Contact Patterns of Healthcare Workers During Simulated Healthcare Activities

BY

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THESIS

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LIST OF ABBREVIATIONS

EVD	Ebola Virus Disease
SARS	Severe Acute Respiratory Syndrome
MRSA	Methicillin-resistant *Staphylococcus aureus*
VRE	Vancomycin-resistant *Enterococcus*
PPE	Personal Protective Equipment
CV	Central Venous
IV	Intravenous

SUMMARY

Healthcare workers are at a high risk for contracting infectious diseases due to their long hours in hospitals and proximity to infected patients. Certain diseases such as influenza, Ebola Virus Disease (EVD) and Severe Acute Respiratory Syndrome (SARS), disproportionately affect healthcare workers. Awareness and concern among healthcare associated infections has increased, leading to research focused on characterizing the process of disease transmission to healthcare workers.

Many infectious diseases that spread through healthcare settings are thought to be transmitted by contacts between the patient, healthcare workers, and the environment. Understanding the contact patterns of healthcare workers can help to evaluate the contribution of this pathway to disease transmission, if any, and identify new ways to stop the spread of infectious diseases in healthcare settings. The goal of this study was to expand our knowledge of potential contact patterns among healthcare workers and identify high-risk behaviors by healthcare workers that may contribute to the spread of disease.

In this study we observed experienced healthcare workers performing seven simulated healthcare activities. These activities included: intubation (extubation), suctioning, intravenous access and venipuncture (IV access), central venous access (CV access), bathing, physical exam, and vital signs assessment (vitals). After the experiments were performed, the levels of contamination of simulated body fluid, and the location and number of contacts were recorded.

Our results indicate that healthcare activities produce varying levels of contamination and contact frequency for healthcare activities. Personal contact with personal protective equipment (PPE) did not appear to affect the measured contamination on PPE after experiments were completed. The number of PPE adjustments by healthcare workers were much lower than the number of self-contacts or contacts with environmental surfaces.

I. INTRODUCTION

A. Healthcare Associated Infectious Diseases

Healthcare associated infections affect millions of patients and healthcare workers each year (Zingg et al., 2015). Healthcare workers are at a high risk for contracting infectious diseases from patients due to their long hours in a hospital and proximity to infected patients (Nichol et al., 2013). Healthcare associated infections have both health and economic impacts on hospitals. In the European Union, there are approximately 4,544,100 healthcare associated infections annually, resulting in 37,000 deaths and an additional 16 million days of hospitalization, all of which incur substantial costs (Zingg et al., 2015). In the United States, it is estimated that there are about 1.7 million healthcare associated infections annually (Klevens et al., 2007), costing $9.8 billion annually (Zimlichman et al.,2013).

Certain diseases such as influenza, Ebola Virus Disease (EVD) and Severe Acute Respiratory Syndrome (SARS), disproportionately affect healthcare workers. There is no surveillance for seasonal influenza among healthcare workers in the United States, but exposure analysis has estimated that healthcare workers in acute care hospitals experience 7.69 million occupation exposures per year (Jones and Xia, 2016). During the 2013 EVD outbreak, healthcare workers, especially in developing countries, were at high risk for acquiring the infection. In Guinea, the risk of EVD infection among healthcare workers was 42 times greater than the risk among of non-healthcare workers (Kilmarx et al., 2014). And, healthcare workers accounted for one fifth of the global total of SARS infections during the 2003 outbreak (Liu et al., 2009). The total burden of occupationally-acquired infections among healthcare workers is unknown, because surveillance is limited. While infections among healthcare workers from emerging infectious diseases, such as SARS, are readily identified owing to the low disease prevalence in the community, it is more difficult to associate infections from endemic diseases, such as seasonal influenza, with occupational exposures because healthcare workers also have exposure to the disease in the community.

As awareness and concern regarding healthcare associated infections has increased, research is beginning to expand beyond characterizing the process of disease transmission to patients, to characterizing the process of disease transmission to healthcare workers. With this knowledge interventions can be implemented to prevent occupationally-acquired infections.

B. Disease Transmission Routes

Patients, healthcare workers, and visitors can all carry and transmit infectious diseases. Infectious diseases in healthcare settings are considered transmitted by contact, droplet, and by airborne routes (Siegel et al., 2007). Contact transmission can be direct or indirect. Direct contact transmission occurs when an infectious bodily fluid directly contacts and infects another person. Indirect contact transmission is when there is an intermediate object – a fomite – through which the pathogen is transferred to a susceptible person, such as when a hand transfers pathogen from the body of an infected person to the mucous membranes of a susceptible person. Droplet transmission is a special type of direct contact transmission in which respiratory droplets containing pathogens project on the facial mucous membranes of a susceptible individual, such as by a sneeze or cough.

Airborne transmission can occur in healthcare settings from bodily processes and medical procedures that generate aerosols. These processes generate different sized particles, including respirable particles (often termed droplet nuclei) that remain suspended in air and can travel through the air from the source. Larger aerosol particles (often termed droplets) will be removed from air rapidly owing to gravitational settling, and deposit on the ground and environmental surfaces (Jones and Brosseau, 2015). The behavior of an aerosol particle depends on the size of the particle, the liquid content and viscosity of the fluid, and the air movement in the environment.

Many infectious diseases that spread throughout hospitals, such as methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Enterococcus* (VRE), are thought to be transmitted by contacts between the patient, healthcare workers, and the environment (McBryde et al., 2004; Ganczak and Szych, 2007). Evidence for the role of environmental surfaces in contact transmission of infectious diseases, arises from the observation that improved hand hygiene and environmental cleaning methods reduce infections among patients (Eames et al., 2009). Infectious diseases transmitted through the droplet and/or airborne routes, such as influenza and tuberculosis, require healthcare workers to protect their respiratory tract from exposure through the use of personal protective equipment (PPE). Knowing the route of transmission for infectious diseases is one of the first steps in stopping the spread of infection, as it guides the selection of interventions. With many diseases, the main route of transmission is disputed, leading to the examination of all potential modes.

C. Role of Contact Patterns

Hospitals contain a network of people moving in and out of patient rooms, using shared equipment, and encountering many environmental surfaces and people. Both people and surfaces play a role in transmitting pathogens in healthcare settings. Conceptually, the amount of time and frequency healthcare workers spend touching contaminated surfaces and patients should increase the risk of the spread of infection through the contact route. Studying patients' rooms and the contact patterns of healthcare workers throughout the room will help to increase our understanding of the role environmental surfaces play in hospital outbreaks.

Healthcare worker contacts with the environment may lead to contamination of their clothing and body with pathogens, which can enable pathogen transfer to diverse sites in a hospital, including susceptible patients (Jackson et al., 2018). Studies have documented the presence of pathogens on healthcare workers' gloves and bodies after providing patient care (Blanco et al., 2017; Pineles et al., 2017), on environmental surfaces (Poliquin et al., 2018; Killingley, 2016) and in the air (Thompson et al., 2013; Bischoff et al., 2013). Thus, it is clear that pathogens are present in the environment, but there is less knowledge about how pathogens are moved from one location to another, and the role of human activity in this process (Cheng et al., 2015; Creamer et al., 2014; Lau et al., 2004).

A study done in Hong Kong examined the contact location and frequency of patients, visitors, and healthcare workers in an individual patient's room with the aim of determining what environmental items were frequently touched, and thus in need of cleaning and disinfection. The study found that patients, visitors, and healthcare workers all had the most frequent contact with bed rails (Cheng et al., 2015). Multiple studies have looked individually at environmental contact in patients' rooms or hand to-face contact of healthcare workers, however no study has looked at both environmental and self-contacts across the whole body together (Beam et al., 2014; Cheng et al., 2015; Kwok et al., 2015; McBryde et al., 2004).

D. Study Goals and Significance

The overall goal of this research is to improve our understanding of aspects of healthcare delivery that may contribute to the risk of disease transmission to healthcare workers and patients. This study focuses on the contact patterns of healthcare workers during specific healthcare activities, which are thought to contribute to the transmission of contact-transmissible infectious diseases. Understanding which surfaces are touched at what frequency by healthcare workers can help to target interventions, such as room cleaning and use of personal protective equipment but can also inform the design and parameterization of mathematical models used to predict exposure and infection risk (Nicas and Jones, 2009). The specific aims of this study are to:

1) Describe the type and frequency of contact by healthcare workers with surfaces and themselves during patient care activities, and
2) Identify if contacts with high risk areas (head, neck, and face) contribute to elevated contamination levels on PPE.

The five main hypotheses tested in this study are:

1) Environmental contacts would vary among activities,
2) Personal contact rates would vary among activities,

3) Participants would adjust their PPE more frequently the longer they performed the activity,
4) The majority of self-contact of PPE would be to adjust it, and
5) Self-contact with the face and head would be associated with contamination at those locations.

II. METHODS

A. General Study

Participants with experience as healthcare workers were recruited to perform simulated healthcare activities in a room-scale chamber. Participants were adults (≥ 18 years of age), English-speaking, and had experience performing one or more of the simulated healthcare activities. Participants were not excluded based on race, ethnicity, sex or gender. Participants were assigned to perform specific healthcare activities based upon their experience in healthcare.

A total of seven healthcare activities were simulated, and included intubation and extubation (intubation), suctioning, intravenous access and venipuncture (IV access), central venous access (CV access), bathing, physical exam, and vital signs assessment (vitals). A description of these activities can be found in Table I (Weber, 2018). These activities were chosen due to their frequency of performance in healthcare settings, and because they were anticipated to produce different patterns of contamination. For example, intubation and suctioning are aerosol generating procedures (Siegel, 2007). Bathing, physical exams, and vitals are all tasks that require the healthcare worker to be in close contact with the patient.

In all healthcare activities, a fluorescein-containing simulated body fluid was used to represent body fluids that may contain pathogens (Su et al., 2017). Fluorescein is non-toxic synthetic organic molecule, that can readily be measured in the environment and quantified at a low-level using fluorometry.

TABLE I: SUMMARY OF SEVEN HEALTHCARE ACTIVITIES PERFORMED DURING EXPERIMENTS, INCLUDING DEFINITIONS, TOOLS AND METHODS.

Activity	Activity Definition	Mannequin	Tools	Simulated Body Fluid Volume & Placement	Method	Mannequin Response
Intubation/ extubation	Patient's head is tilted back, and a laryngoscope blade inserted to visualize the respiratory tract. An endotracheal tube is then inserted into the trachea, and the cuff of the tube inflated. The endotracheal tube is then removed from the patient (Roberts 1986).	Laerdal Airway Management Mannequin	Endotracheal tube, laryngoscope, laryngoscope blade, and a 10 mL syringe	300 mL poured through mouth to lungs and stomach	Participant performs consecutive intubations for at least 10 minutes.	Researcher squeezes lungs to simulate cough/vomit
Suctioning	A suction device is attached to a catheter that is placed in the mouth briefly to remove secretions (Custalow et al. 2010).	Laerdal Airway Management Mannequin	Vacuum device, vented Yankauer suction handle, and 250 mL of deionized water in a 500 mL beaker	300 mL poured through mouth to lungs and stomach	Participant performs 20 individual suctioning procedures, totaling 10-15 minutes of suctioning.	Researcher squeezes lungs to simulate cough/vomit and ensure fluid is in the mouth to suction.
IV access and Venipuncture	Intravenous access is achieved when a fine needle with a plastic tube, or catheter, is inserted in a patient's vein; the catheter is then connected to an IV bag through IV tubing. Venipuncture includes inserting a small butterfly needle in the patient's vein, attaching the tubing to a tube holder, and using collection tubes to draw blood (Custalow et al. 2010; Thomas 2015).	Laerdal IV Arm	Vacutainer Butterfly Blood Collection Set, Baxter Standard Bore Catheter Extension Set, venipuncture needle-pro needle protection device, IV Kit, Vacutainer Tubes with Hemogard Closure, monoject multiple sample luer adapters, IV bag, and tourniquet.	The mannequin arm is connected to an IV bag filled with simulated body fluid	Participant places an intravenous access port into the mannequin's arm and draws 1 vial of blood 3 consecutive times	No
Central Venous Access	A catheter is inserted through major veins in the upper chest or groin and ultimately reaches the heart to ensure patients rapidly receive fluids, medications, and nutrition (Custalow et al. 2010).	Laerdal IV Torso Mannequin	Pressure Injectable Two-Lumen CVC Kit	The mannequin's femoral or jugular pad reservoirs were filled with simulated body fluid	Participant places at least 2 central venous access lines in the neck or femoral pad, depending on random assignment.	No

TABLE I. SUMMARY OF SEVEN HEALTHCARE ACTIVITIES PERFORMED DURING EXPERIMENTS, INCLUDING DEFINITIONS, TOOLS AND METHODS (CONTINUED).

Activity	**Activity Definition**	**Mannequin**	**Tools**	**Simulated Body Fluid Volume & Placement**	**Method**	**Mannequin Response**
Bathing	A routine procedure to ensure cleanliness, hygiene for a patient by using disposable bathing wipes to cleanse soiled regions of the patients' body (Craven, Hirnle, and Henshaw 2017). Mannequin was consistently lifted and turned throughout the trial to cleanse the entire body.	Full-size adult mannequin	Disposable bathing wipes and clean hospital gowns	50 mL poured on the patient's chest and 50 mL poured on the patient's groin prior to each individual repeated bathing activity; 200-300 mL was used total for each bathing trial	Participant bathes the patient 2-3 times, repeating this activity for at least 25 minutes.	No
Physical Exam	A full examination of the patient that involves examining the patient's mouth, lymph nodes, heart, lungs, abdomen, legs, and skin (Craven, Hirnle, and Henshaw 2017). Participants consistently lifted the mannequin to sit them up to examine the back.	Full-size adult mannequin	Stethoscope and digital clock	25 mL spread on mannequin's face, hands, and chest	Participant performs 10 full physical exams on the mannequin.	No
Vital signs	Measuring the patient's pulse, temperature, respiratory rate, and blood pressure (Thomas 2015).	Full-size adult mannequin	Blood pressure cuff, digital thermometer, stethoscope, and a digital clock	25 mL spread on mannequin's face, hands, and chest	Participant takes the mannequins vital signs 10 times.	No

Weber, 2018

Participants were provided with the basic materials and kits required to perform each task. The room-scale chamber in which activities were performed contained a metal hospital bed covered with a plastic sheet, a cart with the necessary tools for each activity, and an IV pole. An image of the room can be seen in Figure 3, Appendix. Participants were given and asked to wear scrubs and PPE that would typically be found in a hospital setting. The PPE included: nitrile gloves, disposable gown, facemask, face shield, headcover (CV access only), and shoe covers (Figure 4, Appendix). Participants performed each healthcare activity for 12-25 minutes. Each activity was repeated multiple times during each trial without changing PPE or equipment to maximize the likelihood of quantifying environmental contamination. The mass of fluorescein was measured on the PPE worn by participants.

After each trial the participant removed his or her PPE and placed each piece in a plastic bag. A known volume of sodium phosphate buffer was added to the bag, and the piece of PPE agitated in the liquid for a fixed period of time. Details are provided in Weber (2018). The concentration of fluorescein in the buffer was quantified in units of ug/L using a Trilogy benchtop fluorometer (Turner Designs, Sunnyvale, CA), and converted to the mass of fluorescein.

B. <u>Specific to this Study</u>

Experimental trials were recorded using a 7-camera video surveillance system if the participant consented. At a later date, the video recordings were viewed by investigators and contacts were recorded on a standardized worksheet (Figure 5, Appendix). Specifically, the number and location of self-contacts (the participant touches his or her own body), environmental contacts (the participant touches a surface in the environment), patient contacts (the participant touches the mannequin), and PPE adjustments (the participant moves his or her PPE) were recorded over the duration of the experimental trial. Self-contact includes PPE adjustments, in that if a healthcare worker adjusted his or her PPE, that action was considered both a self-contact and a PPE adjustment. For each experiment, the total number of contacts were divided by the number of activities and the duration of the experimental trials to determine the contact rate. The average duration of each activity performed in an experimental trial was determined by dividing the observed duration of the experimental trial by the number of activities performed in the experimental trial. Spearman's correlation was used to describe associations. The Kruskal-Wallis rank sum test were used to test for differences among groups.

All data was double-entered into databases (Microsoft Access® 2016). Statistical analysis was performed using R: A Language and Environment for Statistical Computing.

III. RESULTS

A. Overview

Overall each healthcare activity was performed in 10-12 experimental trials (Table II). In each experimental trial, the participant performed the activity multiple times. Experimental trials for intubation and suctioning were shorter than other activities, with mean durations of 14.78 and 12.09 minutes respectively; other experimental trials required about 25 minutes. Intubation, physical exam, suctioning and vitals were quick for participants to perform, requiring less than 5 minutes per activity, on average.

TABLE II: SUMMARY OF EXPERIMENTAL TRAILS

Healthcare Activity	Number of Trials	Mean (Range) Observed Trial Duration (min)	Mean (Range) No. of Activities Performed per Trial	Mean (Range) Activity Duration (min)
Bathing	10	24.68 (12.97-32.00)	2.0 (1-3)	14.33 (8.38-26.52)
CV access	10	24.95 (17.05-34.32)	1.9 (1-3)	14.92 (7.00-32.00)
Intubation	10	14.79 (11.50-19.53)	15.0 (15-15)	0.99 (0.77-1.30)
IV access	11	23.77 (11.63-39.35)	3.6 (2-4)	6.90 (2.91-12.99)
Physical exam	11	23.05 (14.77-31.55)	9.1 (6-10)	2.69 (1.48-4.83)
Suctioning	10	12.09 (7.50-23.17)	17.3 (3-32)	1.37 (0.31-7.72)
Vitals	12	27.68 (21.47-33.67)	9.4 (6-10)	3.04 (2.15-4.99)

The total number of environmental contacts, self-contacts, and PPE adjustments were highly variable among experimental trials and between healthcare activities (Table III). On average, participants made more environmental surface contacts than self-contacts, and PPE adjustments were rare. Not all participants made self-contacts or PPE adjustments.

TABLE III: TOTAL NUMBER OF CONTACTS DURING EXPERIMENTAL TRIALS OF EACH HEALTHCARE ACTIVITY.

	Median (Range) Number of Contacts		
Healthcare Activity	**Environmental Surfaces**	**Self-Contact**	**PPE Adjustment**
Bathing	47.0 (13-54)	1.0 (0-6)	0.0 (0-1)
CV access	9.0 (1-33)	0.5 (0-6)	0.0 (0-0)
Intubation	26.5 (15-38)	1.0 (0-3)	0.0 (0-1)
IV access	38.5 (19-57)	2.0 (0-20)	0.5 (0-20)
Physical Exam	20.0 (8-69)	7.5 (2-35)	1.0 (0-13)
Suctioning	1.0 (0-6)	0.0 (0-3)	0.0 (0-2)
Vitals	36.0 (22-69)	12.0 (2-32)	3.0 (0-13)

B. <u>Hypotheses One and Two</u>

Contact rates with environmental surfaces, self-contact, and PPE adjustments were determined for each healthcare activity (Table IV) by dividing the number of contacts observed in each experimental trial (Table III) by the number of activities performed per trial (Table II), and then dividing by the mean activity duration (min). The distributions of environmental surface contact rates and self-contact rates were found to be significantly different among the healthcare activities (Table IV). Differences in PPE adjustment rates were not tested because so many healthcare workers had zero PPE adjustments. We expected that different healthcare activities would not have the same contact rates because they required participants to perform very different activities with different types of engagement with the environment. Bathing, for example, required participants to have extensive physical contact with the full-body mannequin, and was observed to have relative high surface contact rates (median 1.59 contacts per minute). IV access, in contrast, required the participants to perform simple manipulations of an arm, but the arm was on the gurney, increasing the potential for environmental surface contacts (1.49 contacts per minute).

Differences in the distributions of environmental surfaces and self-contact rates among healthcare activities are more clearly shown in Figures 1 and 2. Intubation, IV access, vitals, and bathing had the highest average environmental contact rates of the activities. Suctioning had a much lower environmental contact rate than the other activities. Self-contact rates were highest among vitals and physical exam, which require more body movement of participants than the other healthcare activities.

TABLE IV: CONTACT RATES (CONTACT PER MINUTE) DURING EXPERIMENTAL TRIALS OF EACH HEALTHCARE ACTIVITY.

Healthcare Activity	**Median (Range) Contact Rates (contacts per min)**			
	Environmental Surfaces	**Self-Contact**	**PPE Adjustment**	**Facial Contact**
Bathing	1.59 (0.92-2.11)	0.03 (0-0.24)	0 (0-0.04)	0 (0-0.04)
CV access	0.38 (0.04-0.96)	0.02 (0-0.29)	0 (0-0)	0 (0-0)
Intubation	1.80 (0.97-2.70)	0.07 (0-0.26)	0 (0-0.09)	0 (0-0)
IV access	1.49 (1.08-2.22)	0.09 (0-0.48)	0.02 (0-0.51)	0 (0.38)
Physical Exam	1.09 (0.42-3.16)	0.43 (0.10-1.60)	0.05 (0-0.59)	0.03 (0-0.55)
Suctioning	0.10 (0-0.75)	0 (0-0.30)	0 (0-0.119)	0 (0-0.12)
Vitals	1.33 (0.74-2.98)	0.41 (0.08-0.95)	0.13 (0-0.45)	0.12 (0-0.32)
Test for Difference Among Groups	KW = 40.3 $p < 0.001$	KW = 30.2 $p < 0.001$		

Figure 1: Distribution of environmental contact rates for each healthcare activity

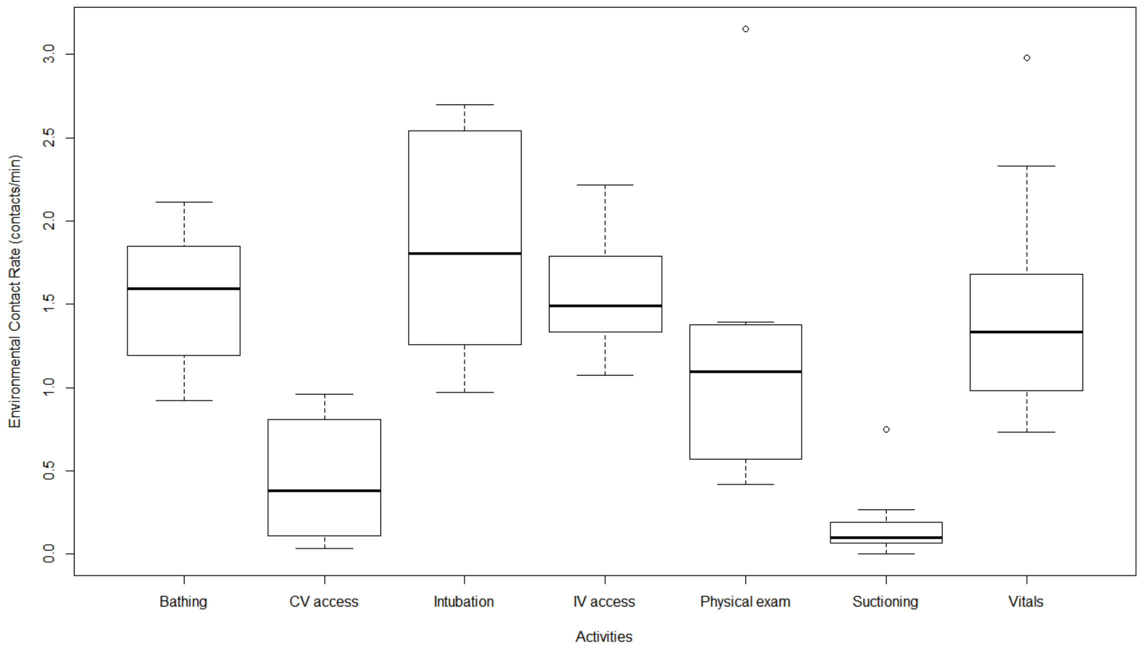
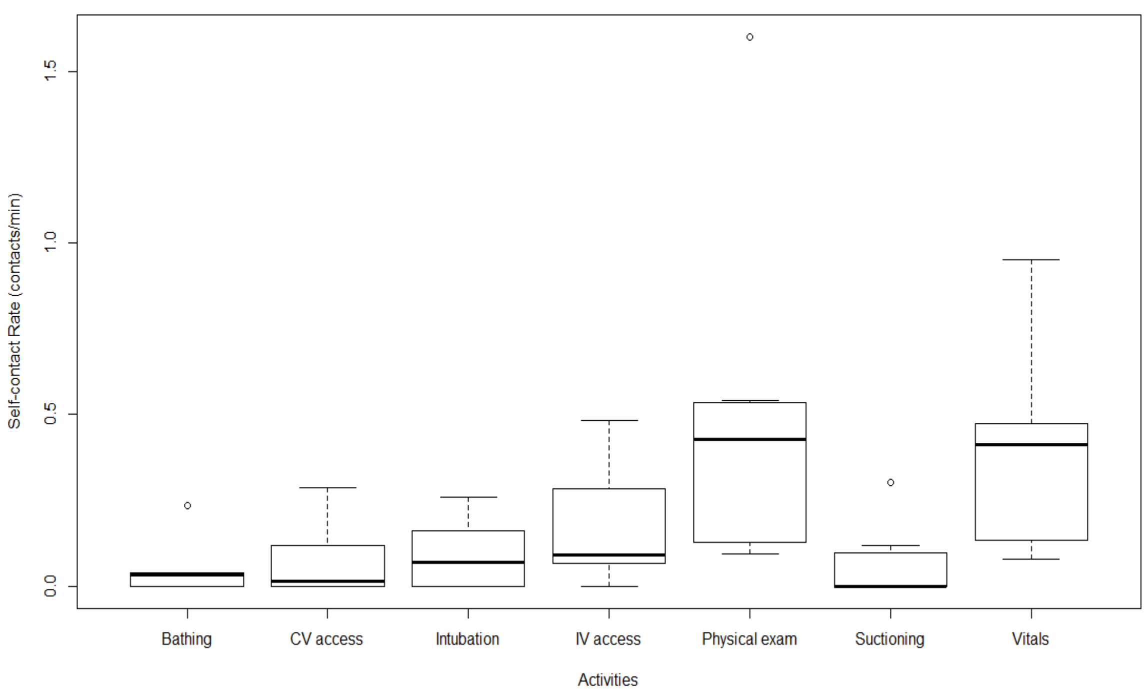


Figure 2: Distribution of self-contact rates for each healthcare activity



C. Hypothesis Three

We hypothesized that participants would adjust their PPE more times the longer they performed the activity, owing to increased discomfort. We found that the number of PPE adjustments was positively associated with duration of the experimental trial (Spearman's $\rho = 0.41$, $p < 0.001$) and PPE adjustment rates were positively associated with the duration of the experimental trial (Spearman's $\rho = 0.36$, $p = 0.002$). This means that the frequency of PPE adjustments increases with duration, yielding a larger total number of PPE adjustments over time.

D. Hypothesis Four

Self-contact is different than PPE adjustments, as the later involves moving the placement of one's PPE. We hypothesized that the majority of self-contact of PPE would be to adjust it. We found that the proportion of self-contacts of PPE that are PPE adjustments was 36%. Thus, the majority of PPE contact was not to adjust the PPE, but PPE adjustments did make up a significant amount of personal contacts.

Table V displays the total number of PPE adjustments for each piece of PPE. The face shield and gloves were the pieces of PPE that were adjusted most frequently for all activities. The facemask was adjusted least for all activities. CV access procedures had zero total PPE adjustments, while vitals had the highest total number of 50.

Table V: TOTAL NUMBER OF PPE ADJUSTMENTS FOR EACH HEALTHCARE ACTIVITY.

Healthcare Activity	Glove	Gown	Face Shield	Facemask	Head Cover[a]	Total PPE Adjustments
Bathing	1	1	1	0	NA	3
CV access	0	0	0	0	0	0
Intubation	0	1	0	0	NA	1
IV access	6	11	5	4	NA	26
Physical Exam	6	3	8	6	NA	23
Suctioning	0	1	1	0	NA	2
Vitals	14	6	22	8	NA	50
All Activities	27	23	37	18	NA	105

[a] NA = head cover was not worn for these activities

E. Hypothesis Five

We considered the face and head to be areas where contamination poses a relatively high risk for infection since many infections are initiated in the facial mucous membranes. That is, the face and head are "high-risk" areas. We hypothesized that self-contact with the face and head would be associated with contamination of the participant's facial PPE (facemask, face shield, headcover) owing to the transfer of contamination from gloves. Table VI presents the number of self-contacts to the facemask and face shield along with the total fluorescein contamination measured on those pieces of PPE. We found that the number of self-contacts to the face and head was not associated with facial PPE contamination levels (Spearman's $\rho = 0.11$, $p = 0.38$). This result suggests that sources of contamination other than self-contact with contaminated gloves contribute to contamination of the facemask and face shield during these patient care activities.

Table VI: NUMBER OF SELF-CONTACTS AND FLUORESCEIN CONTAMINATION ON FACIAL PERSONAL PROTECTECTIVE EQUIPMENT AND GOWN.

	Facemask and Face shield		Gown	
Healthcare Activity	**Mean (Range) Contacts**	**Contamination (ng)**	**Mean (Range) Contacts**	**Contamination (ng)**
Bathing	0.11 (0-1)	1.34 (0.00-7.57)	0.22 (0-2)	89.31 (2.27-338.47)
CV access	0.00 (0-0)	0.65 (0.13-2.74)	0.00 (0-0)	9.67 (0.13-39.31)
Intubation	0.00 (0-0)	8.50 (0.43-45.39)	0.38 (0-1)	44.93 (2.62-114.45)
IV access	1.90 (0-10)	0.78 (0.19-5.63)	1.20 (0-10)	1.69 (0.09-7.97)
Physical Exam	2.38 (0-12)	4.71 (0.27-21.92)	0.50 (0-4)	78.00 (2.87-290.29)
Suctioning	0.30 (0-2)	17.94 (0.23-131.80)	0.00 (0-0)	17.04 (0.16-82.78)
Vitals	3.80 (0-9)	0.67 (0.13-2.93)	1.90 (0-8)	69.69 (0.57-137.59)

We explored the association between self-contacts and contamination on the gown because gowns were heavily contaminated and frequently touched in some activities, such as vitals (Table V). The association between self-contacts with and contamination on the gown, however, was not statistically significant (Spearman's ρ = 0.19, p = 0.14). This result suggests that sources of contamination other than self-contact with contaminated gloves contribute to gown contamination during these patient care activities.

IV. DISCUSSION

The seven healthcare activities simulated in this study were chosen based on the frequency in which they are performed in healthcare settings and because they were anticipated to result in unique healthcare worker behaviors and exposures to bodily fluids. Each activity required healthcare workers to perform different tasks, use different equipment, and perform the activities for different durations. As expected, we observed different numbers and rates of environmental surface contacts and self-contacts by participants among the different healthcare activities (Tables III and IV).

Hand contact to contaminated surfaces, including both the patient and environmental surfaces in a patient's room, have previously been determined to be an exposure pathway for infectious diseases (Nicas, 2009; Jackson et al., 2018; Cheng et al., 2015). Cheng et al. found that in a hospital ward in Hong Kong, healthcare workers contacted either an item or a patient 57.5 times per hour, which is similar to the mean rate of 75.7 contacts with environmental surfaces and participants per hour that we found. Cheng et al. could have a slightly lower observed contact rate due the healthcare workers being observed throughout the day, not just for specific procedures that require healthcare workers to engage with patients and the environment.

Both the total number of PPE contacts and PPE adjustment rates were found to be positively associated with length of the trial performed in this study. Ganczak and Szych (2007) found that one of the main reason's healthcare workers did not comply with PPE recommendations was that the PPE interfered with patient care and was not comfortable. Healthcare workers may be able to tolerate uncomfortable PPE for short tasks but become irritated with the equipment as time goes on, causing an increase in PPE adjustments. Re-design of PPE with greater consideration for the comfort of the users could decrease the amount of PPE adjustments and contacts healthcare workers make during procedures.

Self-contact rates, and specifically the nature of self-contacts involving PPE, during the trials were observed to determine if most of the time healthcare workers were touching their PPE was to adjust it, due to movement or discomfort. Our results showed that only 36% of self-contacts were to adjust the PPE, meaning that it was more common for a healthcare worker to simply place their hand or fingers on their PPE than to adjust their PPE. We were interested in the issue of PPE adjustment because we thought participants may be uncomfortable wearing the PPE for the duration of the experimental trials. Participants were requested to use specific pieces of PPE in this study, some of which (e.g., face shields and facemasks) are not routinely used during all of the healthcare activities simulated. For example, University of Illinois at Chicago hospitals use fabric gowns, not disposable ones used in this study. In addition, healthcare workers frequently wear incorrect ensembles of PPE (Katanami et. al., 2018). Thus, if the healthcare workers in our study were not used to wearing the provided PPE on a routine basis, they may have adjusted their PPE more frequently due to the unfamiliarity of the protective clothing.

Contact with facial PPE is seen as especially risky due to the proximity with facial membranes, where many infections may be initiated (Nicas and Best, 2008). Johnston et al. (2014) monitored the frequency of hand to face contacts by workers in a biosafety laboratory while they performed their daily work activities, and found that, on average, workers contacted their face 2.6 times per hour. Another study by Kwok et al. (2015) found that when observing students in a class room, students touched their face on average 23 times per hour. Students in this study were sitting and idle, while in the Johnston et al. (2014) and in our study, workers were performing tasks. Both values are higher than the facial contact rate found in our study, which had a mean of 1.5 face contacts per hour. The low facial contact rate observed in this study could be due to the training of healthcare workers to not touch their face, or to the intensity of contacts with the mannequin and environmental surfaces.

Despite the number of personal contacts and PPE adjustments made on high-risk areas (face, head, neck), we did not observe contacts with these areas to be associated with the amount of facial contamination on the facemask and face shield. This result was unexpected. Previously, Jackson et al. (2018), observing interactions between patients and healthcare workers in a hospital, found that VRE contamination levels on gloves and gowns increased with the number of patient touches and environmental touches (odds ratio of 1.22). The lack of association observed in our study could be because the fluorescein dried quickly, so the majority of the contamination found on the face shield and masks were not from glove transfer, but from droplet spray during experiments.

Simulating healthcare activities in a controlled environment allowed us to record contact and contamination patterns that occur during healthcare activities. However, this experimental design, including the repeated performance of the healthcare activities in experimental trials, may not reflect real-life. In hospital settings most healthcare workers are not performing the same task repeatedly, and participants in our study may have changed their behavior across the repetitions of the healthcare activity. In addition, participants may have modified their behavior because they knew they were being observed, a problem called observer bias.

Future studies could increase the number of participants and determine if training or re-designed PPE could decrease the amount of personal and environmental contacts.

V. CONCLUSION

We found that the seven healthcare activities studied produce varying levels of contamination, contacts and contact frequencies for healthcare workers. Intubation and bathing procedures had the highest average contact rates with environmental surfaces, while assessing vital signs and performing physical exams had the highest self-contact rates. The number of PPE adjustments was lower than the number of self-contacts or contacts with environmental surfaces. The number of PPE adjustments, and rate of PPE adjustments, that participants made during each trial both increased with trial duration but were not the main cause of contacts with PPE.

Personal contact with PPE did not appear to affect the measured fluorescein contamination on participants' PPE after the experiment was completed: gown, facemask, and face shield contamination was not positively associated with the number of contacts with their PPE, then those who did not. This suggests the PPE comfort is not the driver of self-contact, and more emphasis should be placed on training healthcare workers to resist contact with any unnecessary surfaces, including themselves.

Healthcare worker's contact patterns during patient care are an important factor in understanding worker exposure and role in disease transmission. Future studies could include more healthcare activities and recruit participants from more workplaces to provide a broader range and understanding of how healthcare workers perform patient care activities in practice.

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APPENDIX

Figure 3: Experimental Chamber with Surface Sampling Locations

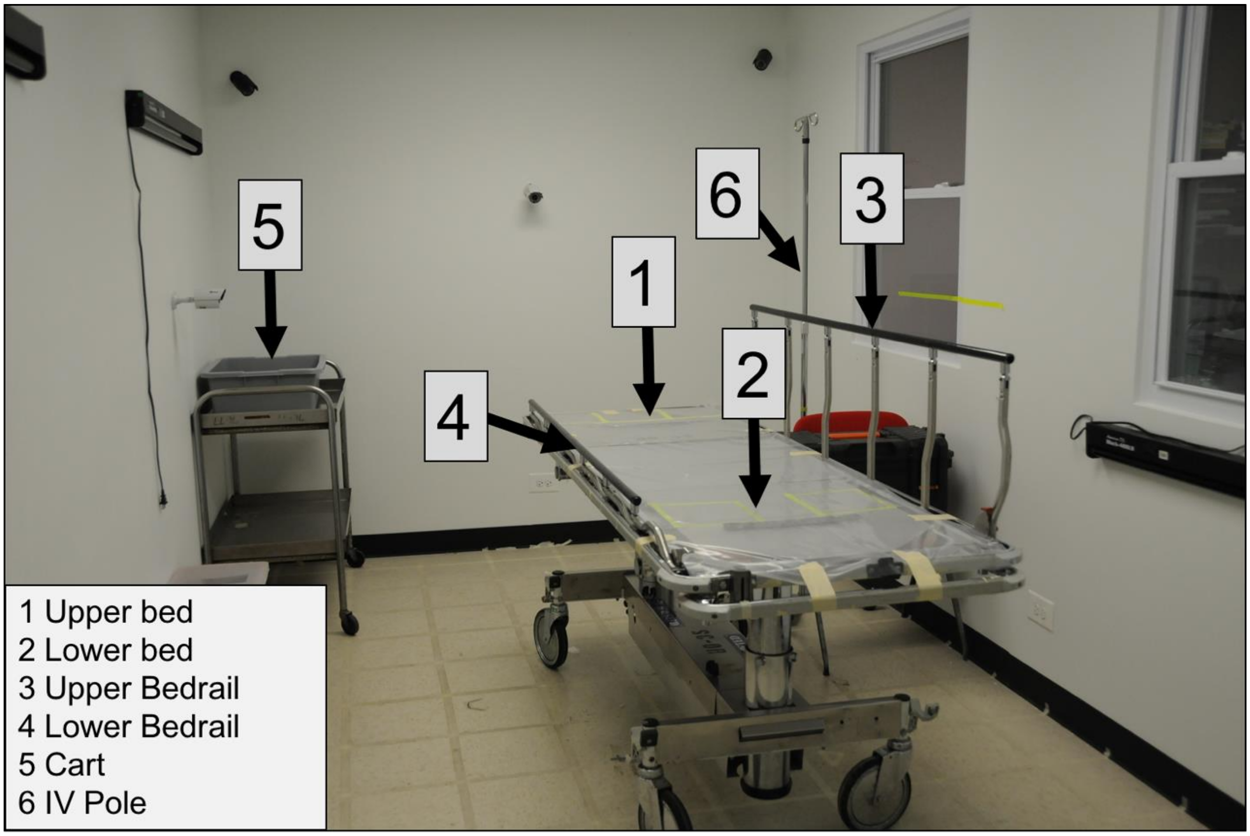


Figure 4: Figure Labeled with Qualitatively Observed Body Areas

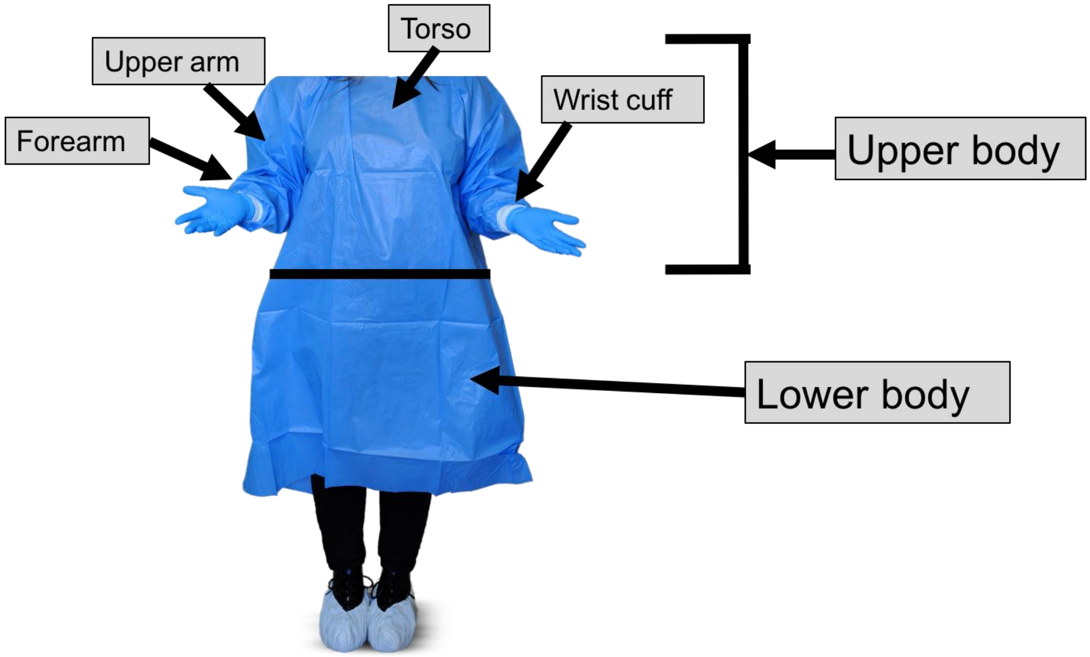


Figure 5: Healthcare Simulation Contact Frequency Data Form

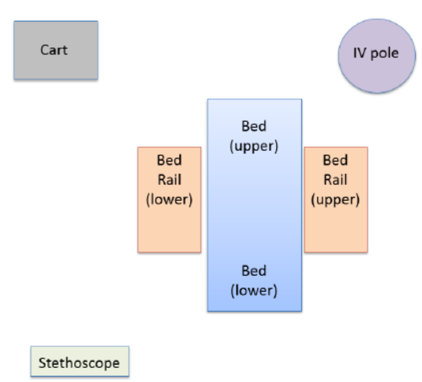
Healthcare Simulation Contact Frequency Data Form

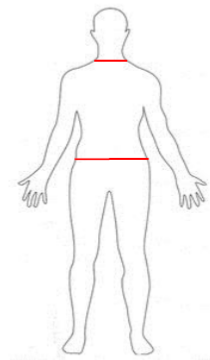
Experiment Code		Observation Code	
Trial Activity		Participant Code	
Observation Start Time		Observation Stop Time	
Date Video Watched		Observer Initials	

Trial Activity Codes: IT: Intubation, CL: Central Line, BT: Bathing, PE: Physical Exam, VT: Vitals, IV: IV Access and Blood Draw, SC: Suctioning

Contact Frequency: Environmental Surfaces, Patient, Self-Contacts, and PPE Adjustment

Tally the locations in the diagrams that the participant touches with hands during one observation and record totals in table below





Count of Close Proximity to Patient's Head

Tally the number of times the HCW's head dips below the bed rail towards the patient's head

	Total Count:

Patient Contact Time

Total time HCW is in contact with patient (min:sec)

PPE Adjustment

Tally the number of times the HCW adjusts PPE: count as ***both*** *PPE Adjustment* ***and*** *Self-Contact*

PPE	***Tally***	***Total Count***
Gloves		
Gown		
Faceshield		
Mask/Respirator		
Headcover		

Environmental Surface/Object	**Contact Totals**
Cart	
IV Pole	
Bed (upper)	
Bed (lower)	
Bedrail (upper)	
Bedrail (lower)	
Stethoscope	
Other	
Other	
Other	

Self-Contact	**Contact Totals**
Face	
Neck/Head	
Upper Body	
Hand-to-Hand	
Lower Body	

Notes:

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