Observation of Neurosurgical Operating Room Door Traffic to Establish Baseline for Intraoperative Prevention of Surgical Site Infections

by

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Background: Surgical site infections (SSIs) are healthcare-associated infections that cause increased morbidity and mortality. Operating room (OR) traffic disrupts airflow and increases the particle counts in the surgical field. Increasing particle counts in the surgical field are correlated with increased incidence of SSIs. To evaluate OR traffic, this study aimed to (1) evaluate two different methods of observation; (2) identify behaviors of staff related to OR traffic and infection control intraoperatively; and (3) interview OR staff to understand their perceptions about OR traffic.

Methods: OR traffic was observed through direct observation by the researcher and indirect observation through a sensor. Three surgeons performed the 107 observed neurosurgeries. Direct observation recorded the number of people and times the door opened as well as why staff entered/exited. Indirect observations recorded the number of people entering/exiting per hour on a larger scale. Short interviews with multiple types of staff were performed to determine reasons for entering/exiting the OR, how often they and all staff entered/exited the OR, and their recommendations to reduce OR traffic.

Results: Direct observation resulted in the OR door opening 18.1 times per hour, with 20.2 people entering/exiting per hour. Going to get supplies, performing hand hygiene, or having a clearly observable task made up 39% of the reasons the door was opened while a procedure was taking place. The remaining 61% of the reasons were not observable. The indirect observations resulted in an average of 31.4 people entering/exiting the OR per hour. The procedure length was significantly associated with the number of people entering/exiting the OR per hour (p-value <0.0001). Interviews with staff revealed that most believed 1-6 people entered/exited per hour. Most staff were shocked to hear the OR traffic averaged 31 people per hour.

Conclusions: OR traffic is higher than the staff expected, and processes should be implemented to reduce the number of times the OR door opens. Implementing simple practices such as using the phone for updates during the procedure and staff education can reduce the OR traffic and control for at least one factor in SSIs.

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Preface

I want to acknowledge and thank Dr. Yassin for the time and energy he spent with me to make this project happen, as well as the rest of the incredible Infection Prevention team for the support they provided to me and this project. I would also like to thank Dr. Martinson and Dr. Baumann for being on my thesis committee and answering all of my questions. None of this could be possible without the support of my friends, family, and the people I have met along this journey.

List of Abbreviations

NHSN – National Healthcare Safety Network

HAI – Healthcare Associated Infection

SSI – Surgical Site Infection

OR – Operating room/suite

OR Traffic – Movement of staff in and out of the OR

Crani – Surgical procedure type including craniotomies, cranioplasties, and craniectomies

cfu – colony forming units

1.0 Background

1.1 SSI Background

Infection has been one of the significant risks of surgery since it was first performed hundreds of years ago and still is today. Advancements in preventing infection through germ theory, hand hygiene, the use of antibiotics, and much more have made surgery safer and more routine. Today, in an 85-year lifespan, the average person will undergo six procedures in the OR (Lee & Gawande, 2008). According to the National Center for Health Statistics, in 2009, 48 million inpatient procedures were performed ("Surgery Statistics - Surgery Clinic | Stanford Health Care," n.d.). About 2-5% of surgeries will develop a surgical site infection (Fuglestad, Tracey, & Leinicke, 2021). Between 2006 and 2009, 1.9% of procedures developed SSIs (Berríos-Torres et al., 2017). SSIs result in significantly increased morbidity and mortality and are associated with a 2- to 11-fold increase in the risk of death (Birgand, Saliou, & Lucet, 2015; Patient Safety Network, 2019). 75% of deaths involving surgical site infections can be directly attributed to the infection (Patient Safety Network, 2019). SSIs also influence the public's perception of medical care as they perceive that SSIs reflect poor quality of care (*Global guidelines for the prevention of surgical site infection*, 2018).

SSIs also have financial implications as they increase readmissions to the hospital and are associated with additional health care costs. Infection due to surgery increases the number of days spent in the hospital after the surgery and may also cause otherwise unnecessary readmission. Infections that are deep or in the organ space may require another corrective surgery further increasing cost and the risk of complications. Hospital stay data from the 2005 US Nationwide

Inpatient sample found that 9.7 additional hospital days were due to SSIs, with an increased cost of $20,842 per admission (de Lissovoy et al., 2009). Nationally this amounts to 406,730 extra days in the hospital, with costs exceeding $900 million annually (de Lissovoy et al., 2009). There are 91,613 readmissions due to SSIs accounting for an additional 521,933 days in the hospital, costing nearly $700 million annually (de Lissovoy et al., 2009). Surgical site infections account for 20% of all healthcare-associated infections and are the costliest, with an estimated $3.3 billion in additional costs (NHSN, 2023). The WHO estimates that the cost of SSIs may reach up to 8.6 billion dollars annually (*Global guidelines for the prevention of surgical site infection*, 2018). These additional costs are also passed down to the patients causing a financial burden.

Infections due to neurosurgical procedures are important to prevent. Bacteria in the intracranial space may cause meningitis, cerebritis, intracerebral abscess, fistulas, and subdural empyema formation (Arad Senaobar Tahaei, Ashkan Senobar Tahaei, Mencser, & Barzo, 2021). Spine infections may cause spondylitis and other progressive neurological symptoms that can be hard to distinguish from other neuromuscular disorders (Arad Senaobar Tahaei et al., 2021). Some of these conditions require surgeons to operate again, with one study showing that 1.2% of neurosurgeries required revisions to treat an SSI (S. Patel et al., 2019). Surgeries with implants have a higher risk of infection. The majority of neurosurgeries have implants associated with them. Neurosurgeries that had implants increased the risk of SSI by 2.74 times (S. Patel et al., 2019). Foreign hardware implantation has significant infectious risk due to the potential for biofilm-related deep surgical infections (DiBartola et al., 2019). Due to these reasons, it is important to surveil and mitigate SSIs in neurosurgical procedures.

1.1.1 Pathogens Causing SSIs

Bacteria are the most common cause of SSIs. Staphylococcus aureus is the most commonly reported at 30.4% of overall infections (*Global guidelines for the prevention of surgical site infection*, 2018). A small amount of Staph aureus is enough to cause infection in an open incision, making it the leading bacterial cause of SSIs (Sadrizadeh, Pantelic, Sherman, Clark, & Abouali, 2018). Staph aureus is released from the skin flora of the patient and surgical staff, becoming an airborne pathogen (Sadrizadeh et al., 2018). Phenotype P is most likely found on patient skin surfaces and environmental samples, while phenotype H is derived from provider hands, both of which are highly transmissible (Loftus, 2016). The following six top pathogens that are associated with SSIs are coagulase-negative staphylococci (11.7%), Escherichia coli (9.4%), Enterococcus faecalis (5.9%), pseudomonas aeruginosa (5.5%), Enterobacter spp (4%), and klebsiella spp (4%) (*Global guidelines for the prevention of surgical site infection*, 2018). Many of these pathogens also have reservoirs on providers' hands, patients, and the environment (Loftus, 2016). Contamination of the surgical wound mainly occurs in the OR via four main routes of microbial entry: (1) patient skin, (2) surgeons and other OR personnel, (3) airborne microbes, and (4) by surgical instruments (Birgand et al., 2014).

1.1.2 SSI Surveillance

Healthcare-associated infections (HAIs) occur while a patient receives care at a healthcare facility. HAIs are reported to the National Healthcare Safety Network (NHSN) at the CDC. Required HAIs to report are bloodstream infections, urinary tract infections, ventilator-associated pneumonia, surgical site infections, and other types of infections. SSIs account for 14-20% of all

HAIs (Birgand et al., 2014). NHSN followed 2,759,027 procedures from Acute Care Hospitals in 2021, 21,186 (0.77%) of which developed SSIs that met the requirements detailed by NHSN (NHSN, 2022). There are three types of SSI, superficial incisional (skin and subcutaneous tissue), deep incisional (deep soft tissues such as the fascia/muscle), and organ/space (NHSN, 2023). SSIs are likely underreported due to approximately 50% occurring after discharge (Berríos-Torres et al., 2017). SSI rates vary between hospitals, procedures, surgeons, and patients (Lo Giudice, Trimarchi, La Fauci, Squeri, & Calimeri, 2019). In specific procedures, the CDC decreased post-discharge surveillance from one year to 90 days to simplify surveillance and reduce delayed feedback (Ogce Aktaş & Turhan Damar, 2022).

NHSN only requires reporting for three neurosurgical procedures: craniotomies, spinal fusions, and laminectomies. Craniotomies and fusions have a surveillance period of 90 days, while laminectomies are surveilled for 30 days (NHSN, 2023). Lumbar microdiscectomies (~0.6-3%) have lower rates of postoperative infection than more complicated surgeries such as fusions (~6-18%) (Arad Senaobar Tahaei et al., 2021). In 2021, the standardized infection ratio (compared to the 2015 baseline period) for craniotomies was 1.154 with 578 observed infections, spinal fusions were 1.071 with 1,889 observed infections, and laminectomies were 0.756 with 373 observed infections (NHSN, 2022).

1.1.3 Preventing SSIs

There are many risk factors for SSIs. These include patient characteristics (such as age, diabetes, obesity, and other comorbidities), type of surgical procedure, duration of the operative procedure, surgeon's skill, control of hypothermia, the OR environment, and the postoperative care of the patient (Birgand et al., 2014). Many of these risk factors are modifiable to prevent SSIs. It is estimated that 70% of SSIs can be prevented by perioperative personnel compliance with evidence-based practices (Ogce Aktaş & Turhan Damar, 2022). Compliance in hand hygiene, skin prep, hair removal, normothermia, glucose control, single-use items, sterile instruments, maintaining a sterile field, post-op wound care, and other areas reduces the risk of SSIs to patients.

Intraoperative SSI prevention consists of many factors, including the environment, equipment, and healthcare workers. The operative environment is tightly controlled, including the positive pressure of the room, temperature, humidity, and air filtering. Many ORs have air handling systems that use laminar airflow. These systems suck air from the OR through high-efficiency particulate air (HEPA) filters around the room's perimeter and return the highly filtered air above the operating table. Equipment used in procedures has exceptionally high standards for sterilizing operative tools. Items with a lumen are especially important as the lumen can retain a bioburden (organic material) that may cause infection. The OR staff also plays a role in preventing SSIs. Staff lead infection prevention includes sterile/non-sterile dress, masking, scrubbing with antiseptic wash, how many people are in the OR, traffic patterns around the room as well as entering and exiting the OR, how many times the door opens, and other measures. Compliance with these practices can decrease SSIs, as seen in a case study from the Nebraska State Health Department that saw an increase in SSIs over a period. After investigating, the Nebraska State Health Department found that the number of people in the OR was potentially associated with SSIs. There were no additional cases after implementing policies that limited OR door openings and OR traffic (Pedati et al., 2018).

1.2 OR Traffic and the Door

1.2.1 Organizational Recommendations

There are many evidence-based recommendations that the CDC and other organizations have established for the prevention of SSIs. The CDC first published guidelines in 1983, but OR traffic was not included until 1999 (Mangram, Horan, Pearson, Silver, & Jarvis, 1999). This guideline stated, "limit the number of personnel entering the operation room to necessary personnel," a category II recommendation indicating suggestive evidence, and the CDC suggests implementation (Mangram et al., 1999). They also recommended "keep operating room doors closed except as needed for passage of equipment, personnel, and the patient" as a category IB recommendation (strongly recommended and supported by evidence) (Mangram et al., 1999). The CDC published updated guidelines for preventing SSIs in 2017 but did not include any new guidelines about OR traffic (Berríos-Torres et al., 2017).

Other organizations besides the CDC also publish recommendations. NICE (National Institute for Health and Care Excellence, UK) published guidelines in 2008 similar to the 1999 CDC recommendations. NICE updated these guidelines in 2019 to state, "Staff wearing non-sterile theatre wear should keep their movements in and out of the operating area to a minimum" (*Surgical site infections: prevention and treatment*, 2020). The Association for Perioperative Practice (AfPP) published guidelines in 2016 that state ORs are restricted areas with limited traffic but do not quantify a limit (Brown & Owen, 2019). AfPP (2016) and NICE (2008) both state that to avoid loss of positive air pressure and enable effective ventilation, movement throughout the OR environment (within and in/out of the OR) should be restricted (Brown & Owen, 2019). Further recommendations from the general assembly of Orthopedics recommend decreasing the number of personnel and door openings during surgery due to correlation with the number of airborne particles in the OR, which predispose to subsequent infections. They cited a moderate level of evidence to support this, with only 2% of the delegates disagreeing (Baldini et al., 2019). These different organizations have established a recommendation about restricting/decreasing OR traffic, but they have yet to suggest the limit due to a lack of sufficient evidence.

1.2.2 OR Traffic

Traffic in and out of the OR during a procedure occurs for many reasons, such as getting supplies, emergencies, breaks for staff during lengthy procedures, clinical discussions, and many other situations. Gathering good evidence on OR traffic is difficult. However, many studies have shown a correlation between traffic in the OR and surgical complications such as SSIs. Many studies have demonstrated that OR traffic has a negative effect on the air quality of the OR (Andersson, Bergh, Karlsson, Eriksson, & Nilsson, 2012). Skin particles that are dispersed by the movement of staff are the main reservoir of air contaminants in the OR and increase with the amount of traffic in the OR (Brown & Owen, 2019). Humans shed large amounts of particles and skin fragments, which makes limiting the number of people and movement within the OR important for minimizing environmental contamination (Birgand et al., 2015).

Microbial levels in OR air are directly proportional to the number of people moving in the room (Mangram et al., 1999). Microbial levels in the air, measured in colony forming units (cfu)/m^3, are positively correlated with traffic flow rates (Andersson et al., 2012; Brown & Owen, 2019). Air contaminants settle on surfaces, the patient, and other sterile items in the OR. Reducing the number of contaminants in the air and traffic in the OR is essential for maintaining the sterility of implants, as breaking the sterile field may be a source of contamination (Agarwal et al., 2018).

Implanting surgical hardware increases the OR traffic due to the required procedures' complexity (DiBartola et al., 2019). Reducing the traffic in the OR is important for air contamination levels and other factors.

OR traffic may also lead to clinical care errors by creating additional noise and being a potential distraction (DiBartola et al., 2019). Opening the OR doors increases movement and interruptions that break concentration and contribute to the risk of adverse events during the procedure (Birgand et al., 2015). OR traffic can be used as a measure of team discipline; thus, reducing OR traffic can improve discipline and concentration while reducing at least one external variable for SSI (Alizo, Onayemi, Sciarretta, & Davis, 2019). Staff, in general, are aware of OR traffic being an important risk factor of SSIs as a Turkish study found that 98.7% of nurses were aware that "The most important factor that increases the risk of SSI is the number of people in the OR, so there should be as few people as possible" (Ogce Aktaş & Turhan Damar, 2022). The study also found that 91% of nurses in a Turkish study were aware that the door of the OR was to be kept closed during the operation, but only 43% reported that it was occurring (Ogce Aktaş & Turhan Damar, 2022).

1.2.3 Opening the Door to Contaminants

Not only are the people moving in and out of the OR associated with increasing air contaminants, but the door opening itself can be associated with the entrance of contaminants into the OR. Frequent door openings are independently associated with an increased risk for SSI (Roth et al., 2019). Door openings correlate with increased bacterial counts and contribute to the risk of increasing SSIs (Buckner, Lacy, Young, & Dishman, 2022). No matter how far from the door, a high number of door openings lead to more bacteria airborne and on surfaces in the OR (Lansing et al., 2021). The number of door openings is statistically associated with increased cfu in the OR overall and outside the laminar air flow (Perez et al., 2018). Many other studies also found statistically significant correlations between the frequency of door openings and increased airborne bacterial counts (Buckner et al., 2022). When adjusting for the length of the procedure and the number of people in the OR, every time the OR door opened increased the likelihood of the cfu/m^3 being higher than 20 (recommended maximum is 20 cfu/m^3 within 30 cm of incision) by 5% (Mathijssen et al., 2016). Air particulate counts increased by 13% when the door to the OR was opened, and large particles correlated to bacterial size were significantly elevated (Teter et al., 2017). Another study agreed with this finding that particles larger than 0.5 microns were significantly increased when the door was open, and particulate levels were higher during cases than between cases (Guajardo, Teter, Al-Rammah, Rosson, & Manahan, 2015).

Opening the door to the OR disrupts the positive pressure environment, which is vital for preventing airborne particle transmission (Sadrizadeh et al., 2018). The positive pressure can be overwhelmed if the door is opened too long or too frequently, causing the ventilation system to fail to maintain the required pressure (Sadrizadeh et al., 2018). If one door is open, the positive pressure is not defeated, but if two doors are simultaneously opened, contaminated air can flow into the OR (Weiser, Shemesh, Chen, Bronson, & Moucha, 2018). When the door is opened, air from the adjacent corridor enters the OR, bringing particles that dramatically increase overall cfu concentrations (Sadrizadeh et al., 2018). Hinged doors cause a sweeping action that can move a significant volume of infectious air through the open doorway (Sadrizadeh et al., 2018). When the door is opened with a frequency of once per 2.5 minutes, it results in an overall elevation of contaminant level of about seven cfu per cubic meter of OR air (Sadrizadeh et al., 2018). It takes

4 minutes for the particle concentration to decline and reach a steady-state level (Sadrizadeh et al., 2018).

Connecting door openings or staff traffic directly to SSIs is difficult due to the low incidence rate of SSIs and feasibility issues in collecting OR traffic data. Thousands of procedures would need to be observed for a large enough sample size to understand the relationship between OR traffic and SSIs. Directly observing staff behaviors regarding OR traffic is time-consuming and not feasible on a large scale for most facilities. Automatic devices can be used to overcome some of these issues. Other studies have used video systems to understand the door openings and movements inside the OR during procedures (Birgand et al., 2015). This study will use direct observation methods, an indirect observation method, as well as interviews with staff to understand the current OR traffic during neurosurgical procedures.

2.0 Methods

2.1 Study Aims

Aim 1: Implement and evaluate two methods of observing OR traffic, direct and indirect.

Aim 2: Observe and identify behaviors of OR staff that influence infection control intraoperatively.

Aim 3: Interview OR staff to understand their perception of OR traffic and behaviors.

2.2 Overview

This prospective observational study occurred in a university-associated hospital that is known for performing a large number of neurosurgical procedures. The study was done in progressive stages, beginning with direct observation, then indirect observation, and concluding with staff interviews. Three different surgeons performed observed neurosurgical procedures in two different ORs (OR 4 and 9), where most neurosurgical procedures are performed. OR 4 has a single door entering the hallway (termed patient door 4) and another door that accesses the "sterile core," which is a supply room. For OR 4, only the hallway (patient door) was observed, as it is the main door for traffic. OR 9 has two doors that open into the hallway and no other access doors. As shown in Figure 1, the door to the scrub sink (termed scrub door) is intended to be mainly used for staff, but the other door to the hallway (termed patient door 9) is also used.

Figure 1: OR 9 Layout

The blue arrow points to the door that exits to the scrub area (scrub door), and the red arrow points to the door that exits into a high-traffic hallway that is also used to move the patient in and out (patient door).

2.3 Direct Observation

Direct observations were performed by randomly selecting neurosurgical procedures and timing during the procedure. All procedures observed were confirmed to be after incision and before closure. Data about the procedure, such as length of procedure, primary surgeon, primary procedure, incision, and closure time, were collected from the electronic health record.

Observations were made from a discrete area in the hallway where the door and adjacent area were in clear view. When asked, the researcher would identify themself and answer any questions asked. Every time the door opened was recorded, as well as how many people entered/exited. A door opening was recorded if the door had opened any distance, even if no one had walked through the door. If the door was held open for longer than a standard door swing (~14 seconds for the scrub door, ~6 seconds for the patient door), it was recorded as an extended open door. The length of time the door was open was not measured as this was not feasible to measure accurately. The reason for the door opening was recorded if observable, such as if a staff member was carrying something, did a task within sight, or another identifiable task. Hand hygiene was also recorded every time a person entered or exited the OR. If the staff member exited to perform hand hygiene and reentered, the hand hygiene was recorded only on entry. In this case, two door openings were recorded if the door completely shut after exiting the OR and then had to be reopened to reenter. The type of staff member was not recorded as all the staff is dressed relatively the same, with badges not always visible or readable.

Ten hours of observation were completed of 7 different procedures. Each procedure was observed for at least one consecutive hour, with three procedures (one of each procedure type) being observed for two consecutive hours. Surgeon A was the primary surgeon for three procedures, while Surgeons B and C were primary for two procedures each. The types of procedures observed are listed in Figure 2. These procedures ranged from 3 hours and 8 minutes to 6 hours and 38 minutes long.

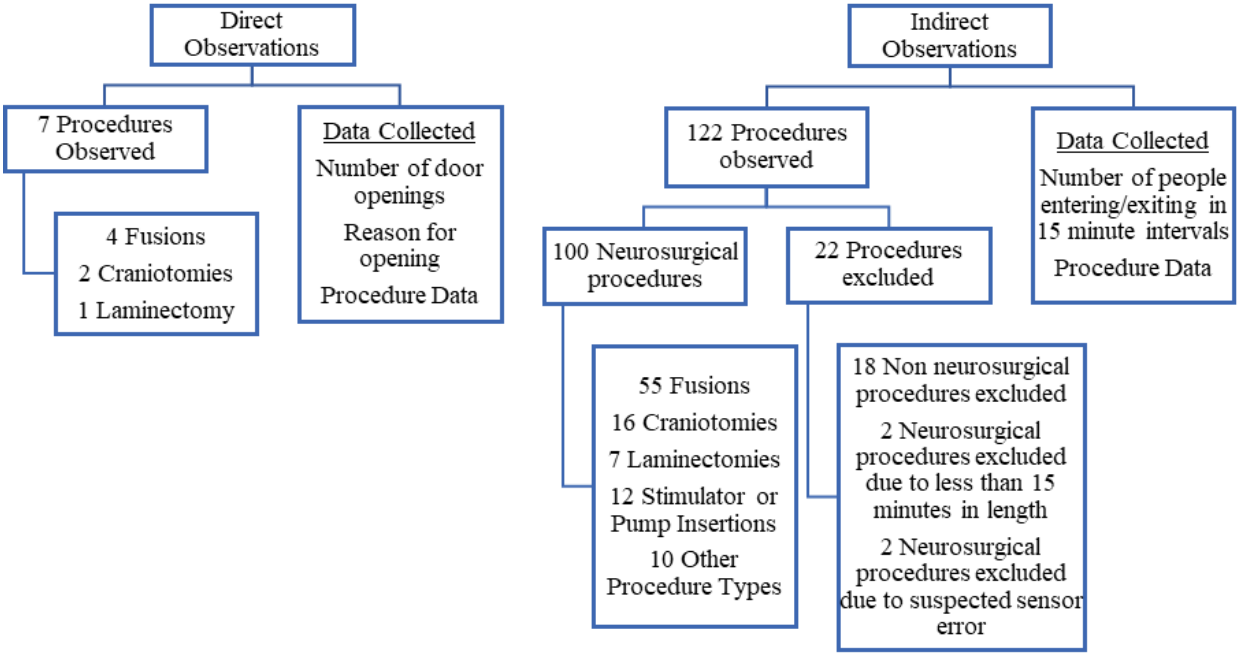

Figure 2: Flow Chart of Procedures Included for Each Observation Method

2.4 Indirect Observation

Indirect observations were completed with three PEARL Wireless People Counters and the associated T.M.A.S software by SMS Storetraffic. This device is a battery-powered wireless sensor that counts the number of times a sensor is crossed. It also differentiates the direction (in or out) the sensor was crossed. The three devices were placed on either side of the three OR doors to the hallway (Patient Door 4, Scrub Door 9, and Patient Door 9). This device is small and reasonably discrete, as shown in Figure 3. The light flashing is the only visual indicator of the device registering movement between the sensors. The devices collect data for every 15 minutes of traffic starting on the hour. The associated device software generates Excel reports of specified time periods and the traffic that was counted for each 15-minute interval by direction (in or out). The devices were validated to ensure they were accurately counting and to determine if any factors would influence them. Influencing factors were identified, such as equipment crossing sensor, hesitation at the door, and placement of notes on the door. This is a limitation of the device to collect accurate data. Data was collected from the electronic health record to determine the procedures performed in the observed ORs. Demographic data (sex and age) was recorded about each patient. The time when the incision was made and the patient was closed was recorded. The procedure type and primary surgeon were also collected from the electronic health record.

Figure 3: Device Placement on Doors of ORs 4 and 9

Left: OR patient door 4, Right: OR scrub door 9. The sensors that collect data are circled in red. Not pictured is the sensor for OR patient door 9.

Four of the neurosurgical procedure for which data was collected had to be excluded for various reasons. Two were excluded because the procedures were less than 15 minutes long, and the sensors do not report the number of entries/exits for intervals shorter than 15 minutes. One was excluded due to a device error where no traffic was recorded for an hour before, during, or 2 hours after the procedure. The last one was excluded because it was a significant outlier compared to the rest of the data, with 106 people entering or exiting per hour. This could have been a device error, or the count may have been accurate, but it does not represent a standard procedure as there may have been an emergency. One hundred neurosurgical procedures had complete analyzable data.

Surgeon A was the primary surgeon for 47 procedures, Surgeon B was the primary for 44 procedures, and Surgeon C was the primary for nine procedures. Forty-five procedures were performed in OR 4 and 55 in OR 9. Sixty of the patients were male, while 40 were female. The age of the patients ranged from 18 to 88 years old. Spinal fusions were the most common procedure performed (n=55). 25 lumbar or thoracic fusion, 19 cervical fusions, 16 crani procedures (craniotomies, cranioplasties, or craniectomies), 11 extreme lateral fusions, seven stimulator insertions, seven laminectomies, five pump insertions, three battery replacement/removals, three microdiscectomies, and three miscellaneous other procedures on the neurosurgical service were in this sample (Figure 4). The procedure's length varied from 31 minutes to 9 hours and 38 minutes, averaging 2 hours and 48 minutes long. The device did not record between 1 and 28 minutes of the beginning or end of each procedure, with an average of 13.98 procedure minutes without data. Procedures were counted as occurring during lunch if the procedure was ongoing between 10:30 and 13:30. Staff relief occurs at 14:30 when the shift changes. Lunch and relief were categorized together as a single variable.

When analyzing the number of people entering/exiting the OR and the procedure length, the appropriate t-test was used, such as students t, sign, or Kruskal Wallis test. Variables with more than one categorical variable were analyzed with Welch's ANOVA, and a post hoc Tukey analysis was performed when appropriate. Linear regression was performed to analyze the relationship between the length of the procedure and the number of people entering/exiting the OR. The threshold for statistical significance used was $\alpha=0.05$. All statistical analyses were performed in SAS.

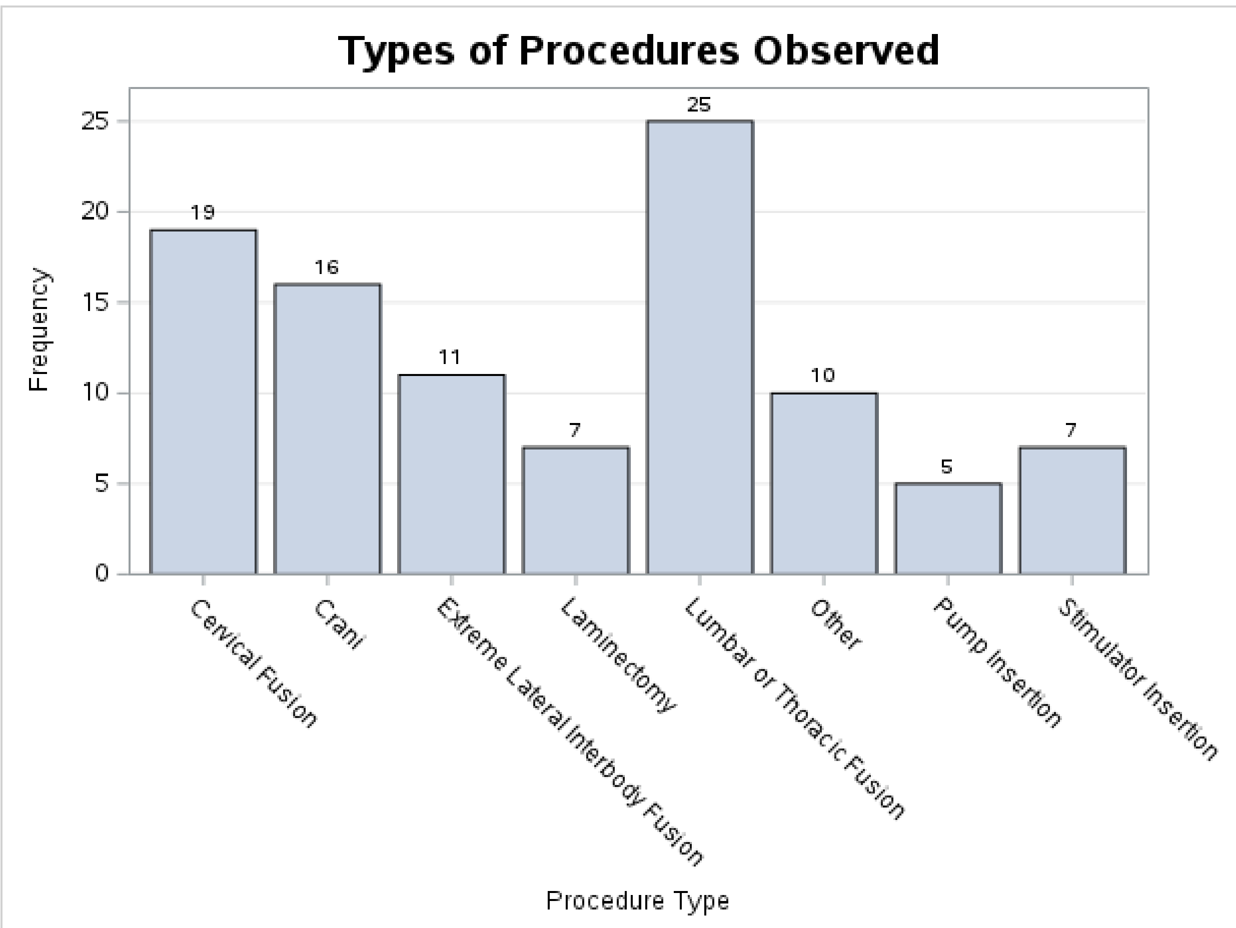

Figure 4: Indirect Procedure Types Observed

Histogram of the number of each type of procedure that was indirectly observed.

2.5 Interviews

Interviews of staff members were performed to determine the perception of staff members around behaviors entering and exiting the OR while a procedure was taking place. Staff members were asked why they would enter/exit an OR during a procedure, how often they would, and how many times they thought all staff entered/exited. The staff member was then told that, on average, 31 people entered/exited the OR during a procedure and asked about their reaction. Based on the information, they were also asked if they would change their behaviors. Finally, the staff was asked if they had any recommendations for reducing the number of times staff enter or exit. The full interview guide of questions is available in Appendix A.

Interviews took place within the department and took 2-3 minutes to complete. Staff were intercepted and sampled by convenience on two separate days to complete interviews. Surgeons, nurses, technicians, anesthesiologists, vendors, and housekeeping were included in the different staff types interviewed. Interviews were audio recorded after obtaining consent from the staff members being interviewed. Two surgeons, three anesthesiologists, four nurses, three technicians, two vendors, and one housekeeper were interviewed. Twelve complete interviews were conducted, three of which included more than one staff member. Audio recordings were then transcribed and analyzed using thematic analysis to identify similar points between staff members interviewed.

3.0 Results

3.1 Direct Observation Results

During the 10 hours of observation, the door opened 174 times during the procedure, with 198 people entering or exiting. The door was opened on average 0.30 times per minute or 18.07 times per hour (SD 3.59). Figure 5 shows the number of door openings per hour for each observed procedure. 87% of the time the door was opened, one person entered/exited. Of the 174 times the door was opened, only 23 times did more than one person go through the door. On average, 0.33 people entered or exited the OR per minute or 20.21 people per hour (SD 5.54). The time between door openings ranged from 0 to 24 minutes, with an average of the door opening every 3 minutes and 18 seconds. Although the average door opening occurred every 3 minutes, 67% (110/163) of the door openings occurred within 0 to 2 minutes of the previous door opening. The door was opened for an extended period 23 times, with an average of 2.2 times per hour. The number of times the door was opened positively correlates with the procedure length (Figure 6). From incision to closure, on average, one door was open for a total of 18 minutes or 6.4% of the procedure. There was a negative correlation between the number of times the door opened and the average length of time between door openings during the observed part of the procedure.

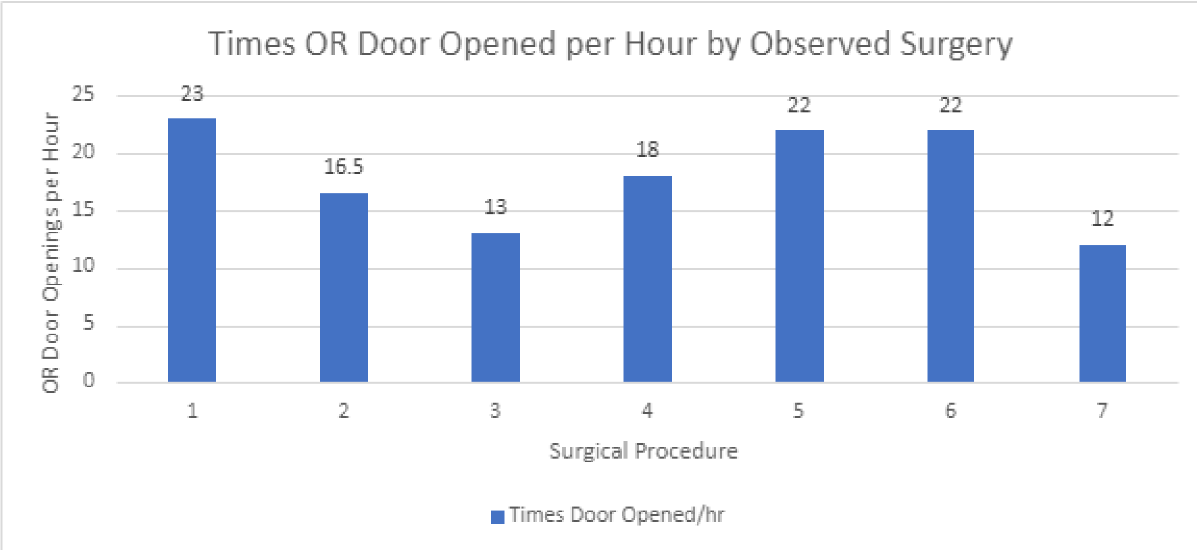

Figure 5: OR Door Opening per Hour in Directly Observed Procedures

Number of times the OR door opened per hour by individual directly observed surgery.

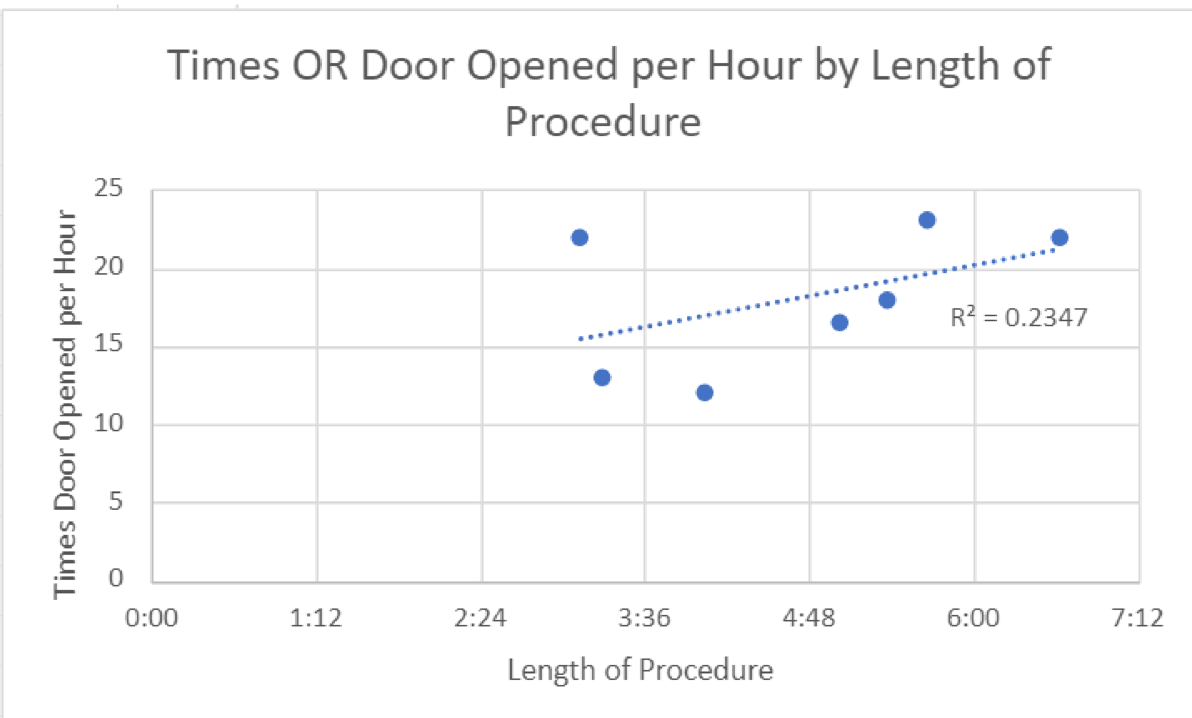

Figure 6: Scatter Plot of Door Openings per Hour by Length of Procedure

The relationship between the number of times the OR door was opened per hour by the length of the procedure during direct observation.

Staff entered or exited the OR for many reasons during a procedure (Figure 7). Staff opened the door to retrieve supplies 18% of the time or had a clear task 16% of the time. Examples of clear tasks were bringing in or out imaging equipment, sending off samples, emergencies in nearby areas, and other visually identifiable reasons within the area of the observer. The staff opened the door to perform hand hygiene 5% of the time. Hand hygiene was not performed outside of the OR by a majority of the people that entered during a procedure (averaging 82.3%). The rest of the time the door was opened, there was no observed task (59%), or no one entered or exited, but the door was opened for no reason (2%).

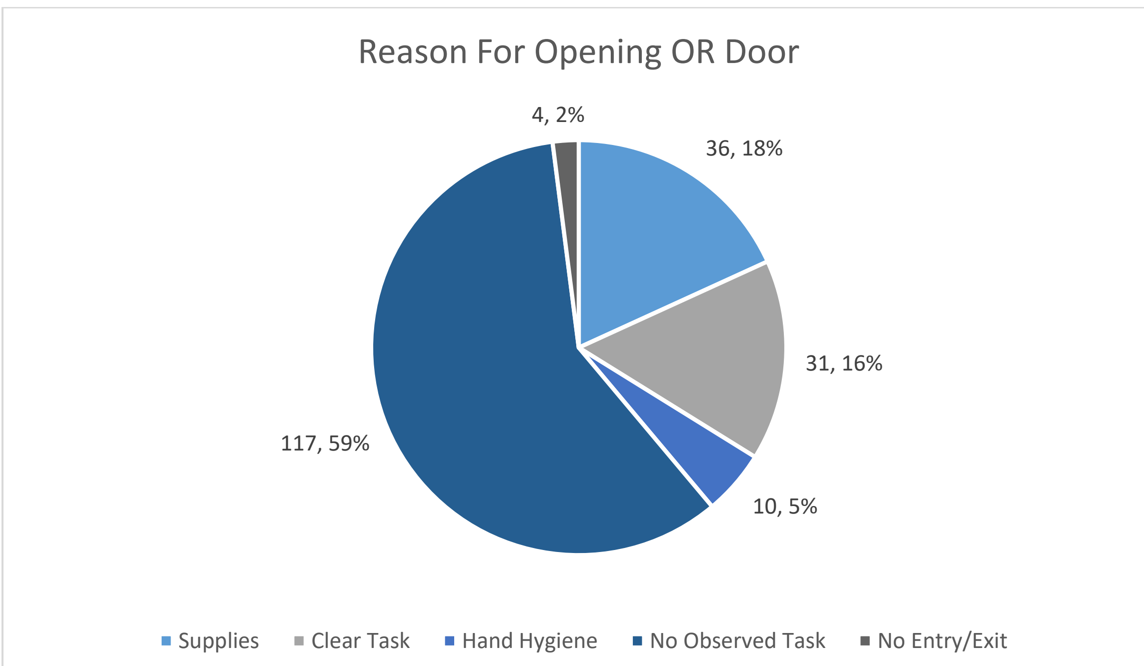

Figure 7: Pie Chart of Reason for Opening OR Door

The different reasons for opening the OR door while a procedure was taking place during directly observed surgeries.

3.2 Indirect Observation Results

Of the 16,818 procedure minutes, 15,420 minutes (257 hours) of the procedure had data on how many people entered or exited the OR. The average length of the procedure was just over 2 hours at 154.2 minutes ranging from 15-570 minutes. No data was collected for an average of 13.98 minutes per procedure, ranging from 1 to 28 minutes. The sensor was crossed 9,143 times in 257 hours. Roughly 91.42 people entered or exited per procedure ranging from 1 to 557 people per procedure. On average, 31.36 people entered or exited per hour during the observed length of the procedure. This ranged from 4 to 69.17 people entering or exiting while the procedure took place per hour. There was a significant association (p-value of <0.0001, with an $r2 = 0.2501$) between the length of the procedure and the number of people entering/exiting per hour. This relationship is shown in Figure 8. There was a statistically significant difference between the two doors in OR 9, where there are two doors to the hallway (picture of OR and the doors in Figure 1). The staff favors the door exiting to the scrub sink, with significantly more people entering/exiting per hour (5.6 people/hour) on average than the patient door. Age, sex of patient, surgeon, and which OR the procedure was performed in were not significantly associated with the number of people entering/exiting per hour.

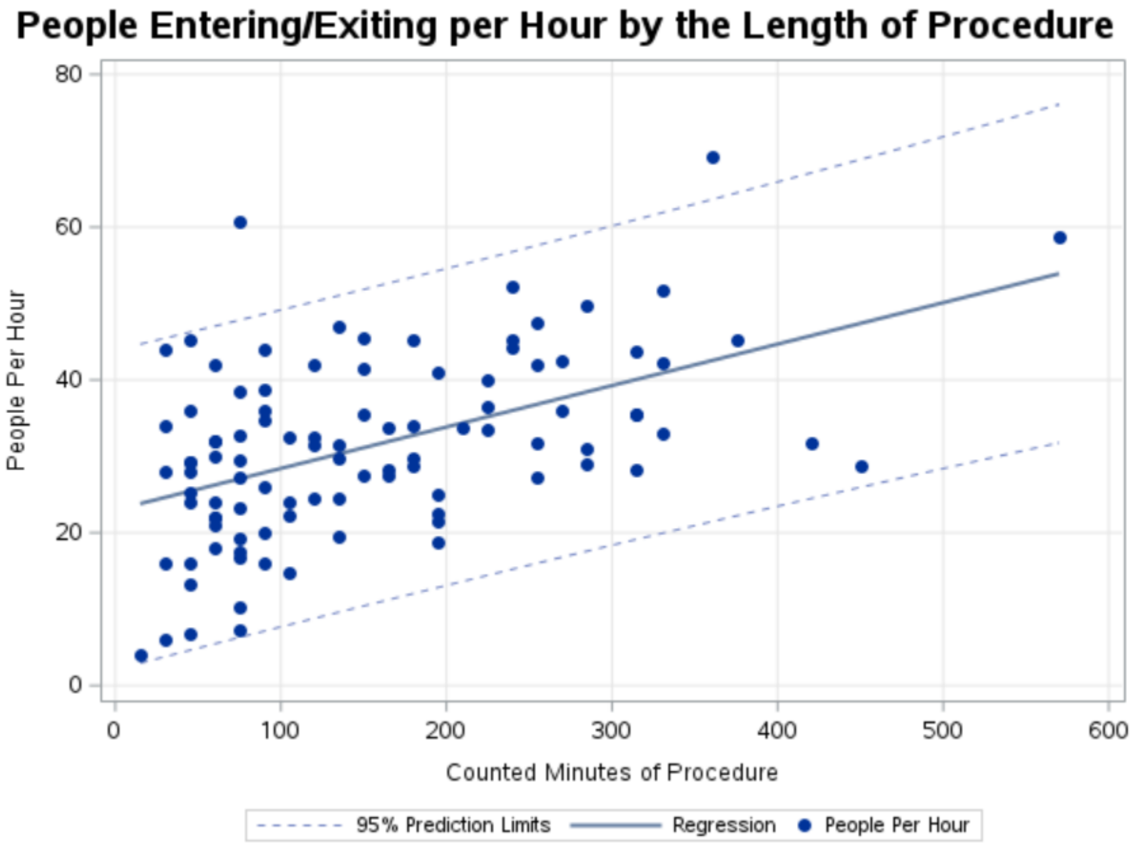

Figure 8: Scatter Plot of People Entering/Exiting per Hour and Length of Procedure

The linear regression of people entering/exiting per hour and the procedure length was statistically significant with a p-value of <0.0001 and r^2 of 0.2501.

Table 1 analyzes the mean number of people entering/exiting per hour. There was a significant increase of 9.91 people entering/exiting per hour if the surgery was longer than 120 minutes (p-value <0.0001). If the procedure occurred during lunch (10:30-13:30) or relief (14:30), there was a statistically significant difference (p-value of 0.007) in the number of people entering/exiting the OR when compared to if the procedure did not occur during these times. If lunch or relief occurred, the average number of people per hour increased by 7.91 people entering/exiting the OR per hour. If lunch or relief occurred during the procedure, the length of the procedure was significantly longer (Table 2, p-value <0.0001). Procedures that began before 12:00

were not significantly different from those that began after 12:00 in either the length of the procedure (p-value of 0.8082) or the mean number of people who entered/exited (p-value of 0.1376).

The type of procedure performed (Figure 9) also significantly influenced the number of people entering/exiting the OR per hour (p-value 0.002). There was a significant difference between the lumbar or thoracic fusions (36.39 people per hour) and stimulator insertions (20.87 people per hour). The type of procedure also significantly influenced the procedure length, with lumbar or thoracic fusions being, on average, 251.6 minutes, while stimulator insertions were the shortest, with an average of 96.71 minutes. Of note, only one of the seven stimulator insertions occurred during lunch or relief, while 18 of the 25 lumbar or thoracic fusions occurred during lunch or relief.

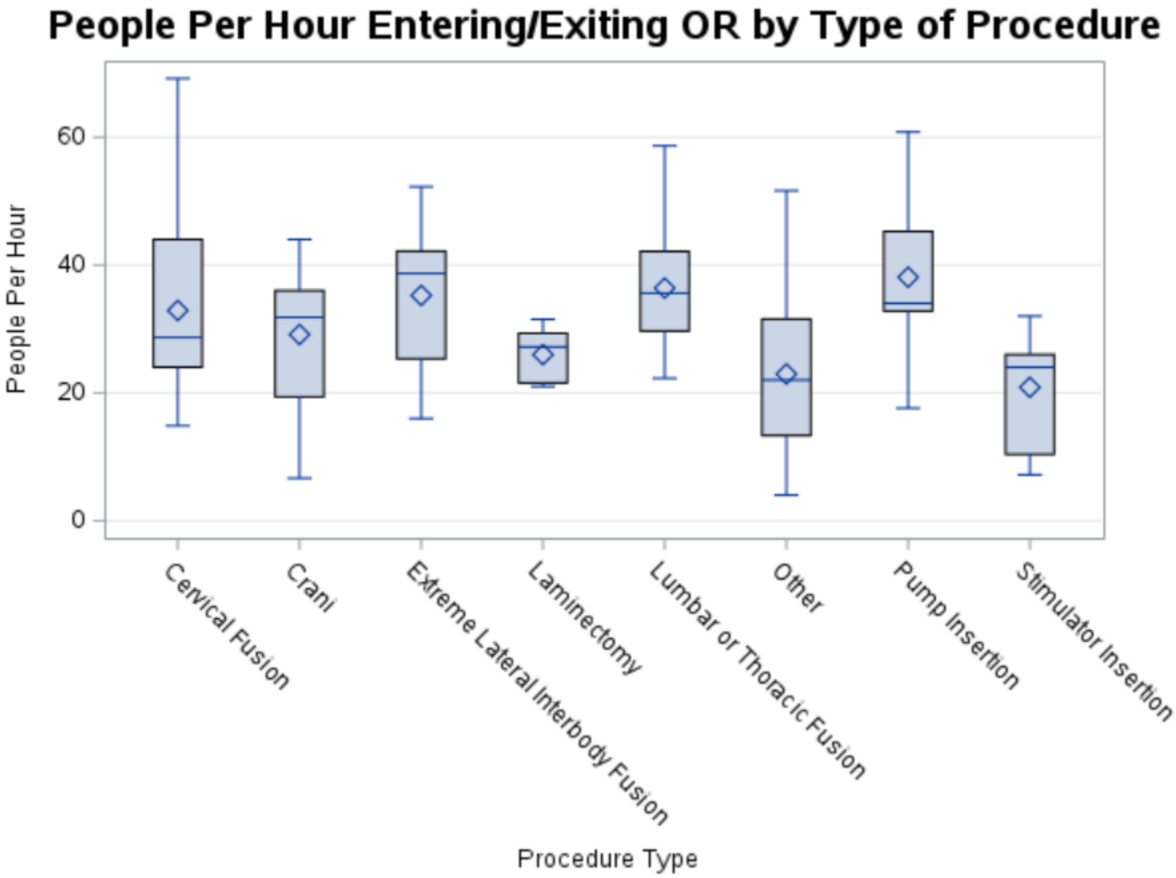

Figure 9: Box plot of People per Hour by Procedure Types

Box plot of how many people entered/exited the OR per hour while the procedure was taking place by the type of procedure. Only the Lumbar or Thoracic Fusions and Stimulator Insertions were significantly different.

Table 1: Characteristics of Procedures in Relation to the Number of People Entering/Exiting per Hour

	Sample Size	Mean Number of People Entering/Exiting per Hour (SD)	Range	p-Value
Length of Procedure †				
<120 Minutes	46	26.01 (11.73)	4.00-60.80	<.0001*
>120 Minutes	54	35.92 (10.16)	18.77-69.17	
Start Time ‡				
Before 12:00	60	33.00 (12.93)	4.00-69.17	0.1376
After 12:00	40	28.89 (9.91)	7.20-49.68	
Staff Change for Lunch or Relief during Procedure ‡				
Lunch/Relief	54	35.00 (11.44)	6.67-69.17	0.0007*
No Lunch/Relief	46	27.09 (11.16)	4.00-60.80	
Difference between doors in OR9 ¶				
OR 9 Scrub Door	55	20.69 (7.34)	5.00-35.16	0.0001*
OR 9 Patient Door	55	15.01 (6.73)	3.00-39.33	
Surgeon §				
A	47	33.15 (13.16)	4.00-69.17	0.2463
B	44	29.08 (10.54)	6.00-52.25	
C	9	33.15 (10.91)	18.00-51.64	
Procedure Type §				
Lumbar or Thoracic Fusion	25	36.39 (8.44)	22.29-58.63	0.0020*
Cervical Fusion	19	32.88 (13.45)	14.86-69.17	
Crani (All types)	16	29.12 (10.07)	6.67-44.00	
Extreme Lateral Interbody Fusion	11	35.24 (11.31)	16.00-52.25	
Laminectomy	7	25.98 (3.95)	21.00-31.50	
Stimulator Insertion	7	20.87 (8.86)	7.20-32.00	
Pump Insertion	5	38.09 (16.06)	17.60-60.80	
Other	10	22.96 (14.59)	4.00-51.64	

* Significant differences in the mean number of people entering/exiting per hour. P-values below the alpha level of 0.05 are significant.
† Student t test
‡ Kruskal-Wallis test
¶ Sign t-test
§ Welch's ANOVA
Note: SD standard deviation

Table 2: Analysis of Variables by Length of Procedure

	Sample Size	Mean Length of Surgery (minutes) (SD)	Range	p-Value
Start Time ‡ Before 12:00	60	177.5 (124.5)	31-578	0.8082
After 12:00	40	154.2 (79.93)	48-329	
Staff Change for Lunch or Relief during Procedure ‡ Lunch/Relief	54	221.4 (113.3)	32-578	<.0001*
No Lunch/Relief	46	105.7 (60.33)	31-329	
Procedure Type § Lumbar or Thoracic Fusion	25	251.6 (108.37)	88-578	0.0001*
Cervical Fusion	19	179.4 (99.44)	52-397	
Crani (All types)	16	153.1 (109.26)	54-430	
Extreme Lateral Interbody Fusion	11	132.7 (89.72)	54-335	
Laminectomy	7	129.7 (80.17)	56-269	
Stimulator Insertion	7	96.7 (23.14)	78-140	
Pump Insertion	5	110.0 (80.85)	48-252	
Other	10	107.4 (103.09)	31-347	

* Significant differences in the mean length of procedure in minutes. P-values below the alpha level of 0.05 are significant.
‡ Kruskal-Wallis test
§ Welch's ANOVA
Note: SD standard deviation

3.3 Interview Results

All staff types except housekeeping had entered the OR while a procedure was taking place. Reasons staff reported to have entered/exited for were supplies, medications, equipment, to assist elsewhere or in the OR, lunch/breaks, to teach staff/students, and to check on the patient or staff. Each staff member reported having entered the OR during a procedure between 1 to 3 times a procedure. One staff member commented that they enter/exit "as minimal as possible," but it depends on the situation as they enter/exit "for urgent cases probably pretty frequently." Another staff member said that the staff present will influence the number of times they enter/exit, “If there is staff that is competent in there and they don’t need me, then usually just once just to check on them.” Surgeons are one group that reports leaving less than other staff types as “besides bathroom breaks, we (surgeons) are in there until the surgery is complete or almost complete.”

When asked how many times they thought, on average, all staff entered/exited the OR during an hour of procedure, the majority responded that 1-5 people entered or exited. One staff member said, “There's quite a bit of traffic. It’s not like the room is closed,” and then reported that 2-3 people enter/exit per hour. Only two staff members reported anything higher than five times per hour, with one saying that “at least six times, maybe even more. It depends. Anesthesia is in and out all the time, circulators get their breaks in and out all the time, we get one, and if there are reps (vendors). The doors are always going.” The other staff member said that “at most 10” people entered or exited per hour. When asked how many people entered or exited for the average procedure, their answers varied more widely, with 2 to 20 people entering/exiting per procedure. This seemed to depend on what the staff member thought the average procedure length was.

After being told that the average from the data collected was 31 people entering or exiting per hour, the majority of staff thought that it was “shocking,” “insane,” were surprised and that it was “excessive” and “eye-opening.” One staff member commented, “I'm sure it all adds up, but that is a big number.” Only two staff members disagreed with the majority response and commented that there seemed to be "an army of people that come in" and that it was "not surprising at all." Many staff members, after being told this, started listing all the things that staff enter/exit for that they hadn’t considered previously, such as, “Nurses come in and want to know where I am at in the case, can they call for the next one, are you available, there is always a question.” One recognized this and commented, "It’s funny; it’s more than I realize even.”

Two different staff members commented on the behaviors of surgeons, saying that "Residents and surgeons also pop in and out a lot" and "surgeons come and go a lot because they have more than one room (more than one procedure occurring at the same time), and trainees so they go back and forth." When asked more about two procedures being run simultaneously by the same primary surgeon, the staff member said, "They do it all the time. If two rooms (are) going (they are) breaking scrub, going over there doing time out, coming back over here. It's constant. They get their residents started, then they go to another room and start another one." Two procedures occurring simultaneously were observed in the electronic health record on many occasions when pulling procedure data for the indirect observations.

When asked if they would consider changing their behaviors, all staff except a couple said they maybe or would change their behaviors about entering/exiting when possible. Many said they would think about it more and pay more attention to how many people go in and out. Surgeons were the only staff type who unanimously said they would not change their behaviors. One surgeon replied, "No, I won't change a thing. Why would I change? I have the lowest infection rate in the hospital." When asked this question, one staff member talked about the importance of traffic when doing implantations. They said, "If we are putting implants in, we shouldn't be leaving, we shouldn't be exchanging, we shouldn't be this shouldn't be that, and the doctors will look at me and be like yeah tell me about it like they get pissed, and they are mad because it shouldn't happen. Everywhere else I have worked, you are not allowed to swap in or out when there are implantations going on. Here it's all the time."

Many staff members provided suggestions about how to reduce the number of people entering/exiting the OR. The most common suggestion was to use phones more for communication during the procedure. They also talked about having supplies already in the OR, increasing staff awareness, putting a sign on the door, changing break schedules so they are less frequent but longer, and no longer letting one surgeon run two procedures simultaneously. During the interview, two staff members who had worked at other hospitals said there was less traffic in and out of the OR because it was closely monitored or part of the culture. One staff member said reducing OR traffic is "challenging because of the culture in place."

4.0 Discussion

4.1 Direct vs. Indirect Observation

Direct and indirect observation of OR traffic enables the collection of similar but different understandings of people entering and exiting the OR during procedures. While direct observation allows for the collection of how many times the door opened, how many people entered/exited, and why the door opened, it takes a considerable investment of personnel resources to collect sufficient data for comparison. The bulk investment in indirect observation is the initial setup and cleaning of the sensor's data. However, it restricts the data that can be collected to only the number of people that enter or exit. Directly comparing the results of the two allows for interesting conclusions.

The average number of people entering/exiting the OR while a procedure was occurring in direct and indirect observation was 20.21 and 31.36 people per hour, respectively. These numbers may differ because of many reasons. The sample size of the direct measurement is very small compared to that of the indirect measurement, which may skew this comparison. The direct measurement could also be underrepresented due to only one of OR 9's doors being monitored, not accounting for the traffic through the other door. The indirect measurement could be inflated due to the sensor miscounting because of equipment passing through, people leaning into the door but not entering, and other situations not described here that the sensor counted as traffic.

The difference between the number of people going through each of OR 9's doors may demonstrate the potential over-counting of the people. Patient door 9 has no window for people to look in and is not used as a communication board for staff. Thus, people are far less likely to cross the sensor on accident. This may explain the roughly five-people-per-hour difference between the two doors. It is unclear if this difference indicated that staff favors the scrub door for entering or exiting the OR during a procedure or if they are used equally. Increasing the sample size of the direct observations and fixing problems with the methodology of both methods should decrease the difference between the mean number of people per hour.

4.2 Procedure Length and OR Traffic

The data from the indirect counter and suggestive data from the direct observations indicate that the length of the procedure is an important factor in the number of times people enter/exit the OR during a procedure. The length of the procedure is a significant risk factor for SSI risk, as every 30 minutes of surgery increases the risk of infection by 2.5% (Harrop et al., 2012). The indirect observation data found that the length of the procedure is significantly correlated with the number of people entering/exiting the OR. The type of procedure and if the procedure occurred during lunch or the afternoon relief were confounding factors of this relationship, as both factors were significantly related to the mean number of people entering/exiting the OR and the length of the procedure. It is unclear what the nature of this relationship is. One explanation may be that many of the longer, more complicated procedures were scheduled to start in the morning and, due to their length, went through the lunch/relief period. This is not indicated to be true of the present data, as there was no significant difference between the length of the procedure or the mean number of people entering/exiting during the procedure if the procedure occurred before or after noon. Therefore, the procedure type and if the procedure occurred during the lunch/relief period may increase the number of people who enter/exit during a procedure. However, it is unclear from this data how much influence these factors have.

Bohl et al. also found that the procedure length and type of procedure were significantly associated with SSI. Cranioplasty, open craniotomy, and posterior spinal fusion were the neurosurgical procedure types with the highest rates of SSI compared to other neurosurgeries (Bohl et al., 2016). Other researchers have found that when looking at start times for procedures, there was no difference in door opening rates if the procedure started during the morning, lunchtime, or afternoon (P. G. Patel et al., 2021). The findings from the present study agree with this in that there was no difference between procedures that started before or after noon. 9.91 more people entered/exited per hour if the procedure is longer than 2 hours. This may be a factor in why a surgical duration of >2 hours is an independent risk factor for SSI (Harrop et al., 2012). Procedures longer than 180 minutes for neurosurgical procedures also significantly increase further operation risk by 1.85 times (S. Patel et al., 2019). The length of the procedure is an important factor in the risk of SSI, but it is unclear what other factors may be influencing that risk.

4.3 Comparison of OR Traffic in Other Studies

Considering the reasons mentioned above why the data may not be perfectly accurate, let us compare what other studies have found when doing similar methodologies in different hospitals. At a different hospital in the same hospital system where this study took place, researchers found that the door opened 6.27 times per procedure (Laughman & Jones, 2020). A French study found a rate of 10.6 entries/exits from the OR from incision to closure, but their median procedure length was 37 minutes (Loison et al., 2017). Another study found 13.4 door openings per hour (Teter et al., 2017). A study in Switzerland found that the mean number of door openings per hour was 14.9 for an external door in cardiac procedures (Roth et al., 2019). When adjusted for the operative time, a study found that the mean rate of door opening per hour for all cases was 19.2 (6.4 - 38.2) (Young & O'Regan, 2010). All five of these previous studies have fewer times the door opened than the data from this study showed.

A study of hip replacements using cameras to monitor door openings found a baseline of 21.6 per hour (Hamilton, Balkam, Purcell, Parks, & Holdsworth, 2018). The case length averages 159.9 min, with observations averaging every 2.1 min (28.5/hour) from the opening of sterile instruments to closure (Anderson, Lipps, Pritchard, Venkatachalam, & Olson, 2021). Orthopedic operations had a rate of door openings ranging from 12.6 to 41.4 per hour (Lansing et al., 2021; Perez et al., 2018). Overall, many of these studies were done in orthopedic procedures and are similar but not directly comparable to the work done here. Many of the methodologies included differing definitions of procedure start time that prevent direct comparison due to the difference in traffic while the patient is being prepped and put under compared to after the first incision. The data collected in this study is within the range of values from these other studies but is higher than many, indicating room for improvement.

Understanding why the doors open is essential for implementing changes to reduce the number of people entering/exiting the OR. Many of the reasons that were found in the direct observations were necessary, but there was a large chunk that was unknown. The interviews with staff shined a light on the possibilities of why these people entered or exited the OR. 39% of the times people entered/exited were to get supplies, instruments, equipment, or other tasks. This is a similar percentage of traffic as similar studies in observing why the door opened (Anderson et al., 2021; Guajardo et al., 2015; Loison et al., 2017). Unfortunately, it was unclear what the remaining

61% of times the door was opened in this study. In those same similar studies, the remaining reasons were for communication/status updates (9-15%), meal/bathroom breaks (8-10%), and the rest also unclassifiable (Anderson et al., 2021; Guajardo et al., 2015; Loison et al., 2017). Staff provided insight that teaching, assisting in the OR or elsewhere, and checking on the patient may be the reasons for entering/exiting the OR that was not identifiable. From interviewing staff, it was clear that their perception of the number of times people entered/exited was significantly lower than what was happening.

4.4 Limitations

The limitations include previously stated reasons such as overcounting of people by the indirect sensors and only one door being observed in the direct observations. There may also have been some Hawthorne effect due to staff knowing they were being observed. However, this was likely minimal due to the random times of direct observation and the length of time the sensors were in place for indirect observation (8 weeks). The sample size of this study is not large enough for direct or indirect observations to determine the differences between different types of neurosurgical procedures due to the wide variability in the procedure length. Also, each procedure may have more than one type of procedure occurring simultaneously (for example, the primary procedure was a cervical fusion while the secondary procedure was a laminectomy). This study was also not designed to evaluate the risk of SSI due to the project's scope and low SSI rates that would require thousands of procedures to have been observed. Thus, it cannot directly add to existing knowledge of the risk of SSI due to OR traffic. Of note, none of the procedures observed in this study developed an SSI.

For the staff interviews, one limitation is that saturation may not have been reached. More interviews would be necessary to determine if this is the case. Interviews were also short to respect the staff's time while performing their normal duties. Longer interviews may have illuminated more information about OR traffic. Another limitation of the interviews is that they may be influenced by social desirability or response bias. Staff may not have wanted to say what they thought or may have given an answer they thought was correct due to the researcher's association with the Infection Prevention Department. The staff has been observed to change their behaviors and answers when interacting with Infection Prevention staff. One example is that staff will be sure to use hand hygiene appropriately when a known infection preventionist observes them, but it does not represent their normal behaviors.

4.5 Recommendations

There are a couple of recommendations for decreasing the number of times people enter/exit the OR during procedures that can greatly impact the reduction of OR traffic. Staff education on the subject has proven to be an effective measure. One study found a decrease of 71% in the door opening rate after staff education and real-time counters (DiBartola et al., 2019). Another had their OR traffic decreased by 11% to 19.2 times per hour when normalized for procedure length after the implementation of staff education (Hamilton et al., 2018). Implementing an intercom system for staff communication and education significantly decreased traffic (Esser, Shrinski, Cady, & Belew, 2016). Birgand et al. suggest that simple things can be implemented to improve traffic. These include "the storage of components and frequently used instruments in the OR, a clear and advanced communication, a shift change of the surgical team prepared in advance, a sign on the door advising caution, proper education of OR team and visitors, and a robust audit process" (Birgand et al., 2015). When asked during interviews, the staff reflected many of these same process changes. They most commonly suggested increased use of the phones within the OR to communicate, reevaluating the supplies needed for these procedures so they can be in the OR before the procedure starts, and coordinating breaks. All of these suggestions are process changes that are relatively easy to initiate and would reduce the amount of traffic into and out of the OR.

4.6 Public Health Significance

SSIs are deadly, costly infections that are preventable with proper prevention measures. Patients who have the highest risk factors for SSIs are those who are elderly, smoke, are overweight, have diabetes, have weak immune systems, cancer, and other medical conditions. Outcomes from SSIs include complications from the infection itself, the cost of additional days in the hospital, potential loss of trust in their medical providers, and other factors negatively impact patients. Patients who are especially vulnerable to the financial cost and burden to their health are people with low income and less access to healthcare. People with Medicaid (a marker for poverty) and those living in low-income zip codes are associated with higher SSI rates (Qi et al., 2019). Preventing infection in these populations whenever possible is important for increasing their quality of life and preventing disability. Simple measures to reduce the risk of SSIs for all populations, such as reducing OR traffic, are essential to preventing SSIs and their associated complications.

5.0 Conclusion

Designing studies to evaluate the influence of SSIs is difficult due to many influential factors and a low incidence rate. Because of this, developing evidence-based guidelines about OR traffic to reduce SSIs is complicated. Without good evidence, it is up to the staff involved in surgery to do what many experts agree is the best practice, reducing OR traffic as much as possible. As demonstrated by interviewing staff, their perception of the OR traffic is often lower than what is occurring. Thus, good auditing measures need to be implemented. In this study, both direct and indirect observations were tested with different strengths. Direct observation can gather the most information per procedure, but it takes many hours for staff to collect a representative sample. Indirect observation through sensors counting the number of people entering/exiting can collect significantly larger representative samples but also has accuracy limitations. Other indirect observation measures (such as door contact sensors that only count when doors open) may collect more accurate results of the number of times the door is opened. Videography may be an observation method that combines both the strengths of direct and indirect measurement with fewer limitations. Taking a bundled approach (implementing more than one intervention at a time) to both intraoperative and postoperative prevention measures is crucial in preventing and reducing the burden of SSIs.

Appendix A Interview Guide

Introduction: Hello, I am a graduate student from Pitt Public Health working with the Infection Prevention Department and Dr. Yassin on a project in the OR looking at staff traffic during surgical procedures. There are seven questions which will take about 2-3 minutes. Are you ok with me audio recording your responses? What is your title?

Questions:

1. Have you ever entered or exited the OR while a procedure was taking place? (Y/N)
2. What are specific reasons you have entered or exited an OR during a procedure? (Open-ended)
3. How many times do you enter or exit during a procedure? (#)
4. In your experience, how many times do you think people enter/exit during an hour? (#) During the entire procedure? (#)

Tell them the counted number of times people entered and exited "The data that we have collected suggests that, on average, 31 people enter or exit during an hour for neurosurgical procedures."

5. What do you think about this? (Probes: Does this surprise you? Does this lead to any concerns for you?) (Open-ended)
6. On a scale of 1-5, how likely are you to change your entry/exit behaviors after this discussion?

    a.1 – Definitely will not make any changes

    b.2 – Probably will not make any changes c.3 – May make changes

d.4 – Will probably make changes

e.5 – Will definitely make changes

7. What would be your recommendations for reducing the number of entries/exits during procedures? (Open-ended)

Anyone who answers no to question 1 will only be asked questions numbered 4, 5, and 7.

Appendix B OR Environment Measurements

The temperature inside the ORs ranges from 18-22 degrees Celsius with 50-65% humidity. Particulate levels were measured with an AeroTrak Handheld Particle Counter 9303 with 30-second samples in µm/L. Measurements were taken at least three times in each area. Inside the LAF of the OR, there was an average of 1.6 large (5.0 µm/L) particles, 9.9 medium (1.0 µm/L) particles, and 1,169.7 small (0.3 µm/L) particles. Outside the LAF was an average of 2.1 large particles, 13.1 medium particles, and 1,567.9 large particles. The number of particles was slightly lower directly under the LAF than around the perimeter of the OR. Outside the ORs and in nearby "clean" areas were 11.7 large particles, 70.8 medium particles, and 10,419.8 small particles. This is where the doors of the ORs open into and represents the air that may enter the OR when the door is opened. In other areas of the hospital, the average was 17.8 large particles, 215.2 medium particles, and 13,730.2 small particles. This was significantly lower than outside the hospital, with 56.7 large particles, 631 medium particles, and 16,473.7 small particles. The area with the highest number of large particles was an area inside the hospital with carpeting that averaged 106.8 large particles, 445.8 medium particles, and 10,679.3 small particles.

Figure 10: Particulate Counter

Left: One particulate measure in the hallway outside OR 4. Right: Particulate measure inside OR 4.

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