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Ambulatory Movements, Team Dynamics and Interactions during Robot-Assisted Surgery

Nabeeha Ahmad, BS¹, Ahmed A. Hussein, MD^{1,2}, Lora Cavuoto, PhD^{1,3}, Mohamed Sharif, BS¹, Jenna C. Allers¹, Nobuyuki Hinata, MD, PhD⁴, Basel Ahmad¹, Justen G. Kozlowski, BS¹, Zishan Hashmi, BS¹, Ann Bisantz, PhD^{1,3}, and Khurshid A. Guru, MD¹

¹The Applied Technology Laboratory for Advanced Surgery, Roswell Park Cancer Institute, Buffalo, NY

²Department of Urology, Cairo University, Egypt

³Department of Industrial and Systems Engineering, University of Buffalo, Buffalo, NY

⁴Department of Urology, University of Kobe, Japan

Abstract

Objective—To analyze ambulatory movements and team dynamics during robot-assisted surgery (RAS), and investigate whether congestion of the physical space associated with RA technology led to workflow challenges, or predisposed to errors and adverse events.

Methods—With IRB approval, we retrospectively reviewed 10 recorded RA radical prostatectomies in a single operating room (OR). OR was divided into 8 zones, and all movement were tracked and described in terms of start and end zones, duration, personnel, and purpose. Movement were further classified into avoidable (can be eliminated/improved) and unavoidable (necessary for completion of the procedure).

Results—Mean operative time was 166 minutes, of which ambulation constituted 27 minutes (16%). A total of 2,896 ambulatory movements were identified (mean=290 ambulatory movements/procedure). Most of movements were procedure-related (31%), and were performed by the circulating nurse. We identified 11 main pathways in the OR (Figure 1); the heaviest traffic was between the Circulating Nurse Zone, Transit Zone and Supply-1 Zone. Fifty percent of ambulatory movements were found to be avoidable.

Conclusion—More than half of the movements during RAS can be eliminated with an improved OR setting. More studies are needed to design an evidence-based OR layout that enhances access, workflow and patient safety.

Keywords

surgical flow; disruption; error; robot; robotic surgery; operating time; layout

Corresponding Author: Khurshid A. Guru MD, Elm & Carlton St Buffalo NY 14263, 716-845-4155, 716-845-3300 (fax), Khurshid.guru@roswellpark.org, Robert P. Huben Professor of Urologic Oncology, A.T.L.A.S (Applied Technology Laboratory for Advanced Surgery) Program.

Conflicts of Interest

None disclosed.

Introduction

Non-technical errors have been recognized by the Joint Commission as the primary cause of sentinel events during surgery [1]. Surgical workflow may be impeded by factors related to teamwork, communication, physical layout, tools/technology, workload, and institutional policies, which may increase the likelihood of non-technical errors [2, 3]. The operating room (OR) is an intense environment that involves interaction between multiple interdisciplinary teams. The incorporation of new technology, especially during robot-assisted surgery (RAS), may create new variations in errors, affecting workflow, and rendering team interactions more challenging [4]. RAS has changed the traditional OR layout, with equipment occupying more physical space without a proportionate increase in room size. The resultant cluttering of equipment, wires, and tubes may hinder flow within the OR [Figure 1] [5]. Obstructed and unnecessary movements may restrict team interactions; increase distraction, tension, and frustration; and impair team performance, thereby compromising patient safety [6]. A previous study that analyzed 1,080 disruptions in a cardiac OR linked 33% of the observed disruptions to the OR physical layout and design [7, 8]. However, there is paucity of literature concerning non-technical adverse events and flow disruptions in the setting of robot-assisted surgery (RAS).

Human factors methodologies have been used successfully in medicine to reduce adverse events, improve efficiency, and promote patient safety [2, 9, 10]. The main objective of the current study was to analyze ambulatory patterns of the surgical team using human factors approaches during RAS.

Methods

Setting

The “Techno-Fields” Project (RPCI- I 244113) initiated in 2013 aims to identify and categorize obstacles to design evidence-based strategies for a more efficient modern OR. As part of this project, a digital data collection system was installed in the OR and three cameras were used to maximize the coverage of the OR environment. The intra-operative console feed was also obtained to provide the operative context. Up to eight audio tracks were recorded for each team member via lapel microphones. Ten robot-assisted radical prostatectomies (RARP) were included in this study. All patients and surgical staff consented to participate in the study.

Process

Recording started after timeout (to maintain anonymity of patients) and completed at the time of robot undocking. Camera and the console feed recordings were synchronized via a movie editing software (Adobe Premiere Pro CS6), analyzed in video coding software (Noldus Observer XT 12), and streamed simultaneously using a custom programmed software. The videos were viewed by a trained medical student and physician assistant (PA) student supervised by a Urology fellow and a Human Factors engineering expert.

A scaled diagram of the OR and its constituents was created and the OR was divided into eight zones based on where team members were typically stationed and the location of the major supplies and equipment [Figure 2a]. *Console Zone* was the standard location of the daVinci™ surgical console, lead surgeon and surgical fellows; *Circulating Nurse Zone* contained the circulating nurse workstation; *Anesthesiology Zone* comprised the anesthesia station, monitors and supply carts; *Sterile Zone* included the operating table, the robot and the supply tables for the PA and scrub nurse. *Supply Zone 1* consisted of a suture cart, computer and access to the irrigation system; *Supply Zone 2* consisted of cabinets containing supplies; *Transit Zone 1* connected most of the zones together and also contained the garbage, biohazard bins, and the gauze disposal stand; *Transit Zone 2* was used for patient entry, and was not used during the surgery. These eight zones were used to define start and end points of the pathways identified.

Ambulatory movements of the OR personnel were tracked from the start to the end of a walking motion. Each pathway was defined in terms of starting and ending zones, and the duration and purpose of movement. Ambulatory movement patterns were plotted on the OR schematic and the most commonly used pathways and problem areas were identified. The purpose of each trip was established based on visual and audio cues from the recordings. Ambulatory movements were classified based on their purpose (adapted and modified from Palmer et al) [7] [Table 1]. We further sub-classified ambulatory movements as either avoidable (if they could be eliminated with an improved setting without impacting the procedure), or unavoidable (necessary to complete the procedure) [Table 2].

Statistical analysis

Variables were summarized using descriptive statistics including proportions, means and standard deviations. Univariate associations were statistically assessed using Pearson Chi-square test for categorical variables. Mixed-factor analysis of variance (ANOVA) was used to assess the main and two-way interactive effects of person, pathway, movement purpose, and whether they can be eliminated or not. Cohen's kappa coefficient was used to determine inter-rater agreement for qualitative data. All tests were two-side and the level of significance for all analyses was set at $p < 0.05$. All statistical analyses were performed using SPSS software (version 22, IBM Corporation).

Results

Ten RARPs were analyzed by two observers (kappa coefficient of 0.67, acceptable inter-rater reliability). Three lead surgeons, three surgical fellows, eleven circulating nurses, seven scrub nurses, three PAs and thirteen anesthesiologists were tracked during the study. A total of 2,896 ambulatory movements (mean, 290; range 115–530 ambulatory movements/procedure) were observed over a total of 27 hours and 40 minutes (mean 166; range 111–272 minutes/procedure). Mean ambulatory duration totaled for all personnel 27 minutes/procedure. (range 11–46)

The number of movements differed significantly among the OR staff ($p < 0.001$, Table 4). The circulating nurse contributed to the majority of traffic (39% total ambulatory movements, 42% of the total ambulatory time)[Figure 3]. The lead surgeon followed with

20% of total ambulatory movements and time. The remaining ambulatory movements were contributed by fellow (18% of movements), anesthesiologist (17%), and scrub nurse (5%).

The distribution of classifications was relatively consistent across the ten procedures. Procedures 2 and 9 were longer due to deviation from the normal surgical flow (an intraoperative biopsy was required in procedure 2 and accidental clipping of the obturator nerve that required correction occurred in procedure 9). Overall, procedure-related ambulatory movements were the most common (31%) followed by miscellaneous (28%) and technology-related (19%) ($p < 0.001$, Table 4). Further analysis showed that 50% of these ambulatory movements were avoidable. Unavoidable movements were predominately technology-related, whereas avoidable movements were predominately categorized as miscellaneous [Figure 4].

A total of 31 pathways (P_n) were identified throughout the ten procedures and pathways with a mean usage greater than four were considered commonly used or important. Eleven pathways were found to be important and further analyzed, with a main effect of pathway on the movement time by pathway ($p = 0.029$, Figure 2c and Table 3). The most commonly used pathway was P_3 between the *Circulating Nurse Zone* and *Transit Zone 1*. The number of ambulatory movements were primarily contributed by the circulating nurse (83%) for miscellaneous (28%), room layout (23%) and procedure-related (19%) ambulatory movements. P_6 was the second most used pathway, primarily used by the circulating nurse (81%) for miscellaneous (43%) and procedure-related (28%) activities. P_2 was used primarily by the lead surgeon (49%) and fellow (36%) for technology-related (38%) and communication (23%) movements. P_1 was primarily used by the lead surgeon (44%) and circulating nurse (28%) largely for technology-related (31%) and miscellaneous (24%) activities. In terms of the movement time, there was a significant interaction between pathway and purpose ($p < 0.001$) and between person and purpose ($p < 0.001$), however the interaction between person and pathway was not significant ($p = 0.12$). The spaghetti diagram identifies a “hot spot” where the OR traffic was most intense (between the *Circulating Nurse Zone*, *Transit Zone 1* and *Supply Zone 1*) [Figure 2b].

Discussion

The OR frequently encounters preventable “near miss” or adverse events [11]. Accumulation of latent and minor events weakens the system and thus reduces the available resources for challenging situations [12]. Workflow disruptions have previously been attributed to the physical layout of the OR and congestion, and understanding impediments to efficient surgical flow is crucial for patient safety [6, 7].

In our study, the circulating nurse was responsible for the majority of the ambulatory time during surgery (42%), and the majority of his/her ambulatory movements were procedure-related (33%). This was consistent with expectation based on the responsibilities assigned to the circulating nurse. Extensive ambulatory movement of the lead surgeon was unexpected as their primary role revolves around the surgical console. However, the lead surgeon’s ambulatory movements constituted 20% of the ambulatory time during surgery, that were

mainly technology-related (31%) including observation of surgery, console swap with fellow, and use of computerized medical records and communication.

Unavoidable ambulatory movements were primarily categorized as technology-related (37%), procedure-related (33%), or miscellaneous (21%). Unavoidable technology-related movements were necessary for progression of surgery, including equipment handling, training interaction, and the use of computers to access patient records. Approximately half of the procedure-related ambulatory movements were unavoidable, including delivery of biopsies, patient paperwork, checking fluid levels, scrubbing and teaching/training. Teaching/training accounted for 22% of procedure-related ambulatory movements, and shift changes comprised 20% of miscellaneous ambulatory movements. Although necessary, both have previously been associated with more disruptions to the surgical procedure [13]. When personnel switch places, the disruption may be prolonged to allow for the transfer of critical patient information, a process that can result in errors.

To identify how to modify the OR layout, the avoidable vs. unavoidable usage of each pathway was compared. P₁ through P₈ were used for unavoidable purposes more than 45% of time and were used by all personnel. Although these ambulatory movements are necessary they can still be reduced. P₁, P₂ and P₅ were used primarily by the lead surgeon; these pathways helped facilitate communication and usage of the computer stored in *Supply Zone 1*. P₃ and P₆ were used primarily by the circulating nurse; these pathways facilitated communication, retrieval of supplies, the disposal of garbage, and entry and exit from the OR. P₄ was most often used by the fellow followed by the circulating nurse; this path facilitated communication and access to patient paperwork. P₇ and P₈ were used predominantly by the anesthesiologist, allowing for entrances and exits from the OR, access to patient paperwork and communication with the circulating nurse.

Avoidable ambulatory movements (50%) had no contribution to the surgical procedure or could have been avoided with a refined OR layout. Avoidable ambulatory movements resulted from miscellaneous (35%), procedure-related (29%), communication (20%) and room layout (15%) activities. Ambulatory movements including the retrieval and delivery of supplies and equipment were considered avoidable since a revised layout would allow for improved economy of motion. Based on the principles of *Lean Six Sigma*, a methodology for process improvement, elimination of any activity that does not add to the procedure is necessary to maximize efficiency [14]. Considering each ambulatory movement as a distraction and a potential impediment to surgical flow, the large proportion of avoidable ambulatory movements identified in this study is alarming for patient safety [6]. Pathways used for avoidable purposes included P₉, P₁₀, and P₁₁. All of these paths were primarily used for the delivery of supplies and equipment by the circulating nurse to the *Sterile Zone*. Repositioning with optimization of supply zones should be a priority to eliminate the potential flow disruptions that could occur.

Procedure-related ambulatory movements were the most prevalent over all ten procedures (31%) and one of the biggest contributors to avoidable movements. Most of these were attributed to retrieving and delivering supplies/equipment, which could be avoided by modifying supply arrangement accompanied by anticipation/setup of needed items prior to

surgery. The delivery of supplies usually involved the circulating nurse obtaining the supply from either supply zones or from outside the OR, and then delivering it to the scrub nurse. With the current setup of the OR, the circulating nurse would have to use four zones (*Supply Zone 1*, *Anesthesiology Zone*, *Transit Zone 2*, and *Sterile Zone*) to reach the scrub nurse. Surprisingly this was the most common pathway used for the circulating nurse to reach the *Sterile Zone* even though it was the longest and narrowest (only 22" wide in *Supply Zone 1*). Its increased use was due to the fact that the scrub nurse was not easily accessible from any other locations. Furthermore, space limitations rendered both supply zones less accessible. *Supply Zone 1* had the highest volumes of "traffic" through a very narrow space [Figure 2b]. Likewise access to *Supply Zone 2* was narrow, which complicated access and diminished the value of storage in this zone.

Room layout represented a small proportion of avoidable ambulatory movements and the major interference resulted from long travel distances as opposed to a high frequency of ambulatory movements. Room layout improvements should target unobstructed views, more efficient locations of computers and monitors, and better access to supplies/equipment, thereby reducing OR traffic. Two-thirds of the ambulatory movements classified as miscellaneous were avoidable, the majority of which lacked any obvious purpose. An increase in ambulatory movements with a lack of purpose was noticed during the two procedures with adverse events. Similarly, greater than two-thirds of communication-related ambulatory movements came from phone calls and pages or communication unrelated to the current procedure. With the increased capabilities and prevalence of cell phones, phone use is being increasingly criticized as a distraction to workflow, and for this reason all phone calls/pages were considered avoidable if other means of safely and timely addressing such issues outside OR are available.

Adoption of wireless transmission as a means to eliminate wires and cables [15], better accessibility to waste bins and supplies [16], and development of an integrated operating table that holds the most necessary equipment and controls may be beneficial for improving movement efficiency in the OR [17]. Along with these recommendations from the literature, our results provide insight into suggested improvements for OR layout. Supplies should be located with consideration to their frequency and sequence of use. The cluttering of main pathways should be avoided and a minimum walkway width of 30" should be provided to enable efficient ambulatory movements [18]. Replacing traditional doors with sliding doors for supply cabinets can reduce the "dead space" occupied by the open doors and facilitate access to supplies. Monitors to access medical records primarily used by the surgical team should be located in the console zone. Simulation training, including high-fidelity OR training and full immersion simulation, may in future evolve to support the surgical staff in optimizing and avoiding unnecessary movements during RAS [19, 20].

Despite the uniqueness of our study, it did have some key limitations. We included only ten procedures among a single specialty in a single OR. Findings may differ across different institutions and procedures or in ORs with different layouts. Additionally there were notable blind spots in the video recordings. These blind spots made it difficult to track where certain ambulatory movements ended and to determine their purpose. More prospective studies

linking this data to clinical outcomes as well as studies examining other consequences of movement in the OR are warranted.

Conclusion

More than half of the movements during RAS can be eliminated with an improved OR setting. Traditional operating room design, especially during robot assisted surgery, may not be optimal for a modern set up where technology plays a key role. More studies are needed to design an evidence-based OR layout to meet modern equipment-related challenges that enhances access, workflow time efficiency and patient safety.

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Figure 1.
Photo demonstrating the congestion of the RAS OR. Image shows the *Sterile Zone* during surgery as viewed from *Transit Zone 1*.

Figure 2a

Figure 2b

Figure 2c

Figure 2.

Figure 2a. The eight zones of the OR.

Figure 2b. Spaghetti Diagram illustrating the 11 major pathways. Average use of each pathway during 10 procedures is represented as (n). The red circle highlights the area of heaviest traffic

Figure 2c. Most common pathway usage by

Figure 3.

Number of ambulatory movements per person divided based on classification.

*It is important to note that the Physician Assistant had 10 total movements documented, all of which occurred in a single procedure (Procedure 2).

Figure 4. Overall prevalence of different ambulatory movements. The sum of avoidable and unavoidable movements represents the overall percentage of movements per classification

Table 1

Classifications of ambulatory movements in the operating room.

Communication	<ul style="list-style-type: none"> • Procedure-related/unrelated communication • Repetitions/Miscommunications • Phone calls/Pages
Technology-Related	<ul style="list-style-type: none"> • Equipment handling/failure • Use of Computers/Monitors • Research-related activities
Room Layout	<ul style="list-style-type: none"> • Clear Pathway (Moving to clear pathway for another individual, or moving furniture, CO2 tanks, wires/connectors) • Use of garbage, biohazards and gauze-disposal stand
Procedure Related	<ul style="list-style-type: none"> • Receiving/delivering biopsies • Paperwork (reading/writing patient notes) • Scrubbing in • Supplies/instruments (retrieving and delivering supplies or instruments) • Check on patient progress (Intravenous fluids, urine output) • Teaching/training (switching positions at console, nurses training other nurses) • Surgical Error
Miscellaneous	<ul style="list-style-type: none"> • Purpose unknown * • Lack of purpose (pacing) • Shift changes/breaks • Wash hands (using hand sanitizer, not scrubbing in) • Retrieve personal item (and returning it) • Return to Zone after multiple movements with multiple purposes

* Purpose was categorized as unknown if it was not possible to determine the reason for the ambulatory movement or if the personnel were out of the camera views.

Table 2

Sub-classification of ambulatory movements in the operating room.

Avoidable	<ul style="list-style-type: none"> • Communication unrelated to procedure • Repetition/Miscommunication • Phone calls/Pages • Equipment failure • Clear Pathway (Moving to clear pathway for another individual, or moving furniture, carbon dioxide tanks, wires/connectors) • Use of garbage, biohazards and gauze-disposal stand Supplies/equipment (retrieving and delivering supplies, instruments, equipment) • Surgical error • Purpose unknown • Lack of purpose • Retrieve personal item (and returning it)
Unavoidable	<ul style="list-style-type: none"> • Procedure-related communication • Equipment handling (i.e. insufflator) • Observation of surgery • Use of computers/monitors • Research related activities • Shift changes/breaks • Teaching/training (switching positions at console, nurses training other nurses) • Receiving/delivering biopsies • Paperwork • Scrubbing in • Check on Patient progress (IV fluids, urine output) • Return to Zone (Returning to their respective start point after multiple movements with multiple purposes) • Wash hands (hand sanitizer, not scrubbing in)

Table 3

Classifications for utilization of most common pathways

Pathway	Description	Primary Purposes (%)
P1	Supply zone 1 ↔ Transit zone 1	Technology Related (31) Miscellaneous (24)
P2	Console zone ↔ Transit zone 1	Technology Related (38) Communication (23)
P3	Circulating nurse zone ↔ Transit zone 1	Miscellaneous (28) Room Layout (23)
P4	Circulating nurse zone ↔ Console zone	Technology Related (36) Communication (30)
P5	Console zone ↔ Supply zone 1	Technology Related (47) Communication (23)
P6	Circulating nurse zone ↔ Supply zone 1	Miscellaneous (43) Procedure Related (28)
P7	Anesthesiology zone ↔ Supply zone 1	Miscellaneous (61) Procedure Related (29)
P8	Anesthesiology zone ↔ Circulating nurse zone	Procedure Related (57) Communication (36)
P9	Circulating nurse zone ↔ Sterile zone	Procedure Related (69) Communication (18)
P10	Supply zone 1 ↔ Sterile zone	Procedure Related (69) Miscellaneous (28)
P11	Sterile zone ↔ Transit zone 1	Room Layout (51) Procedure Related (28)

Table 4

Ambulatory movements and time by person, purpose, purpose, avoidability and duration

Variable	Group	Number of Movements	% of Movements	Amount of Time	% of Time
Person	Anesthesiologist	504	17.4	0:38:35	14.2
	Circulating Nurse	1140	39.4	1:54:38	42.1
	Fellow	516	17.8	0:45:15	16.6
	Lead Surgeon	580	20.0	0:54:54	20.1
	PA	10	0.3	0:00:36	0.2
	Scrub Nurse	146	5.0	0:18:36	6.8
Most Common Pathways	1	232	8.0	0:28:41	10.5
	2	269	9.3	0:21:53	8.0
	3	340	11.7	0:24:57	9.2
	4	142	4.9	0:15:12	5.6
	5	114	3.9	0:15:50	5.8
	6	323	11.2	0:39:13	14.4
	7	107	3.7	0:10:39	3.9
	8	44	1.5	0:06:30	2.4
	9	95	3.3	0:17:03	6.3
	10	59	2.0	0:08:33	3.1
	11	48	1.7	0:13:24	4.9
Purpose	Communication	426	14.7	0:41:01	15.1
	Room Layout	228	7.9	0:18:07	6.7
	Procedure Related	898	31.0	1:28:15	32.4
	Technology Related	544	18.8	0:48:26	17.8
	Miscellaneous	800	27.6	1:16:45	28.2
Avoidability	Avoidable	1448	50.0	2:15:16	49.6
	Unavoidable	1448	50.0	2:17:18	50.4