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The Impact of Operating Room Layout on Circulating Nurse's Work Patterns and Flow Disruptions: A Behavioral Mapping Study

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Abstract

Aim: To assess how the adjacencies of functionally different areas within operating rooms (ORs) can influence the circulating nurse's (CN) workflow patterns and disruptions. **Background:** The CN plays a significant role in promoting patient safety during surgical procedures by observing, monitoring, and managing potential threats at and around the surgical field. Their work requires constant movement to different parts of the OR to support team members. The layout of the OR and crowded and cluttered environment might impact the CN's workflow and cause disruptions during the surgery. **Method:** A convenience sample of 25 surgeries were video recorded and thematically coded for CN's activities, locations, and flow disruptions. The OR layout was categorized into transitional zones and functional zones (workstations, supply zones, support zones, and sterile areas around the surgical table). CN's activities were classified into patient-, equipment-, material-, and information-related activities. Flow disruptions included those related to environmental hazards and layout. **Results:** The CN traveled through multiple zones during 91% of the activities. The CN's workstation acted as a main hub from which the CN made frequent trips to both sides of the surgical table, the foot of the OR table, supply zones, and support zones. Transitional zones accounted for 58.3% of all flow disruption that the CN was involved in whereas 28% occurred in areas surrounding

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the OR bed. **Conclusion:** The similarity of the movement and flow disruption patterns, despite variations in OR layout, highlighted the adjacencies required between major zones that CNs regularly visit. These optimum adjacencies should be considered while designing ORs such that they are more efficient and safer.

Keywords

operating room, architectural layout, adjacencies, flow disruptions, movement pattern, behavioral mapping

Patient care in the perioperative setting is dynamic in nature, and as such, it is dependent on the clinical knowledge, judgment, and reasoning of skilled nurses, particularly the circulating nurse (CN; AORN, 2014). The CN's most critical responsibility in the operating room (OR) is managing intraoperative nursing care and serving as an advocate for patients whose protective reflexes are compromised during operative or other invasive procedures (Alfredsdottir & Bjornsdottir, 2007; AORN, 2014; Spry, 2009; Yang et al., 2012). The CN is the most mobile member of the surgical team, working outside the sterile field, serving as a link between sterile and nonsterile realms. The CN plays a significant role in promoting patient safety during surgical procedures by observing, monitoring, and managing potential threats at and around the surgical field (Spry, 2009; Yang et al., 2012). This is inclusive of intraoperative risk variables related to environmental controls including temperature, humidity, air exchange, traffic, and movement. The CN delegates, supervises, and evaluates the activities of the surgical team while simultaneously responding to various and numerous surgical interventions and needs (AORN, 2014; Ritchie, 2009), such as equipment, materials, supplies, and instruments; medical record and other informational needs; and communication with perioperative or other units and support departments.

The CN's work involves travel between and through various zones within the OR. Zones are defined areas that support specific functions or resources (e.g., supplies). Thus, the zone location of equipment (particularly, the surgical table), storage units, phones/intercoms, computer workstations, and doors are important to the efficiency and effectiveness of the CN's workflow. The arrangement and configuration of zones can affect how far the CN needs to travel and how often, making the layout a significant factor in the CN's overall performance as well as potentially impacting patient and staff safety.

Existing literature on the relationship between architectural layout and healthcare outcomes is primarily focused on understanding the dynamics of movement patterns at the unit level such as across surgical suites (Assem, Ouda, & Wahed, 2012; Chraibi, Kharraja, Osman, & Elbeqqali, 2014), across the hospital, or within units such as critical care units, general units, medical surgical units, and outpatient clinics (Freihoefer, Kaiser, Vonasek, & Bayramzadeh, 2017; Hurst, 2008; Lorenz, Bicher, & Wurzer, 2015; Reiling et al., 2004; Zadeh, Shepley, & Waggener, 2012; Zhao, Mourshed, & Wright, 2009). At the unit level, studies have shown that excessive and unnecessary movement due to long travel paths can cause fatigue (Armstrong et al., 2004), delay task accomplishment, or hinder overall performance (Baker, Salas, King, Battles, & Barach, 2005; Chen, Daraiseh, Davis, & Pan, 2014; Rechel, Buchan, & McKee, 2009). Poor spatial arrangement and adjacencies (or closeness between different areas) are linked to compromised patient safety (Reiling et al., 2004), decreased efficiency (Zhao et al., 2009), longer travel distance and time (Chraibi et al., 2014), and communication outcomes (Gharaveis, Hamilton, & Pati, 2017). However, very few studies have examined the relationship between the design of the physical environment and movement patterns within a smaller space such as an OR. Studying the layout configuration of the OR is important because the layout of the OR may contribute to unnecessary movement or create barriers to movement inside the OR resulting in workflow disruptions. Such interruptions in the OR are known as surgical flow disruptions (SFDs) and defined as events that hinder or interrupt the flow of activity performance leading to distraction or major disruption or sentinel events (Palmer et al., 2013; Wiegmann, ElBardissi, Dearani, Daly, & Sundt, 2007).

This study aimed to understand how the layout and adjacencies of functionally different areas within the OR can influence (a) the CN's movement patterns within the OR and (b) flow disruptions for the CN during the surgery.

Method

Design and Setting

This study used an observational design, known as behavioral mapping, by utilizing prerecorded videos of surgeries conducted in three different ORs, in a major hospital system located in the southeast of the United States. Behavioral mapping is a traditional method of observation in the field of environmental design where subjects under study are observed for their behavior and location while keeping track of time (Weiss & Boutourline, 1962). A convenience sample of 25 procedures was recorded for subsequent analysis including 4 pediatric cases in OR (C), 8 pediatric cases in OR (B), and 13 general adult cases in OR (A). ORs (B) and (C) are located in a surgical suite built in 1986, with select renovations and expansion completed in 2003. OR (A) is located in a surgical suite that was completed in 2007. As such, the ORs varied in size with OR (A) being the largest (690 sq. ft.), OR (B) being the smallest (390 sq. ft.), and OR (C) being midsized (463 sq. ft.).

Prior to conducting the study, the research team obtained approval from the organization's institutional review board. The organization's surgical informed consent is inclusive of surgical procedure videotaping. OR staff involved in the study and video recording were informed and consented.

Video Recording and Analysis

Four video cameras installed in each corner of ORs allowed for maximum visual coverage of the room during procedural videotaping. The video recording system also included two wireless audio receivers centrally located in the room and a computer with Noldus Media Recorder software (The Observer XT 12), which is also used in other environmental studies (Zadeh, Shepley, Williams, & Chung, 2014). A research assistant initiated all recordings before patient transfer into the OR and stopped after patient transfer out of the OR.

To develop a framework for coding and analyzing the recorded procedures, the research team reviewed relevant literature, existing coding protocols, and taxonomies. Then through 12 in-person observations, the research team further refined and validated the initial framework. Noldus Observer XT 12 software facilitated viewing of all four videos simultaneously and coding the observations. Two more rounds of pilot testing of the protocol, with further refinement of codes, trained coders for consistent coding with a high interrater reliability (more than 80%). Total of 11 graduate students and research associates coded the videos after familiarizing themselves with the software and implication of codes, with oversight from clinically trained research team members. The data collection and coding reached completion in Spring 2016 through Fall 2016. The coding protocol includes codes for the location of each of the surgical team members by location (zone), their activities at any time, and any flow disruptions they might experience, which are explained below and can be seen in Tables 1,2, and 3.

In this study, functional areas or zones were adapted from a study by Ahmad et al. (2016), which classified zones into eight categories (1) console zone, (2) CN zone, (3) anesthesiology zone, (4) sterile zone, (5) supply zone 1, (6) supply zone 2, (7) transit zone 1, and (8) transit zone 2. The adapted zones included five overarching types of functional zones (nontransitional) representing the primary functions performed within them, and one category to represent transitional zones, accommodating circulation between different nontransitional zones. Main categories of the nontransitional zones included sterile zones, support zones, supply zone, workstation, and door access. In-person observations in each of the three ORs refined the proposed taxonomy. Each of the overarching categories

Table 1. Definition of zones.

Zone Group	Zone	Definition
Doors	Door to Corridor 1 & 2	Door to/from the operating room and the outer corridor
	Door 1 & 2 to Sterile	Door to/from the operating room and the core
Supply	Supply Zone 1	Used by circulating nurse
	Supply Zone 2	Used by anesthesia personnel
Support	Support Zone 1 Support Zone 2 Support Zone 3 Support Zone 4 Support Zone 5 Support Zone 6	Areas with movable items (e.g. furniture, equipment, trash receptacles, etc.)
Sterile Area	Surgical Table 1 & 2	Areas are either sides of the operating room table, one occupied by the surgeon and scrub nurse, while the other occupied by the resident, PA or NP depending on the type of surgery and laterality
	Foot of Surgery Table	The area at the foot of the operating room table
Transitional	Transitional Zone 1	The Flow area between the circulating nurse workstation, operating room table, and the outer corridor door
	Transitional Zone 2	The Flow area between the transitional zone 1 and 3, operating room table, and circulating nurse workstation or support zones
	Transitional Zone 3	The Flow area between the circulating nurse workstation, operating room table, and the core door
Workstation	Anesthesia Workstation	Head of the table area which includes the anesthesia machine, anesthesia cart, anesthesia supply cabinet, etc.
	Circulating Nurse's Workstation	Area where circulating nurse documents in the electronic medical record, phone, pager staging, etc.
	Surgeon's Workstation	Area where surgeon/resident documents in the electronic medical record

included subcategories, which resulted in 20 zones. Figure 1 shows the layout of three ORs with all designated zones.

The activities of all subjects observed (including the CN) were categorized as being patient related (P); equipment related (E); materials, instruments, or supplies related (MS); or information related (I); therefore, associating the term (PEMSI) to the activities. Table 2 shows the definitions for PEMSI activities. The coded PEMSI activity for the CN remained unchanged as long as she or he continued doing activities related to that category, even if she or he moved to different locations within the OR. Coding of the CN changed from one PEMSI activity to the other with time stamp, every time the CN started a new activity. Thus, a PEMSI activity could be of a short or long duration and take place in one or more zones. The research team studied CN's movement patterns by looking at the primary activities (i.e., patient-, equipment-, material-, or information-related activities), number of zones traveled by the CN while performing an activity, and the time duration for each activity.

The definition for SFDs was adapted based on an existing taxonomy (Palmer et al., 2013) and refers to incidents that hinder or interrupt the flow of activity performance (Wiegmann

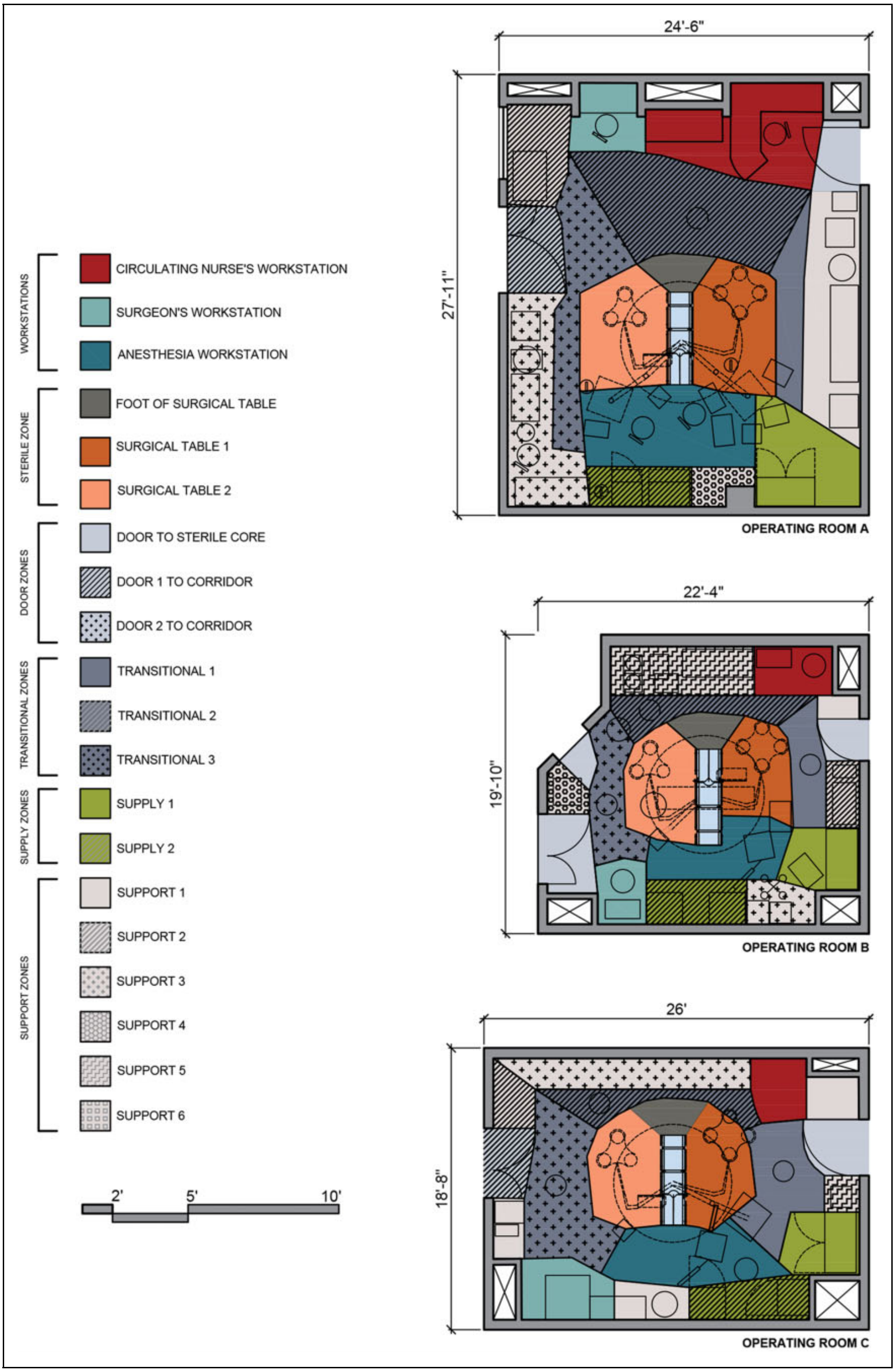

Figure 1. Floor plans of the three operating rooms with assigned zones.

et al., 2007). This taxonomy provides a framework for categorizing disruptions during a surgery into six different categories including general layout, environmental hazards, general interruptions, communication, usability, and equipment failures. In this article, we focus only on the SFDs related to layout and environmental hazards that involved the CN (CN SFD), since these two SFD categories are most relevant to the physical environment (see Table 3).

Analysis

To analyze the frequency and duration of all activities and flow disruptions, the data from Observer XT 12 were transformed into a time-based data set. Using R Version 3.3.1, the descriptive summaries were obtained. The analysis includes summaries of frequency and duration of the overall PEMSI activities as well as their occurrences within each zone and from zone to zone. In addition, the descriptive summaries include locations of the CN SFDs. Additionally, a computer-based simulation software called AnyLogic 7 created a playback of the surgery using data set obtained from Observer XT 12. A model representation of each OR was developed and appropriately scaled to enable this representation to quite an accurate degree. Staff and equipment would move from one zone to another based on the output from the recorded videos. Their actual positions within a zone would depend on the available space within that zone at the time the staff or equipment arrived. The research team customized the software platform extensively to allow for the second-by-second tracking of location, thus allowing the spaghetti diagrams to be drawn with the needed precision to represent CN's flow and movement.

The spaghetti diagrams allowed for richer interpretation of the observational data by showing the CN's travel path for each surgery in each of the three ORs from when they first enter the OR until the end of the surgery when they exit the OR.

To understand the CN's common travel paths, we used the starting and ending zones for each PEMSI activity, by only including the functional zones in the analysis and excluding transitional and door zones. Doing so eliminated those activities that started or ended in transitional zones and door zones. The analysis also included the frequency of travels between different groups of functional zones were obtained. We used bubble diagrams to visualize the connections between zones with high frequency of travels. The size of the bubbles represents the frequency of trips to and from a specific zone.

Results

Types of CN Activities

Over the 37 hr of observations across 25 surgeries, the CN spent 34 hr on PEMSI activities (total number of activities or $n = 1{,}471$), while the remaining 3 hr was spent on waiting, being idle, or being out of the room. Within PEMSI activities, information-related activities were most frequent, accounting for 36% ($n = 517$), followed by 35% for material-related activities ($n = 482$), 23% for equipment-related activities ($n = 341$), and 7% for patient-related activities ($n = 131$).

Information-related activities were not only the most frequent but also had the highest total duration, accounting for a total of 18-hr activities (52%) of the observations. Although the frequency of material-related activities was almost as high as information, the overall duration was only about 6 hr or 18% of all observed PEMSI activities across surgeries. The duration of equipment-related activities was similar at 6 hr. The CN spent the least amount of time on patient-related activities at about 4 hr or 13% of total time spent on activities.

Across all surgeries, the CN visited the CN's workstation most frequently of all zones (32%) followed by transitional zone 2 (14%), transitional zone 1 (11%), door to sterile zone (10%), surgical table 1 (8%), surgical table 2 (5%), and supply and support zones 1 (3%). The CN spent the most amount of time in CN's station (43%) followed by transitional zone 2 (14%), surgical table 1 (10%), transitional zone 1 (8%), and surgical table 2 (5%). In addition, to help understand the purpose of the CN's activities in each zone, the percentages of main PEMSI activities within each zone were calculated (see Table 4).

Table 2. Definition of PEMSI activities.

PEMSI Activity	Definition
Patient (P)	Activities related to patients (e.g. repositioning, transferring, preparing, or anesthetizing patient)
Equipment (E)	Activities related to equipment (e.g. preparing, monitoring, moving, or cleaning equipment)
Material, Instruments, Supplies (MS)	Activities related to material, instruments, or supplies (e.g. using, preparing, or cleaning material/instruments/supplies, gowning dressing/undressing, trash disposal, retrieving supplies from Nurse PYXIS Station or Anesthesia PYXIS Station)
Information (I)	Activities related to information (e.g. phone calls/pagers/texts, handoff equipment/material/supplies, time out, computer work, paperwork, or whiteboard activity)
Waiting	While waiting on something or someone
Idle	Passive waiting without any identifiable reason
Out of Room	While subject out of room and therefore not tracked

Table 3. Definition of surgical flow disruptions (SFDs).

SFD	Definition
Environmental Hazards	Incidents involving the interaction of surgical staff with the environment such as: • Staff's Slipping/falling/tripping • Staff's interaction with sharp objects and contaminated needles • Collision between staff and objects • Excessive reach for accessing patient, objects, or equipment
Layout	Spatial organization or positioning of certain items in the operating room that hinder the surgical staff's performance by blocking the staff's route or impeding visibility. These items include • Connectors or wires • Equipment or furniture • Permanent structures or fixed equipment

Information-related activities (43%) and material-related activities (31%) were the most frequent activities undertaken by the CN in the CN's workstation, followed by equipment-related activities (20%) and patient-related activities (6%). In the sterile area, material-related activities (29%) were the most frequent. This was followed by activities related to equipment (28%), information (24%), and patient (18%). Material-related activities accounted for the majority of the CN's activities in supply zone (54%) and support zone (42%). Both supply and support zones had similar pattern of activities where information was the most frequent activity after material (22% and 28%, respectively) followed by equipment- (19% and 23%) and patient-related activities (5% and 7%).

Single-Zone Versus Multiple-Zone Travels

Across all surgeries, 91.16% (n = 1,341) of the CN's activities required traveling through multiple zones, while only 8.83% (n = 130) of

Table 4. PEMSI Activities Within Each Functional Zone.

Zone	Patient (%)	Equipment (%)	Material (%)	Information (%)
Anesthesia workstation	0	50	25	25
Circulating nurse's workstation	6	20	31	43
Door	5	17	38	40
Sterile	18	28	29	24
Supply zone	5	19	54	22
Support zone	7	23	42	28
Surgeon's workstation	12	25	50	12
Transitional zone	9	24	34	33

activities occurred in the same zone. The CN's multiple-zone travels were mostly associated with information-related activities (31%) and material-related activity (31%). Equipment- and patient-related activities accounted for 20% and 8% of all multizone travel, respectively. Single-zone travels were 4% for information, 2% for material, 2% for equipment, and 1% for patient-related activities.

On average, the CN spent about 35 s (95% CI [28.34, 41.70]) on each single-zone activity, while he or she spent about 53 s (95% CI [50.52, 55.74]) during each multiple-zone activity, roughly twice as long.

The average number of zones crossed varied for different types of PEMSI activities across the three ORs. In OR (A), on average, the CN crossed 7.8 (95% CI [6.2, 9.45]) zones for patient activities, 6.2 (95% CI [5.51, 6.84]) for material-related activities, 5.9 (95% CI [5.06, 6.7]) for equipment activities, and 4.1 (95% CI [3.73, 4.62]) for information activities. In OR (B), CN crossed an average of 5.7 (95% CI [4.47, 6.99]) for information-related activities, 5.5 (95% CI [3.97, 7.03]) for patient-related activities, 5.5 (95% CI [4.02, 6.98]) on equipment-related activities, and 4.5 (95% CI=3.39, 5.61) on material-related activities. Finally, in OR (C), material-related activities required the CN to travel through an average of 7.4 (95%CI [6.26, 8.54]) zones, followed by 6.3 (95%CI [5.39, 7.24]) for information, 6.5 (95%CI [5.02, 7.96]) for equipment, and 5.8 (95%CI [4.22, 7.31]) for patient-related activities, respectively. As the averages of zones crossed show, PEMSI activities patterns across the three ORs do not represent similar orders.

Zones Linkages and CN's Flow

Given that the CN makes frequent trips to different parts of the OR to support the activities of other team members, it was important to understand how the adjacencies between zones might support optimal travel patterns for the CN. Figure 2 shows the zone linkages only between functional zones within each OR based on the frequency of the CN's travel between those functional zones (shown as percentage of all CN travel). The transitional zones were excluded from the visual representation to focus only on zones that support specific functions.

The CN's workstation is the most frequently visited zone. Across the three ORs, the primary destination zones from the CN's workstation included surgical table 1, surgical table 2, foot of the surgical table, and supply zone 1. In OR (A), support zone 1 is another primary zone that the CN traveled to from the CN's workstation, while in OR (C) support zone 3 is linked to the CN's workstation. Support and supply zones are locations where the CN engages in material-related activities. Areas around the OR or surgical table including surgical table 1, surgical table 2, and foot of the surgical table are locations where the CN provides either patient- or equipment-related support.

The spaghetti diagrams (Figure 3) show the continuous path that a CN travels prior, during, and after the surgery to complete various activities. Despite the slight variations in each surgery within each OR, the flow diagrams show that CN's flow and movement pattern are very similar irrespective of the type of surgery.

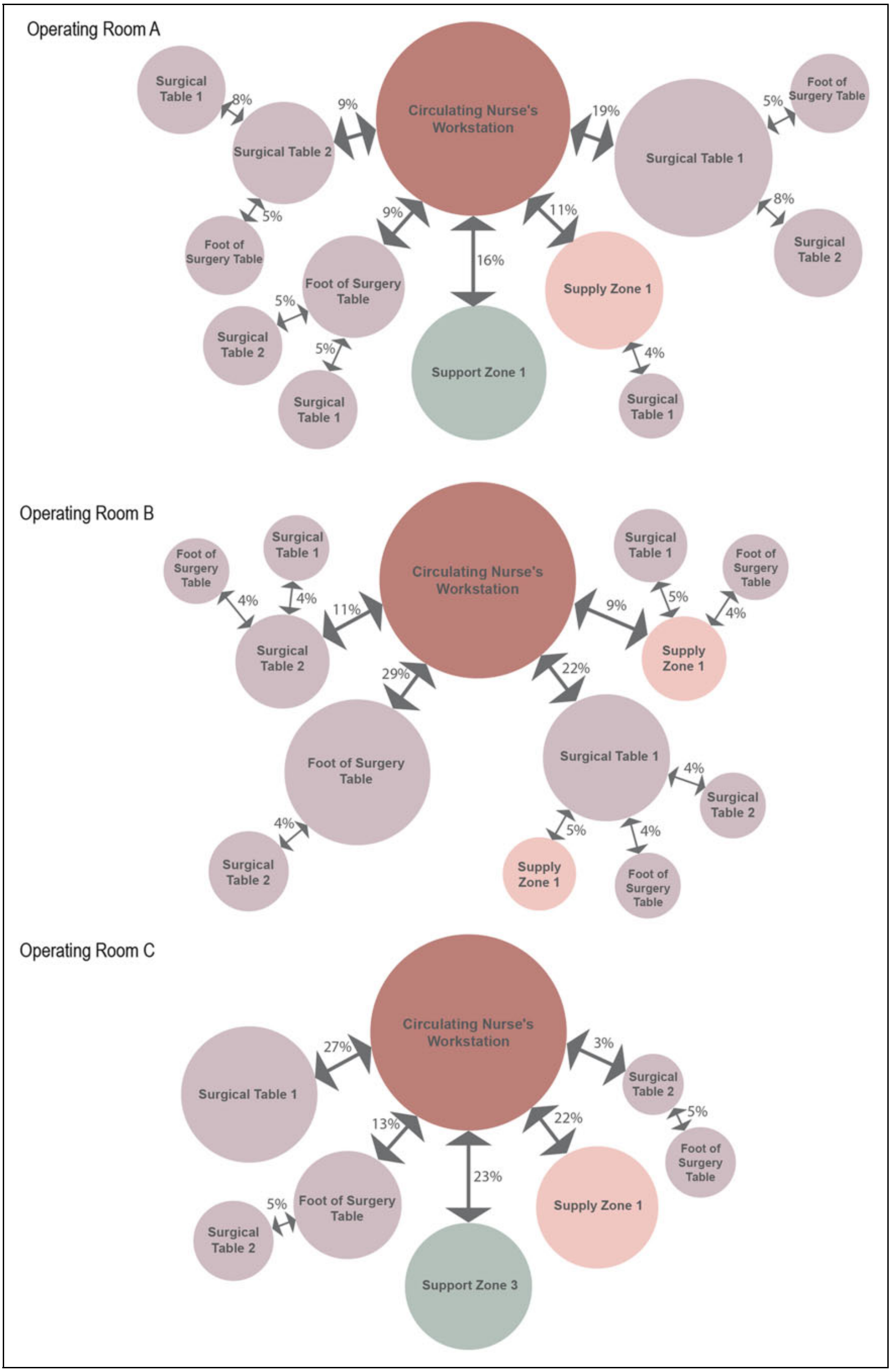

Figure 2. Comparison of linkages between functional zones.

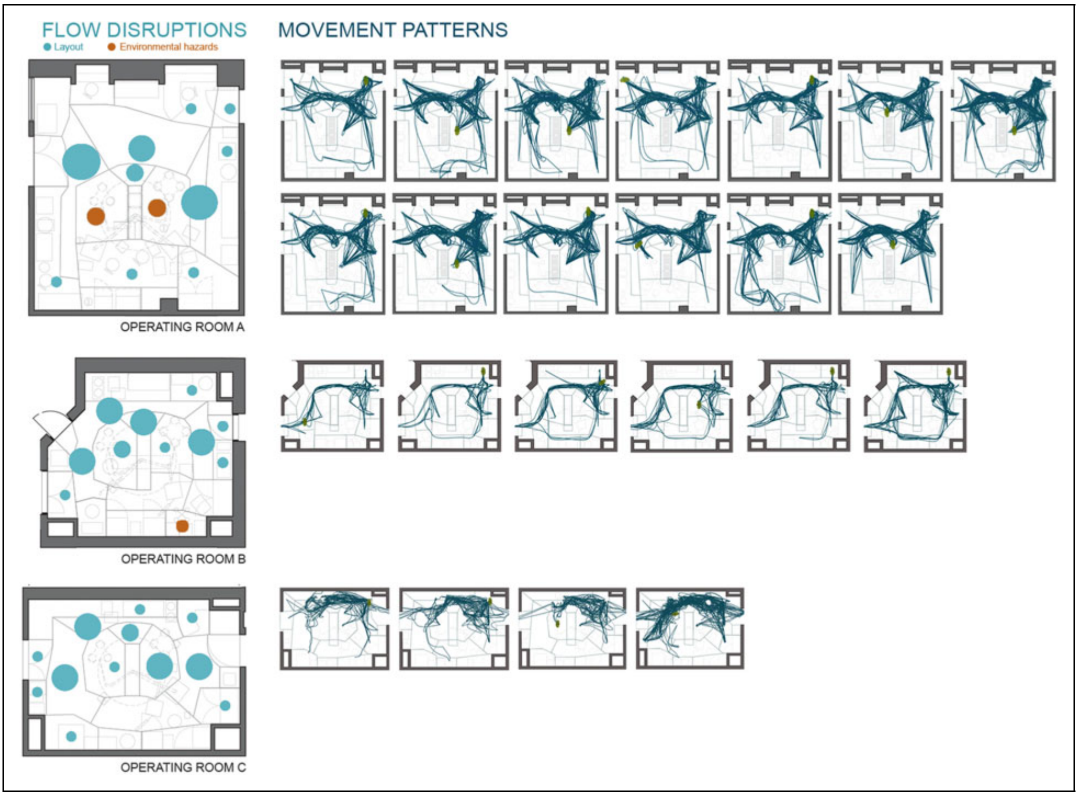

Figure 3. Location and pattern of circulating nurse's (CN) movements and CN-involved flow disruptions across three operating rooms.

Despite the slight variations in each surgery within each OR, the flow diagrams show that CN's flow and movement pattern are very similar irrespective of the type of surgery.

The CN's movement pattern appears similar across all three ORs in that there is a concentration around the CN's station, which extends to the foot and two sides of the surgical table. However, the intensity of flows shown on the spaghetti diagrams varies by OR based on characteristics, such as size and location of functional zones. Although the purpose of this study is to shed light on the influence of the adjacencies between functionally different zones on movement patterns and flow disruptions within the OR, it is noteworthy that the CN's movement patterns show a considerable number of trips to and from the OR doors.

SFDs

For all surgeries taken collectively, the CN was involved in 584 environmental hazard and layout-related SFDs, which roughly constituted 26% of all SFDs (n = 2,200) observed during all the surgeries. Environmental hazards and layout accounted for 152 and 432 occurrences, respectively, indicating that frequency of the layout CN SFDs is roughly 3 times as high as environmental hazards.

The distribution of CN SFDs varied across OR zones, with 58.3% of all CN SFDs taking place in transitional zones, followed by 28% taking place in the three zones surrounding the surgical table. A smaller number of SFDs involving the CN took place at the CN's workstation (4.1%), the door leading to the sterile core (3.4%), and the three supply zones combined (6.3%).

The CN SFD patterns across three ORs were compared by looking at the distribution of layout related and environmental hazard SFD. In OR (A), there were 79 (29%) occurrences of environmental hazard CN SFDs and 194 (71%) occurrences of layout CN SFDs. OR (B) included 25 (29%) environmental hazard CN SFDs and 60 (71%) layout CN SFDs. In OR (C), there were 48 (21%) environmental hazard CN SFDs and 178 (79%) layout CN SFDs. Thus, the patterns of occurrence of environmental hazard and layout SFDs were similar across all three ORs, though OR (C), the largest of the three ORs had a slightly higher percentage of layout-related SFDs as compared to the other ORs.

Figure 3 also shows the location of the layout related (blue) and environment hazard (orange) CN SFDs in each OR. The size of the circle indicates the proportion of total CN SFDs in each zone. As shown in the graph, transitional zones accounted for more CN SFDs than other zones, consistently across all three ORs. Within each room, foot of the surgical table zone was the second most frequent location for CN SFDs. In all floor plans, the CN's workstation also accounted for some CN SFDs.

Discussion

Existing literature shows that the layout of an OR can influence movement patterns (Ahmad et al., 2016) as well as flow disruption (Palmer et al., 2013). This study looked at how the location and adjacency of functional zones within the OR can be factors that influence CN's movement patterns and flow disruptions involving the CN.

The results show that the CN's performance in large part required crossing different functional and transitional zones. Most activities performed by the CN required traveling through multiple zones as opposed to completing an activity within one single zone. Material-related activities resulted in the CN traveling through more zones than any other type of activity; however, information and equipment also required the CN to cross a considerable number of zones. Equipment- and material-related activities required traveling through more transitional zones, which can indicate that the starting and end zones for accomplishing such activities are not adjacent. Material-related activities by nature involve retrieval of supplies and instruments, all of which can be time-sensitive given the operational circumstances. Therefore, adequate proximity of starting and end zones for material-related activities may result in traveling through fewer zones and provide convenient retrieval of materials, supplies, and instruments.

In all three ORs, as expected, the study of the zone linkages showed that the CN's workstation is a main hub for the CN, as it is the most frequent zone from which the CN travels to and from (or where many activities were initiated or ended). The connection of CN's workstation to supply zone 1, surgical table 1, surgical table 2, and foot of the surgical table is consistent regardless of the OR; however, OR (A) and (C) exhibited additional linkages to support zone 1 and support zone 3, respectively. Looking at the layouts of these two ORs reveals that the proximity of the location of the support zones to the CN's workstation may play a role on how often they were visited. In OR (A), support zone 1 and CN's workstation are only two zones away and are set apart by a transitional zone. Therefore, support zone 1 is conveniently located for the CN to provide quick support to the scrub nurse as needed. On the other hand, in OR (C), the CN's workstation is adjacent to support zone 3, where there is a considerable number of travels between the two; in OR (C), support zone 1 is located across the room from the CN's workstation and travel to this zone, located farther away from the CN's workstation, is less frequent.

The primary activity at the CN's workstation is information and communication related, as he or she is responsible for intraoperative medical record documentation and serves as the communication liaison for the other members of the surgical team regarding any communication with other departments (e.g., lab, blood bank, radiology) and other medical, nursing, or support personnel. Thus, perhaps the need to work with a computer when performing information or communication activities requires the CN to primarily work at the CN's workstation. Frequent travels to the areas surrounding the surgical table, prior or after the surgery, reflect CN's responsibilities for performing, coordinating, and delegating patient preparation (e.g., surgical preparation, positioning, temperature maintenance); ensuring the availability of necessary supplies, instruments, and medications for the planned procedure; and acquiring, setting up, and managing equipment.

Further, CN's intraoperative key responsibilities that entail movement within and between zones are monitoring the sterile field for any breaks in aseptic technique and other patent risks (e.g., shift in patient positioning) as well as materials related (anticipate and support supplies, instruments, medications) or communication related (within and external to the OR). Therefore, CN's frequent travels to the support zone 1 can be because of the direct support that the CN provides for the scrub nurse. Throughout the surgery, the scrub nurse remains in the sterile zone and relies on the CN to provide any required items that are located outside of the sterile zone (Ritchie, 2009). Similarly, CN's movement patterns seen in the spaghetti diagram show an extension of flows to the supply areas. This highlights the CN's need to retrieve items frequently throughout the surgery. Therefore, adjacency between supply zone and CN's workstation can be beneficial given the frequency of travels to this area. A study by Ahmad et al. (2016) also highlighted the importance of locating the supply area in relation to other areas that were frequently accessed (Ahmad et al., 2016). Additionally, as illustrated in the spaghetti diagrams, the CN leaves and enters the OR through the door frequently. This is likely due to the need for retrieving items that are stored outside of the OR (Kang, Massey, & Gillespie, 2015). Key decisions regarding location of supplies in the surgical suite can impact the movement of the CN both within the OR and in and out of the OR.

Frequent disruptions during surgery can pose threats to both patient and staff safety and happen through interactions with the physical environment, other personnel, or objects within the OR (Cohen et al., 2016). The literature shows longer travel distances in the OR can result in more interruptions (Ahmad et al., 2016). However, the current study took into account the number of zones traveled and adjacencies as opposed to travel distances. Therefore, reducing the number of zones to be traveled through or in other words locating frequently traveled starting and end zones such that they are closer or where possible adjacent may reduce the involvement of the CN in an SFD while performing an activity.

The data also showed that regardless of the OR type, layout-related SFDs were consistently more frequent than environmental hazard SFDs. An example of a layout-related SFD can be the CN's need to reroute to avoid bumping into equipment or other surgical personnel as they perform their own activities. Therefore, although the flow patterns of the CN can be influenced by adjacency between start and end zone for an activity, it can also be influenced by the need to avoid other surgical personnel or equipment in their path of travel.

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Similar to the existing literature, which indicates OR layouts are contributing factors in SFD occurrences (Palmer et al., 2013), this study found that different zones have different number of CN SFD occurrences, which can be due to several reasons. Analyzing the location of CN SFD occurrences showed that SFDs mostly happened within transitional zones. The spaghetti diagrams of the CN's movement patterns show that the CN spends a lot of time in this area and is moving about frequently during the surgery. Given the high frequency of CN's activities in the transitional zones and in proximity to the surgical tables, the occurrence of CN-involved SFDs in these areas is not surprising. Additionally, other surgical personnel cross these areas frequently to get to the other areas of the OR. Following transitional zones, the areas around the surgical table (surgical table 1 and 2 and foot of the surgery table) include more CN SFDs than any other nontransitional zones. The transitional zones between the foot of the surgical table and the CN zone were very narrow in OR (B) and OR (C), potentially contributing to both layout and environmental hazard CN SFDs. The small size of these areas, which were defined by the research team, can be a contributing factor to the higher number of CN SFDs, as a considerable number of personnel and equipment in these areas can create congestion. Another study also showed the link between the small size of an area and congestion and difficulty of completing an activity (Ahmad et al., 2016).

Understanding the nature of the CN's movement patterns can inform OR design and layout. For the CN whose activities involve circulation within the OR, appropriate adjacencies between zones can help with minimizing unnecessary travels. Traveling through fewer numbers of zones may help decrease the duration of each activity, distance traveled, and risk of being involved in an SFD. Given that OR nurses may suffer from falls, lower back pain, or sprained muscles (Chiou, Chiang, Huang, Wu, & Chien, 2013), it is important to improve their overall experience and occupational safety. This is also important because of the primary role of the CN in protecting patient safety (Yang et al., 2012). Further, these outcomes can help improve the CN's satisfaction, engagement, and retention, which are key concerns for healthcare organizations (Hayes et al., 2012).

Conclusion

While several studies have examined spatial adjacencies and layout configuration at the larger scale of healthcare facilities, the examination of these factors within small-scaled rooms, such as ORs, remains rather sparse. Therefore, this study aimed to explore the contribution of spatial adjacencies to work patterns and flow disruptions at a micro-systems scale. The small size of the OR and the complex dynamics within it requires careful identification of functionally different areas and the relationship between these areas.

By exploring the role of spatial adjacencies in regard to movement patterns of the CN and CN SFDs occurring during PEMSI activities, this study allowed for understanding similarities in utilization of specific zones as well as the need for adjacency between specific zones, overall flow of the CN, and the primary patterns across different ORs. Such understanding offers design practitioners evidence-based insights on the effect of OR layout design on CN's productivity and performance. The CN's workstation remained the central hub for the CN's activities. Given the CN's need to respond to other surgical team members' needs in a timely manner and to reduce unnecessary traffic within the OR, direct proximity between the CN's workstation and the supply zone where key supplies are located is strongly recommended. Indirect adjacency between the CN's workstation and the areas surrounding the surgical table where the CN may need to deliver or exchange items with scrub nurse is recommended. Indirect adjacency allows for a timely response but at the same time allows the CN to maintain distance from the sterile zone to avoid contaminating the area.

While this study was conducted at one healthcare organization, the flow diagrams showed similar flow patterns for the CN across three very different ORs and across different types of surgeries (pediatric and general adult surgeries). This suggests that the role of the CN and the CN's activities during the surgical process are fairly consistent across different surgeries; however, to generalize the findings, this study should be repeated with a representative sample of ORs and surgery types in other organizations.

The physical environment of the OR is a latent risk factor impacting both patient and staff safety, and the CN frequently encounters challenges posed by the physical environment as they navigate the OR. This study provides a foundation for further examination of spatial adjacencies within the OR for the CN as well as other surgical team members, such as the anesthesia personnel or the surgeon. This study also helps in developing evidence-based design recommendations for ORs that takes into account the roles of different team members, the types of activities they perform, as well as their interaction with the physical environment and equipment in the OR. Future studies should focus on assessing the layout configuration in response to the needs of other surgical personnel.

Limitations

This study included various limitations. First, due to the challenging nature of video recording of the OR, only a convenience sample of 25 surgeries were included in this study. The limited number of surgeries in one particular hospital would not allow for generalizability of the findings. Future studies can benefit from a larger sample size for a more robust analysis that may consider different hospitals, cases, and layouts. The differences in the types of surgery could be another limitations as they could influence the flow disruptions and movement patterns; however, the observed similarity in flows supports a hypothesis that regardless of the surgery case, CN's movement pattern in terms of location can be similar but different in frequency.

Implications for Practice

- Unsuitable adjacencies can increase number of zones through which the CN travels. The more number of zones the CNs travels through, the higher the chance of being involved in a flow disruption.
- CN experiences most of the flow disruptions in transitional zones. In addition to size, there are several factors leading to flow disruptions, due to the nature of transitional zones accommodating for personnel and equipment travel.
- CN's most common travel path is between their workstation and the OR table. Therefore, adjacencies between these two zones might be beneficial but should be carefully considered, given that the OR table area is sterile and there should be no disturbances in that area.
- The second most common travel path for the CN is between their workstation and the storage area, suggesting that the adjacency between these two zones could reduce the number of unnecessary trips for the CN.

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