	0.22 (0.55)	-0.33 (0.35)	0.76 (0.01)	-0.24 (0.50)
Bedside Assistant TLX	-0.50 (0.12)	-0.10 (0.76)	-0.31 (0.36)	-0.31 (0.35)
Scrub Nurse	.028 (0.41)	0.22 (0.53)	0.23 (0.50)	-0.41 (0.21)
All Team Average TLX	0.29 (0.39)	0.23 (0.51)	0.64 (0.03)	-0.30 (0.36)
Surgeon Average TLX	0.49 (0.13)	0.24 (0.48)	0.77 (.006)	-0.07 (0.83)

Table 5

Stepwise linear regression analysis looking at predictors of team efficiency

	Predictor	Standardized Beta Coefficient	p-value
Console Time	# of Requests	.76	<0.001
	Anticipation Ratio	-.46	0.008