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Major Article

Contact patterns during cleaning of vomitus: A simulation study

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Background: Environmental service workers cleaning bodily fluids may transfer pathogens through the environment and to themselves through contacts.
Methods: Participants with experience in cleaning of hospital environments were asked to clean simulated vomitus using normal practices in a simulated patient room while being videorecorded. Contacts with environmental surfaces and self were later observed.
Results: In 21 experimental trials with 7 participants, environmental surfaces were contacted 26.8 times per trial, at a frequency of 266 contacts per hour, on average. Self-contact occurred in 9 of 21 trials, and involved 1-18 contacts, mostly to the upper body. The recommended protocol of cleaning bodily fluids was followed by a minority of participants (2 of 7), and was associated with fewer surface contacts, improved cleaning quality, and different tool use. Participants used different cleaning practices, but each employed similar practices each time they performed an experimental trial.
Conclusions: Training in the use of the recommended protocol may standardize cleaning practices and reduce the number of surface contacts.

Many infectious diseases result in the emission of pathogen-containing bodily fluids, such as vomitus and diarrhea, associated with symptomatic norovirus infection.[1,2] During cleanup of pathogen-containing body fluids, environmental service and other health care personnel are exposed to pathogens, and are therefore at risk of acquiring infection. Makison Booth,[3] in a qualitative simulation study, demonstrated that during cleaning of vomitus, a worker may unintentionally contact contaminated hands to the face, and thereby contaminate the face with bodily fluid. Workers' contaminated hands may also transfer pathogens to environmental surfaces and other susceptible people, thereby contributing to indirect or direct contact transmission of the infectious disease.[4]

The objective of this study was to characterize contact patterns during vomitus cleanup. Simulation was used to attain this objective because vomiting is a difficult event to anticipate and observe in health care settings. The study objective was motivated by the ubiquity of norovirus infection in health care settings,[5-7] and the lack of knowledge about how people perform cleanup activities. Surveillance does not routinely tabulate the incidence of norovirus infection among health care workers, but outbreak studies consistently identify infections among health care workers, as well as among patients, and vomitus has been identified as a risk factor for norovirus transmission.[8-11]

The contact transmission route is relevant to many infectious diseases that cause gastroenteritis and colitis, including norovirus and *Clostridium difficile*.[12] The number and types of contacts that workers have while cleaning up pathogen-containing bodily fluids may contribute to the risk of infection. Contact patterns, for example, are key variables in mathematical models of exposure to pathogens in the environment transmitted through the contact route.[13] To our knowledge, contact patterns during cleaning activities have not been studied, although contact patterns have been observed in other health care contexts.[14,15] This research begins to fill the knowledge gap about how pathogens are transmitted through the environment to pose a health risk to environmental service workers, who in turn, may transmit pathogens to others.

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METHODS

Participants with experience cleaning in health care settings were recruited via e-mail, flyers, and presentations at staff meetings at 2 hospitals in the Chicago area. Participation involved a 2-hour time commitment, and was incentivized with a $40 gift card. The University of Illinois at Chicago Institutional Review Board approved this study (protocol 2015-0990).

Simulations were performed in a room-scale chamber (2.5 m × 4.5 m × 2.4 m high) with sheetrock walls and vinyl tile flooring, equipped with a 7-camera video surveillance system. A gurney was placed at 1 side of the chamber to simulate a patient's bed. The floor was marked into a 12-inch grid to facilitate observation of contamination, and covered with plastic sheeting for ease of cleaning.

Before a participant's arrival, he or she was randomly assigned to clean 200 mL vomitus spilled in 2 of 4 possible ways: low-viscosity vomitus poured on the side of the gurney, high-viscosity vomitus poured on the side of the gurney, low-viscosity vomitus poured on the floor, and high-viscosity vomitus poured on the floor. The 2 locations (gurney and floor) were based on information from University of Illinois Hospital staff that these were the most common locations cleaned by environmental service workers. High (~170 mPa-s) and low (~6 mPa-S) viscosity vomitus were used to reflect variation in vomitus types.[16] The recipe development is described in detail elsewhere.[17] Briefly, the simulated vomitus was a mixture of carboxymethylcellulose powder (0.19 g or 2.51 g) and fluorescein salt (0.5 g) in 500 mL basic buffer.

Upon arrival, participants were provided a cleaning cart stocked with tools used in the protocol at University of Illinois Hospital and consistent with Centers for Disease Control and Prevention recommendations,[18] including dry and premoistened (with water) 14-inch square microfiber towels, dry and premoistened (with water) Hygen microfiber mop heads (Rubbermaid, Winchester, VA), a mop for use with the mop heads, a bottle of disposable Healthcare Bleach Germicidal Wipes (Clorox, Oakland, CA), and a squirt-top bottle of simulated disinfectant (water). Participants were provided scrubs and shoe covers. Participants were asked to wear, at their discretion, the personal protective equipment (PPE) normally worn to clean vomitus, and they were offered nitrile gloves, BCR 3-layer facemasks with knitted earloops (Berkshire, Great Barrington, MA), N95 filtering facepiece respirators (3M Corp, Minneapolis, MN), and safety glasses.

Participants did not observe the research team introduce the simulated vomitus into the chamber. Participants were asked to clean the simulated vomitus following normal practices. During cleaning, the research team observed the number and type of cleaning products used and the sequence of activities performed by the participant. During 1 visit, each participant performed 1-2 trials with simulated vomitus and 0-1 blank trials (ie, cleaning activity with no vomitus), as time permitted.

Between trials, to prevent cross-contamination, the plastic sheeting on the floor was removed or replaced, and the gurney cleaned by the research team. The absence of cross-contamination was verified by illuminating the chamber with black light to look for visible contamination. In addition, blank trials, in which participants performed cleaning activities without simulated vomitus, verified the absence of fluorescein contamination in the chamber.

Contact patterns and duration of the cleaning activity were observed from digital video recordings. Contacts with the following environmental surfaces were recorded: gurney, cleaning cart, ground, and walls. Contacts with the following surfaces on the participants were recorded: eyes, mouth or nose, head, upper chest and arms, abdomen, lower arms and wrist, and legs. If worn by the participant, contacts were observed with goggles or glasses, and facemask or respirator (ie, facial PPE). Contacts were classified by the nature of the touch: fingers (including rubbing and scratching), hand other than fingers (eg, palm and back of hand, including rubbing), and whole hand.

A crude measure of cleaning quality was defined as the ratio of the spatial extent of contamination after cleaning to the spatial extent of contamination before cleaning. This ratio was then categorized as 0.5, ≥ 0.5-< 1.0, or ≥ 1.0. Category 1, for example, means that after cleaning the extent of contamination was less than one-half the extent of contamination before cleaning, and indicates relatively high quality cleaning. The spatial extent was defined as the area over which contamination was observed, but does not mean that all of that area was contaminated (eg, there were scattered spots of contamination). However, the density of contamination was closely associated with the area of contamination: Trials that fell into category 1 typically involved a few spots of contamination, trials that fell into category 2 typically involved relatively dense spots of contamination over the area, and trials that fell into category 3 involved nearly complete contamination of the area.

Data were initially recorded on paper forms and entered into a database (Microsoft Access 2016; Redmond, WA). All data analysis was performed with the R Project for Statistical Computing (R Foundation for Statistical Computing, Vienna, Austria). Two-way and multiway comparisons were made using the Mann-Whitney and Kruskal-Wallis tests, respectively, with statistical significance set to $\alpha = 0.05$. Although the design involves repeated measures for participants, observations were treated as independent in the statistical analyses due to the small number of replicates and participants.

RESULTS

A total of 7 participants were recruited (6 men and 1 woman), and performed 21 trials with simulated vomitus (5 each with the low viscosity on gurney, HG, and low viscosity on floor conditions, and 6 with the high viscosity on gurney condition). Bodily fluid cleaning protocols recommended by the Healthcare Infection Control Practices Advisory Committee to the Centers for Disease Control and Prevention and by the Occupational Safety and Health Administration involve using an absorbent material to remove the bulk fluid before mopping, and to clean high surfaces before low surfaces.[18,19] Only 2 participants used this approach (Table 1). Cleaning strategies varied among participants, but each participant used the same cleaning strategy each time they performed a trial (Table 1).

The numbers of contacts of different types are shown in Table 1. Contact frequency (contacts per hour) can be calculated by dividing the number of contacts by the hour duration of the trial. On average, the cleaning cart was touched more times, and more frequently, than the gurney (16.3 vs 9.8 contacts, or 171 vs 90 contacts per hour) per trial. Participants were observed to contact their own bodies in only 9 of 21 trials (5 of 7 participants), but the number of self-contacts was highly variable when they occurred (range, 1-18 contacts or 3.3-164 contacts per hour). Most contacts with the body involved the upper body and occurred when participants adjusted their scrubs (worn over their clothing) or PPE. Participants' contacts with their bodies, when they occurred, were more likely to involve the use of fingers, 81% on average, whereas contacts with environmental surfaces involved different parts of the hand more frequently, with 59%, 30%, and 11% involving the fingers, the whole hand, and the hand other than fingers, respectively, on average.

Graphic presentation of the data suggest that participants are relatively consistent from trial to trial in their contact patterns during cleaning of simulated bodily fluids (measured as number of contacts and contact frequency in Fig 1), but there is substantial variability between participants. We verified this intraparticipant consistency from trial 1 to trial 2, and found no evidence to reject the null hypothesis that the mean difference in surface contact

Table 1
Observed contacts during cleaning of simulated vomitus trials

			Number of contacts				% Contact type*		No. of contacts				% Contact type		
Trial†	Condition‡	Duration (min)	Gurney	Cleaning cart	Other¶	All	Fingers only	Whole hand	Lower body	Upper body	Face/ head	All self contacts	Fingers only	Whole hand	Facial PPE contacts
1-A1	LG	7.8	32	20	0	52	40	37	3	0	0	3	67	0	0
1-B1	LF	4.2	3	22	0	25	80	20	0	0	0	0	–	–	0
1-B2	HF	2.8	0	13	0	13	77	15	0	0	0	0	–	–	0
2-A1	LG	7.3	0	5	5	10	50	40	0	0	0	0	–	–	§
2-A2	HF	4.1	1	5	0	6	83	17	1	1	0	2	100	0	§
2-B1	HF	5.1	10	10	0	20	60	40	2	0	0	2	100	0	2
2-B2	HG	4.8	7	6	0	13	38	62	0	13	0	13	92	8	0
3-A1	HF	9.2	14	32	1	47	53	34	1	0	3	4	75	25	0
3-A2	HG	13.6	30	32	3	65	35	43	0	15	0	15	100	0	0
3-B1	LG	7.8	21	49	0	70	36	40	0	0	0	0	–	–	0
3-B2	LF	6.6	12	36	1	49	49	29	0	0	0	0	–	–	0
4-A1	LG	18.3	12	16	0	28	79	11	1	0	0	1	100	0	0
4-A2	HG	19.1	6	18	0	24	92	4	4	0	0	4	0	0	0
5-A1	HG	11.1	1	18	7	26	69	31	0	16	1	18	94	0	0
5-A2	LF	7.9	9	9	0	18	50	44	0	0	0	0	–	–	2
6-A1	HF	4.6	13	6	0	19	26	47	0	0	0	0	–	–	§
6-A2	LF	6.1	12	6	0	18	27	39	0	0	0	0	–	–	§
7-A1	LF	1.1	0	6	0	6	100	0	0	0	0	0	–	–	§
7-A2	LG	2.9	15	9	0	24	33	50	0	0	0	0	–	–	§
7-B1	HG	2.7	7	13	0	20	65	35	0	0	0	0	–	–	§
7-B2	HF	2.2	0	10	0	10	100	0	0	0	0	0	–	–	§
Mean		7.1	9.8	16.3	0.6	26.8	59	30	0.6	2.1	0.2	2.9	81	4	0.3
Median		6.1	9.0	13	0	20	53	35	0	0	0	0	94	0	0

HF, high viscosity on floor; *HG*, high viscosity on gurney; *LF*, low viscosity on floor; *LG*, low viscosity on gurney; *PPE*, personal protective equipment.
*Contacts had 3 types: fingers, whole hand, and hand other than fingers. Because only 2 types are shown, the percentages may not sum to 100.
†Trial identifier includes a 3-digit participant code, a letter indicating first or second visit, and a number indicating the trial performed during that visit. Code 1-A1 indicates participant 1, visit A, trial 1.
‡Condition of vomitus release.
§Participant did not wear facial personal protective equipment (mask, glasses, or goggles).
¶Other category includes contacts with walls and floor.

number ($P = .31$), self-contact number ($P = .59$), or surface contact frequency ($P = .11$) between the paired trials is zero. Each participant, when performing repeated trials, used 1 cleaning strategy. Following the recommended protocol was found to be statistically significantly associated with differences in environmental surface contact frequencies ($P = .006$). Specifically, following the recommended protocol was associated with lower contacts and contact frequencies (median, 15.5 contacts or 139 contacts per hour) relative to other cleaning strategies (median, 31.3 contacts or 315 contacts per hour). This difference in contact frequency appears to be driven by the frequency with which participants contacted the cleaning cart, which was also statistically significantly associated with adherence to the cleaning protocol ($P = .04$). No statistically significant effect of protocol adherence was observed for the number of self-contacts.

We used 4 experimental conditions that varied in the placement and viscosity of simulated vomitus because the location and nature of the bodily fluid might influence cleaning practices. A statistically significant difference was observed in the number of participant self-contacts among the 4 experimental conditions ($P = .04$), but not for the number or frequency of environmental surface contacts. This difference is driven by the high numbers of self-contacts observed in the high viscosity vomitus on the side of the gurney condition, for which 3 of 5 participants in this condition frequently touched their upper bodies (median, 13 contacts), relative to those observed for the other conditions (median, 0-1 contacts).

We considered a crude measuring of cleaning quality (Table 2), relative reduction in the spatial extent of contamination, and found this to be statistically significantly associated with the number and frequency of environmental surface contacts ($P = .04$ and $P = .002$, respectively), but not with self-contacts ($P = .45$). A monotonic trend in the number of contacts was not observed by group because similar numbers of contacts occurred for cleaning quality levels 1 and 3 (mean values, 21.9 and 21.4 contacts, respectively), and were lower than the number of contacts in cleaning quality level 2 (mean, 57 contacts). Based on contact frequency, cleaning quality group 1 had a lower mean value (mean, 182 contacts per hour) than the other groups (mean, 461 and 367 contacts per hour for groups 2 and 3), respectively. Cleaning quality was statistically significantly associated with adherence to the recommended protocol, or not ($P = .03$): All experimental trials in which participants followed the protocol were in cleaning category 1, whereas in experimental trials in which the recommended protocol was not followed the median was category 2.

All participants used premoistened mop heads to clean (mean, 2.5 per trial), and participants used premoistened towels in 18 of 21 trials (mean, 2.4 per trial), but use of dry mops and towels was less frequent (Table 2). There was a statistically significant difference in the use of dry towels ($P < .001$) and dry mop heads ($P = .02$) associated with following the recommended protocol. Participants who followed the recommended protocol used more dry towels and fewer dry mop heads than other participants (mean, 2.2 vs 0 dry towels and 0 vs 1.1 dry mop heads).

DISCUSSION

We found that during cleaning participants touched the cleaning cart (to obtain and dispose of cleaning supplies) and the gurney (to move the gurney, clean the gurney, and for balance) far more frequently than they touched other surfaces, such as the floor (Table 1). Although this observation was true for all participants, there was substantial variability in the contact patterns between individuals (Fig 1). Participants tended to exhibit similar contact

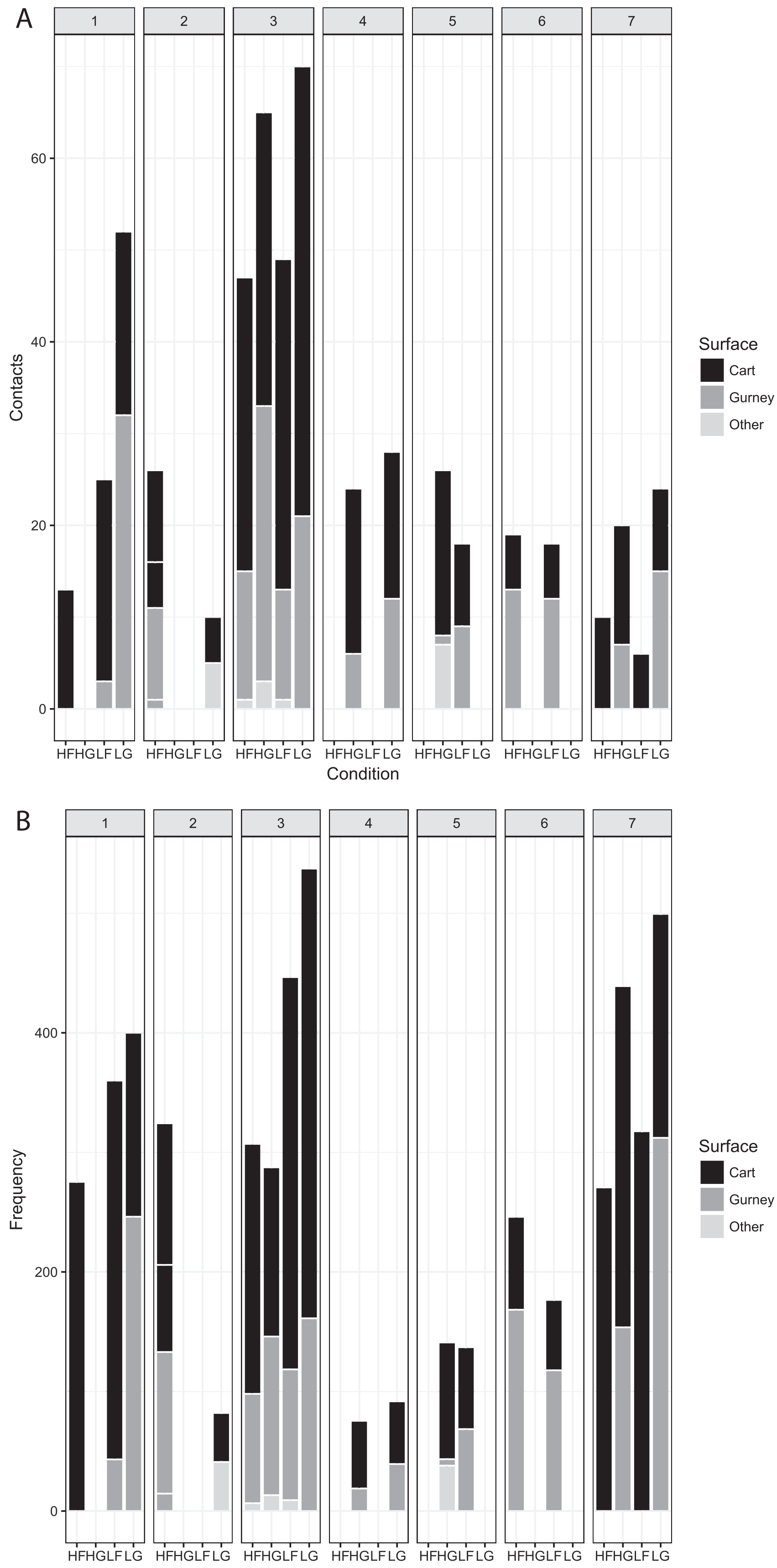

Fig 1. The (A) number and (B) frequency (per hour) of environmental surface contacts are generally more similar within participants, even in different experimental conditions, than between participants.

Table 2
Cleaning quality, strategy, and tools used by participants

Trial	Cleaning quality	Protocol followed/strategy	Cleaning tools used					
			Dry towel	Moist towel	Dry mop head	Moist mop head	Disinfectant wipe	Disinfectant liquid
1-A1	2	No/floor	0	1	0	7	0	Yes
1-B1	1		0	4	0	2	0	No
1-B2	1		0	0	1	3	0	No
2-A1	1	Yes/spot clean	3	2	0	1	–	No
2-A2	1		3	1	0	1	–	No
2-B1	1		0	3	0	2	0	No
2-B2	1		0	4	0	2	0	No
3-A1	3	No/whole room	0	2	0	4	0	No
3-A2	1		0	5	0	4	0	No
3-B1	2		0	2	2	2	0	Yes
3-B2	2		0	1	3	1	0	Yes
4-A1	1	No/spot clean	0	4	3	3	3	No
4-A2	1		0	3	4	2	3	No
5-A1	1	Yes/floor	1	7	0	1	7	No
5-A2	1		6	6	0	3	0	Yes
6-A1	1	No/spot clean	0	1	0	5	0	No
6-A2	1		0	1	0	4	0	No
7-A1	1		0	0	1	1	0	No
7-A2	3	No/spot clean	0	2	1	1	0	No
7-B1	3		0	1	1	2	0	No
7-B2	3		0	0	1	2	0	No
Mean			0.62	2.4	0.81	2.5	0.68	
Median			0	2.0	0	2.0	0.0	

patterns in repeated trials; that is, cleaning for similar durations of time with similar quality, regardless of the experimental condition (Fig 1). This pattern, low within-worker variability and high between-worker variability, is not uncommon,[20] and can be reasonably anticipated among occupational activities with high worker latitude or discretion, such as cleaning.

Alone, variability in environmental cleaning strategies is not problematic, but the association between different cleaning strategies and contact patterns that may increase the risk of self-contamination, or the quality of environmental cleaning, suggests the value of a training intervention to standardize cleaning strategies and practices. We found that participants who followed the recommended protocol (using absorbent materials to remove the bulk simulated vomitus, followed by cleaning from high to low) had fewer environmental surface contacts than other participants, and were more likely to clean the simulated vomitus effectively (all participants who followed the protocol had the highest cleaning quality). This suggests that training to improve adherence to the recommended protocol could reduce environmental surface contacts and improve environment quality, that latter of which is important to decreasing disease transmission in health care settings.

Environmental surface contacts were observed in all trials, but can be reduced by redesign of the job and environment. For example, some participants touched the gurney or floor for support to kneel, bend over, or stand up while cleaning; and touched the gurney or cart to move the item during cleaning. Cleaning tools can be changed to enable access to hard-to-reach spots without kneeling or bending, and changes in room and furnishing design could decrease the need to move items. These changes reduce the potential for contaminant transfer, but also reduce the risk of occupational injury associated with awkward postures, and pushing and pulling heavy items. Although training is important to help ensure workers clean effectively, thoughtful engineering changes to cleaning equipment and the work environment can have a more lasting influence on cleaning practices and bring other benefits to health care workers.

A particular concern associated with failure to follow the recommended protocol was the potential for contamination of the cleaning cart. We observed that participants who did not follow the protocol had more contacts with the cleaning cart than those who did, which may be due, in part, to the patterns of cleaning tool use. Multiple mop heads are required to absorb the bulk material that is otherwise removed with absorbent towels, and disposal of saturated mop heads often resulted in splashing of simulated vomitus onto the outside of the cleaning cart. Participants were observed to clean a portion of the cleaning cart after cleaning the simulated vomitus in 2 trials (1-B1 and 4-A1), and no participants were observed to clean their tools, suggesting the potential for a contaminated instrument to transmit pathogens to other areas of a health care institution.

A limitation of this study was the modest sample size: 7 participants who each participated in 2-4 experimental trials with simulated vomitus. There is always concern that samples are representative of the population of interest, particularly in the context of small sample sizes. We observed variation between participants in cleaning strategy, cleaning quality, cleaning tool use, and contact patterns, suggesting that we captured some, if not all, of the variation in cleaning practices. Similarly, there is always concern that participants modify behaviors when observed, with the expectation that participants are more likely to conform to best practices in a research study than in real life. We minimized this risk by performing the study in the laboratory, away from participants' workplaces where they may feel heightened pressure to perform the work in a certain way when observed. Further, the variation in observed work practices and cleaning quality suggest that participants had different definitions of best practices to which they conformed, if they changed their behavior.

A further limitation of this study is that we simply observed contact events and did not infer whether or not each contact increased the exposure of the participants, or increased environmental contamination: That is, was it a risky contact? For example, contact between 2 clean surfaces (a glove and a surface, or a glove and the face) does not increase contamination, whereas contact between a dirty and a clean surface can transfer contamination to a previously uncontaminated surface. Nonetheless, the contact number and frequency data generated in this study (Table 1) can be used to define time-activity patterns, exposure and risk analysis models,[13] and fill a knowledge gap in our understanding of cleaning tasks.

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Electronic data tables for this article will be available at time of publication at UIC INDIGO (https://indigo.uic.edu); raw data will be available within 16 months at the same location.

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