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A randomized, controlled trial of enhanced cleaning to reduce contamination of healthcare worker gowns and gloves with multidrug-resistant bacteria

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Abstract

Objective—To determine whether enhanced daily cleaning would reduce contamination of healthcare worker (HCW) gowns and gloves with methicillin-resistant *Staphylococcus aureus* (MRSA) or multidrug-resistant *Acinetobacter baumannii* (MDRAB).

Design—A cluster-randomized controlled trial.

Setting—Four intensive care units (ICUs) in an urban tertiary care hospital.

Participants—ICU rooms occupied by patients colonized with MRSA or MDRAB.

Intervention—Extra enhanced daily cleaning of ICU room surfaces frequently touched by HCWs.

Results—A total of 4,444 cultures were collected from 132 rooms over 10 months. Using fluorescent dot markers at 2,199 surfaces, we found that 26% of surfaces in control rooms were cleaned and 100% of surfaces in experimental rooms were cleaned ($p < 0.001$). The mean proportion of contaminated HCW gowns and gloves following routine care provision and before leaving the rooms of patients with MDRAB was 16% among control rooms and 12% among experimental rooms (RR: 0.77, 95% CI: 0.28 – 2.11, $p = 0.230$). For MRSA, the mean proportions were 22% and 19%, respectively (RR: 0.89, 95%: 0.5 – 1.53, $p = 0.158$).

Discussion—Intense enhanced daily cleaning of ICU rooms occupied by patients colonized with MRSA or MDRAB was associated with a nonsignificant reduction in contamination of HCW gowns and gloves after routine patient care activities. Further research is needed to determine whether intense environmental cleaning will lead to significant reductions and fewer infections.

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INTRODUCTION

Environmental surfaces in intensive care unit (ICU) rooms are not cleaned well.^{1–3} These surfaces are often contaminated with antibiotic-resistant bacteria such as methicillin resistant *Staphylococcus aureus* (MRSA) and multidrug-resistant *Acinetobacter baumannii* (MDRAB), and improved ICU room cleaning has been shown to be associated with significant reductions in the environmental burden of antibiotic-resistant bacteria.^{4–8} Proposed methods for improving room cleaning include monitoring and feedback programs, “enhanced cleaning” (extra cleaning targeted at frequently touched, frequently contaminated surfaces), and novel cleaning materials such as microfiber cloths, copper biocides, hydrogen peroxide vapor, and UV lamps.^{9–19}

Contaminated environmental surfaces such as sinks, ventilators, and bed rails are a proposed reservoir for patient-to-patient transmission of antibiotic-resistant bacteria via the hands of healthcare workers (HCWs), and antibiotic-resistant bacteria on environmental surfaces have been associated with antibiotic-resistant bacteria on the disposable gowns and gloves of HCWs in the ICU.²⁰ Many have hypothesized that improved environmental cleaning reduces patient-to-patient transmission of antibiotic-resistant bacteria by reducing opportunities for the clothing of HCWs to become contaminated.^{7,8} It has also been hypothesized that the process of removing contaminated gowns and gloves is a major cause of hand contamination, and therefore reduced gown and glove contamination may ultimately reduce hand contamination and transmission to other patients.^{7,8}

This study is novel in evaluating the effect of daily enhanced cleaning on the outcome of gown and glove contamination. All prior studies of enhanced cleaning protocols in ICUs have taken place in units with the majority of beds in a single open ward rather than in units with individual patient rooms, as in most US hospitals.^{7,8} In this study, we examined the effect of enhanced cleaning in medical and surgical ICUs with single-occupant rooms. We hypothesized that enhanced cleaning of frequently contaminated surfaces in occupied ICU rooms would be associated with less HCW contamination.

METHODS

Study Design and Setting

We conducted a cluster-randomized controlled trial to compare the efficacy of a standard ICU room cleaning plus a single extra cleaning of frequently-touched surfaces versus standard ICU room cleaning alone to reduce the contamination of disposable gowns and gloves with MRSA or MDRAB after routine patient care at the University of Maryland Medical Center (UMMC). The study was approved by the university’s institutional review board. UMMC is a 757-bed urban public teaching hospital in Baltimore, Maryland, affiliated with the University of Maryland School of Medicine. Rooms in 4 ICUs at UMMC were included: one 29-bed medical ICU and three 12-bed surgical ICUs. All 65 study rooms were single-bed, single-occupant rooms. All patients in the study ICUs colonized with MRSA or MDRAB were placed under contact precautions.

Enrollment and follow-up took place between August 2011 and May 2012. Before the study began, all rooms were assigned to the intervention or control (no intervention) arm at a 1:1 ratio, with no more than 2 adjoining rooms having the same assignment. After the first half of the sample size was completed, all study procedures were suspended for a 1-month washout period. Before the second half of the study began, all experimental rooms were reassigned to the control group, and all control rooms were reassigned to the experimental group. This scheme and washout period was used to prevent crossover (because multidrug-

resistant bacteria can persist in the environment for weeks) while still allowing all rooms an opportunity to be in the experimental arm.^{1,21}

A room was eligible for enrollment and follow-up on any day during the study period that it was occupied by a patient colonized with MRSA and/or MDRAB (as indicated in their electronic medical record) if the patient had been in the room for at least 24 hours. Typically, 5–15 rooms per day met these eligibility criteria, so, in order to limit unnecessary study staff, we randomly subselected 2 rooms per day for enrollment and follow-up from the daily list of all eligible rooms. Each time a room was subselected for enrollment, it received a single intervention (sham or experimental) and a single day of follow-up (see “Interventions” and “Study Outcomes”). If a room was not occupied by a patient with MRSA or MDRAB, if the patient had not been in the room for 24 hours, or even if the room met all requirements but was not randomly subselected, no intervention or follow-up was performed.

For example, prior to the beginning of the study, room 1 was assigned to the control group (i.e., did not receive enhanced cleaning). On the first day of the study, room 1 and 4 other rooms met the eligibility criterion of being occupied by patients with either MRSA or MDRAB, and room 1 and 1 other room were randomly subselected for enrollment on that day. On the second day of the study, 7 rooms were eligible – including room 1 – but room 1 was not randomly subselected for enrollment on that day and so did not receive any intervention or follow-up. On the third day of the study, room 1 was occupied by a patient not colonized with MRSA or MDRAB and was not eligible for enrollment. Room 1 was eligible on several subsequent occasions during the study period and was randomly subselected for enrollment and follow-up on 3 other days. During the second half of the study room 1 was reassigned to the experimental group and always received the experimental intervention whenever subselected for enrollment.

Interventions

The experimental intervention was an “enhanced cleaning” – a single extra cleaning by study researchers of high-touch surfaces in the ICU room in addition to routine cleaning by the UMMC housekeeping staff. Surfaces were cleaned using wipes saturated with the same quaternary ammonium solution used by the UMMC housekeeping staff for routine cleaning. The researcher cleaned: (1) the bed rail and bed controls, (2) the movable overbed table, (3) the built-in desk, (4) the intravenous poles and infusion pumps, (5) the nurse call button, (6) the patient telephone, (7) the room sink, (8) the light switches, (9) the supply cart, (10) the ventilator desk and controls, and (11) the telemetry controls. These targets were chosen based on a Centers for Disease Control and Prevention list of frequently touched and frequently contaminated surfaces.¹² The control intervention was a sham enhanced cleaning by the same researcher. For the sham cleaning, a study researcher entered the room with all necessary cleaning equipment and mimed the action of cleaning, but the target surfaces were never touched. The sham cleaning was used to blind the HCWs to the assigned intervention. All extra or sham cleaning was in addition to routine cleaning by the UMMC housekeeping staff. Standard daily cleaning included cleaning of the doorframe, floors, walls (as needed), furniture, bathroom fixtures, overbed table, built-in desk, nurse call button, patient telephone, sink, light switches, and supply cart.

Implementation of the intervention was verified using an invisible fluorescent gel (DAZO®, Ecolab). This gel has been used in several previous studies as a marker of cleaning.^{22–24} In 10% of experimental rooms, a researcher marked all target surfaces with a gel marker and then used an ultraviolet light to check for removal after a second researcher had cleaned the room. The cleaning research staff was blinded as to specific location marked with fluorescent gel. In 100% of control rooms, target surfaces were marked during the sham

cleaning and removal was verified 24 hours later in order to allow the hospital housekeeping staff sufficient time to clean the room. All rooms in the study were cleaned once every 24 hours by the hospital housekeeping staff.

Study Outcomes

The effect of the intervention was assessed by culturing the disposable gown and gloves of HCWs after routine care activity in an enrolled room. The primary outcome was the isolation of MRSA or MDRAB (as applicable to the patient) from the gown and gloves. Gown and glove cultures were performed as described previously.^{25,26} Gloves and gown were cultured using a single double-tipped applicator. All inter-digital spaces of each glove were swabbed twice, and the ventral and dorsal surfaces of each glove were each swabbed once in a large spiral. The length of each gown sleeve was swabbed twice, and then the front of the gown was swabbed once in a large W pattern. All cultures were collected immediately prior to the HCW removing the gown and gloves and exiting the room. Based on previously published low rates of gown and glove contamination prior to entering the room and the additional cost, we did not prescreen HCWs.^{25,26}

Outcomes were analyzed separately for rooms occupied by patients colonized with MRSA or MDRAB. Cultures from rooms occupied by cocolonized patients were included independently in both analyses. Isolation and speciation of MRSA and *A. baumannii* was performed using chromogenic agars (Spectra MRSA, Remel; CHROMagar *Acinetobacter*, CHROMagar). Antibiotic susceptibilities of *A. baumannii* isolates were established by the Kirby-Bauer test against a panel of 10 antibiotics from 6 antibiotic classes. *A. baumannii* isolates were considered multidrug resistant if susceptible to 2 or fewer classes of antibiotics. This was the same definition used by UMMC infection control during the study period to place an indicator in the patient chart and to begin contact precautions.

After application of the assigned intervention, the room was continuously monitored, and the disposable gowns and gloves of any HCW to exit the room were cultured. Follow-up continued until 15 cultures were obtained or 8 hours had elapsed since the intervention.

Sample Size

Sample size calculations adjusted for clustering were made *a priori* to determine the number of cultures and patient rooms necessary for adequate statistical power. We expected a baseline gown and glove contamination rate of 38% for MDRAB rooms and 18% for MRSA rooms based on prior observational studies at UMMC.^{25,26} We estimated that we would need 1,200 cultures from 20 MDRAB rooms and 3,240 cultures from 54 MRSA rooms in order to have more than 90% power to detect a 30% relative reduction in the proportion of gown and glove contamination from each room with a 5% type I error rate.²⁷ We treated each room as a cluster. We assumed that we would collect 60 cultures from each room and that the intraclass correlation coefficient for observations from the same room was 0.01. There were no data to indicate *a priori* the size of the effect, so we included a 30% relative reduction in our calculations because we believed that it was the smallest effect size that would be clinically significant and justify increased efforts towards enhanced environmental cleaning.

Statistical Analysis

Results were analyzed on an intention-to-treat basis. MDRAB and MRSA contamination were analyzed as separate outcomes. For the primary analysis, we calculated the proportion of positive MDRAB and MRSA cultures from each room that was occupied by at least 1 MDRAB-colonized and at least 1 MRSA-colonized patient, respectively, during the study period. We then tested the difference in the mean proportion of positive cultures between

control rooms and experimental rooms using the Wilcoxon-Mann-Whitney test.²⁷ For the secondary analysis, we calculated the proportion of positive cultures from each room on each day and modeled that proportion in a generalized linear mixed model with the intervention group as a fixed effect and the room and the patient nested within the room as random effects. We estimated the intraclass correlation coefficient (ICC) for observations from the same room and the ICC for observations from the same patient by assembling a model with a random effect for the room only and then the final model with random effects for the room and the patient nested within the room. Differences with *P* less than .05 were considered statistically significant. All statistical analyses were performed using SAS software, version 9.22 (SAS Institute).

RESULTS

We enrolled 97 MRSA rooms and 35 MDRAB rooms. A total of 4,444 patient-HCW interactions were sampled: 1,206 from MDRAB rooms and 3,240 from MRSA rooms as guided by our a priori power calculations (Figure 1). During enrollment follow-up 146 MRSA-colonized patients and 44 MDRAB-colonized patients occupied in enrolled rooms, including 19 co-colonized patients. An average of 3.1 patient-HCW interactions occurred per hour during follow-up. An average of 1.8 rooms was enrolled on each study day, and an average of 14.7 cultures was collected per room per study day. Rooms randomized to the experimental and control groups were not different with regard to room or patient characteristics (Table 1).

The intervention was verified in 10% of experimental rooms and 100% of control rooms. Among experimental rooms, 169/169 (100%) of fluorescent marks were removed after cleaning. Among control rooms, 521/2030 (26%) of marks were removed at 24 hours ($p < 0.001$).

Among rooms occupied by patients colonized with MDRAB, those randomized to the experimental group had a lower mean proportion of contaminated gowns and gloves, but this reduction was not statistically significant (12% vs. 16%; RR: 0.78, 95% CI: 0.28–2.11; $p = 0.230$). Similarly, among rooms occupied by patients colonized with MRSA, rooms randomized to the experimental group saw a lower mean proportion of contaminated gowns and gloves, but this reduction was not statistically significant (19% vs. 22%; RR: 0.89, 95% CI: 0.50–1.53; $p = 0.158$) (Table 2).

Among patients with MDRAB in rooms randomized to the control group, 3 (14%) were never associated with a positive culture, i.e., no HCW exiting their room ever had MDRAB isolated from their gowns or gloves. The average rate of gown and glove contamination among the remaining MDRAB-colonized patients was $21\% \pm 15\%$. Among patients with MRSA in rooms randomized to the control group, 24 (32%) were never associated with a positive culture. The average rate of gown and glove contamination among the remaining MRSA-colonized patients was $27\% \pm 18\%$.

In a generalized linear mixed model of the proportion of contaminated gowns and gloves contaminated with MDRAB on each study day, including random effects for the room and the patient nested within the room, rooms randomized to the experimental group had a lower mean proportion of contaminated gowns and gloves, but this reduction was not statistically significant (17% vs. 13%; RR: 0.73, 95% CI: 0.40–1.05; $p = 0.242$) (Table 3). The ICC for MDRAB rooms was 0.19, and the ICC for MDRAB patients was 0.29. Rooms occupied by MRSA patients randomized to the experimental group had a lower mean proportion of contaminated gowns and gloves, but this reduction was not statistically significant (19% vs.

17%; RR: 0.92, 95% CI: 0.65–1.18; $p = 0.646$). The ICC for MRSA rooms was 0.06, and the ICC for MRSA patients was 0.46.

DISCUSSION

In a randomized controlled trial, we successfully implemented enhanced daily cleaning (from 26% to 100% of surfaces cleaned in experimental rooms). We found that ICU rooms that received enhanced cleaning had an 11% relative drop in HCW gown and glove contamination with MRSA and a 22% relative drop in gown and glove contamination with MDRAB but that these reductions were not statistically significant. The results were similar when the proportion of contaminated gowns and gloves was estimated over the entire duration of the trial and when estimated on a daily basis.

Cultures from the same room were highly correlated. Correlation was higher among cultures from HCWs visiting the same patient (after accounting for the room) than among cultures from HCWs visiting the same room without accounting for patient identity, and this was particularly pronounced for MRSA contamination. This result indicates that individual patient characteristics are likely very important in the transmission process, and it was exemplified by the observation that 32% of patients colonized with MRSA did not transmit bacteria, while the remaining MRSA patients transmitted MRSA to 27% of HCWs. Although we did not collect patient-specific data in this study, such patient factors as the presence of tracheostomy sites, open surgical wounds, or the presence of foreign devices have been reported to increase HCW contamination and therefore patient-to-patient transmission.^{20, 28} High correlation among patients may also represent specific strains of MDRAB or MRSA with a high propensity for contamination.

Published studies of enhanced daily cleaning have found significant reductions in the contamination of ICU surfaces with bacteria.^{7,8} We expect we achieved similar reductions based upon 100% removal of fluorescent markers. In subgroup analyses, one study saw a trend toward reduction of MRSA on nurses' hands and a significant reduction in doctors' hand contamination but, critically, no adjustment was made for clustering.^{7,8} The results of our study suggest that any effect of an enhanced daily cleaning on hand contamination or patient infections are unlikely to be detected except by exceedingly large studies designed and powered for that purpose.

Strengths of this study include the cluster-randomized design, the use of standard hospital cleaning products, validation of cleaning with fluorescent markers, and the mixed population of medical and surgical ICU rooms. Measuring gown and glove contamination extends our understanding of one possible route of patient-to-patient transmission. The primary outcomes of all previous trials of enhanced cleaning are environmental contamination. Gown and glove contamination is a more clinically relevant outcome because it represents the first step in a hypothesized chain of events between environmental contamination and acquisition of antibiotic-resistant bacteria and because it measures the potential maximum effect that enhanced environmental cleaning could have on patient-to-patient transmission.

Although we were not able to detect a statistically significant reduction in gown and glove contamination with MRSA and MDRAB following enhanced cleaning, we did observe lower contamination in rooms assigned to the intervention for both organisms. We also only included 2 organisms analyzed separately, whereas cleaning should affect a number of antibiotic-resistant bacteria and may have a stronger cumulative effect. Given the low cost of material and labor for enhanced cleaning, the expense of treating antibiotic-resistant infections in ICU patients, and the frequency of HCW contact, an 11%–22% relative reduction in gown and glove contamination may be a cost-effective method for hospital

infection control services to reduce the chance of patient-to-patient transmission. Further studies are needed to assess the effect of enhanced cleaning on other antibiotic-resistant bacteria and clinical outcomes. In addition, we believe that studies are needed to identify possible risk factors for high levels of gown and glove contamination.

In conclusion, a single enhanced cleaning of frequently touched surfaces in ICU rooms occupied by patients colonized with MRSA or MDRAB did not result in a significant reduction in HCW gown and glove contamination with these pathogens. The effect of enhanced daily cleaning may be between 10% and 20%, and large multicenter trials will be required to conclusively estimate this effect and potentially demonstrate a benefit.

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Figure 1.
 Diagram of room screening, enrollment and follow-up.

Table 1

Baseline characteristics of the study rooms and patient occupants. Results were analyzed separately for rooms occupied by patients colonized with multidrug-resistant *Acinetobacter baumannii* and methicillin-resistant *Staphylococcus aureus*.

Multidrug-resistant <i>A. baumannii</i>			
Variable	Experimental	Control	p
<i>Rooms</i>			
Rooms sampled (<i>n</i>)	19	16	0.37 [*]
Patients sampled per room (<i>mean ± SD</i>)	1.3 ± 0.1	1.3 ± 0.2	0.80 [†]
Cultures obtained per room (<i>mean ± SD</i>)	35 ± 14	33 ± 20	0.69 [†]
Medical ICU (<i>n</i> , %)	9 (47)	8 (50)	0.94 [‡]
<i>Patients</i>			
Patients sampled (<i>n</i>)	24	21	0.38 [*]
Age (<i>mean ± SD</i>)	50 ± 19	55 ± 19	0.45 [†]
Male (<i>n</i> , %)	18 (75)	11 (52)	0.12 [‡]
Length of stay in room (<i>mean ± SD</i>)	7 ± 9	8 ± 14	0.77 [†]
Length of stay in hospital (<i>mean ± SD</i>)	17 ± 15	16 ± 19	0.79 [†]
Charlson Comorbidity Index (<i>mean ± SD</i>)	3.4 ± 3.6	2.8 ± 1.9	0.45 [†]
Methicillin-resistant <i>S. aureus</i>			
Variable	Experimental	Control	p
<i>Rooms</i>			
Rooms sampled (<i>n</i>)	46	51	0.34 [*]
Patients sampled per room (<i>mean ± SD</i>)	1.5 ± 0.1	1.5 ± 0.1	0.95 [†]
Cultures obtained per room (<i>mean ± SD</i>)	32 ± 16	35 ± 16	0.27 [†]
Medical ICU (<i>n</i> , %)	22 (48)	24 (47)	0.94 [‡]
<i>Patients</i>			
Patients sampled (<i>n</i>)	69	76	0.47 [*]
Age (<i>mean ± SD</i>)	51 ± 19	56 ± 17	0.11 [†]
Male (<i>n</i> , %)	45 (65)	45 (59)	0.46 [‡]
Length of stay in room (<i>mean ± SD</i>)	5 ± 5	4 ± 4	0.34 [†]
Length of stay in hospital (<i>mean ± SD</i>)	12 ± 9	10 ± 9	0.15 [†]
Charlson Comorbidity Index (<i>mean ± SD</i>)	2.6 ± 2.6	2.5 ± 2.5	0.72 [†]

^{*} Binomial exact

[†] Student's T

[‡] Pearson's χ^2

Mean percent of contaminated swabs from each room comparing rooms that received enhanced cleaning (experimental) to rooms that received sham cleaning (control). Results were analyzed separately for rooms occupied by patients colonized with multidrug-resistant *Acinetobacter baumannii* (MDRAB) and methicillin-resistant *Staphylococcus aureus* (MRSA).

Table 2

Multidrug-resistant <i>A. baumannii</i>					
	Experimental	Control	Attributable Risk	Relative Risk	p
	% (95% CI)	% (95% CI)	% AR (95% CI)	RR (95% CI)	Wilcoxon
Mean positive cultures per room	12.2 (6.2 – 18.2)	15.8 (9.9 – 21.7)	–3.6 (–11.4 – 4.2)	0.77 (0.28 – 2.11)	0.23
number of rooms (n)	19	16			
cultures per room (mean ± SD)	35 ± 14	33 ± 20			
Methicillin-resistant <i>S. aureus</i>					
	Experimental	Control	Attributable Risk	Relative Risk	p
	% (95% CI)	% (95% CI)	% AR (95% CI)	RR (95% CI)	
Mean positive cultures per room	19.3 (12.4 – 26.1)	21.9 (16.7 – 27.2)	–2.6 (–11.0 – 5.7)	0.89 (0.50 – 1.53)	0.16
number of rooms (n)	46	51			
cultures per room (mean ± SD)	35 ± 16	32 ± 16			

Table 3

Generalized linear mixed model of the proportion of contaminated swabs collected from each room on each day as a function the assigned intervention. Results were analyzed separately for rooms occupied by patients colonized with multidrug-resistant *Acinetobacter baumannii* (MDRAB) and methicillin-resistant *Staphylococcus aureus* (MRSA).

Multidrug-resistant <i>A. baumannii</i>				
Variable	Estimate % (95% CI)	Attributable Risk %AR (95% CI)	Relative Risk RR (95% CI)	p
Experimental intervention	12.5 (6.9 – 18.2)	–4.7 (–13.0 – 3.5)	0.73 (0.40 – 1.05)	0.24
Control intervention (intercept)	17.3 (10.8 – 23.8)			
ICC within rooms	0.19			
ICC within patients (nested in room)	0.29			
Methicillin-resistant <i>S. aureus</i>				
Variable	Estimate % (95% CI)	Attributable Risk %AR (95% CI)	Relative Risk RR (95% CI)	p
Experimental intervention	17.5 (12.4 – 22.7)	–1.6 (–8.7 – 5.6)	0.92 (0.65 – 1.18)	0.65
Control intervention (intercept)	19.2 (14.1 – 24.2)			
ICC within rooms	0.06			
ICC within patients (nested in room)	0.46			