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Interventional evaluation of environmental contamination by vancomycin-resistant enterococci: failure of personnel, product, or procedure?

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Summary It is not clear whether improvement in environmental decontamination is more efficiently achieved through changes in cleaning products, cleaning procedures, or performance of cleaning personnel. To assess the impact of cleaning performance on environmental contamination with vancomycin-resistant enterococci (VRE), we conducted a sequential trial in which a multifaceted environmental cleaning improvement intervention was introduced in a medical intensive care unit and respiratory step-down unit. The intervention included educational lectures for housekeepers and an observational programme of their activities without changes in cleaning products or written procedures. Following these interventions, the proportion of environmental sites cleaned improved from 49% to 85% ($P < 0.001$); contamination of environmental sites declined from 21% to 8% ($P < 0.0001$) before cleaning and from 13% to 8% ($P < 0.0001$) after cleaning. The improved cleaning and contamination rates persisted in a washout period. In a multivariate model, cleaning thoroughness strongly influenced the degree of environmental contamination, with a 6% decline in VRE prevalence with every 10% increase in percentage of sites cleaned. These findings suggest that surface contamination with VRE is due to a failure to clean rather than to a faulty cleaning procedure or product.
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Introduction

The inanimate hospital environment is a reservoir for resistant bacteria that pose hospital infection risks. Data supporting this concept include: (i) environmental surfaces are frequently contaminated with pathogens such as vancomycin-resistant enterococci (VRE), meticillin-resistant *Staphylococcus aureus* (MRSA), multidrug-resistant *Acinetobacter baumannii*, and *Clostridium difficile*;[1–5] (ii) healthcare workers can contaminate their hands after touching these surfaces and transfer potential pathogens to a patient or another environmental site;[6–8] (iii) exposure to a contaminated environment has been shown to be a risk factor for acquisition of VRE, MRSA, and *A. baumannii*;[9–12] and (iv) improvements in environmental cleaning have been associated with reduced incidences of VRE colonisation or *C. difficile* infection.[13,14]

To achieve a cleaner environment, it is not clear whether changes should be made in cleaning products, cleaning procedures, or performance of cleaning personnel. Previously, we reported that improving personnel attention to routine cleaning reduced environmental contamination with, and patient acquisition of, VRE.[13] Here, we examine the specific environmental cleaning intervention and evaluate factors that were associated with improvements.

Methods

Setting and study design

The study was conducted in the 14-bed medical intensive care unit (MICU) and adjacent 7-bed respiratory care step-down unit (RCSU) of Rush University Medical Center (RUMC), a 700-bed tertiary care hospital in Chicago, IL, USA. The units share nursing and medical staff. Environmental cleaning was performed by housekeepers dedicated either to the MICU or RSCU.

Using a sequential trial study design, we examined the effect of a multifaceted environmental cleaning improvement intervention on two outcomes: the proportion of environmental sites that were observed to have been cleaned, and the proportion of environmental sites that were contaminated with VRE following cleaning.

The current investigation analysed additional data generated during three of four periods of a previously published study.[13] Period 1 (5 March to 1 May 2001; duration, 58 days) served as a baseline period, without interventions. This was followed by a 30 day period (1 May 2001 to 30 May 2001) during which an education and intensified observation program to improve environmental cleaning was phased in; the program was fully implemented in period 2 (31 May to 27 July 2001; duration, 58 days). Period 3 (23 August to 18 October 2001; duration, 57 days) served as a 'washout' period, without interventions.

All housekeepers in the study units were eligible for study participation. The study was reviewed by the Rush Institutional Review Board and need for informed consent was waived.

Description of housekeeper education and observation intervention

The intervention consisted of educational sessions, increased overt housekeeping observations to reinforce the need for improved cleaning, and rotation of additional housekeepers through the units; the time a housekeeper spent cleaning a patient room did not increase (Table I). From 1 March 2001 to 26 July 2001, research staff held three 1 h sessions for housekeepers about the problem of VRE and the importance of adequate cleaning to decrease environmental bioburdens. Sessions emphasised the value of housekeepers' contributions to patient care and of thoroughly cleaning surfaces that were likely to be touched by patients or healthcare workers. Barriers to cleaning noted by housekeepers were surfaces they felt unqualified to clean, such as ventilator and infusion pump control panels, and obstacles such as items left on countertops. In response, MICU nursing staff conducted training sessions with housekeepers on safe cleaning of infusion pump control panels, and respiratory therapists were recruited to clean ventilator control panels daily. In addition, research staff members instructed staff in ways they could assist housekeepers, such as moving items from surfaces to be cleaned.

During period 3 (the 'washout' period), infection control efforts returned to those used in period 1: educational sessions for housekeepers were no longer held, no attempts to identify barriers to appropriate cleaning were made, and instruction of staff in ways to assist housekeepers ceased.

Environmental cleaning procedures

All cleaning procedures followed Centers for Disease Control and Prevention (CDC) Healthcare Infection Control Policy Advisory Committee (HICPAC) guidelines, and included daily cleaning of patient rooms and 'terminal cleaning' at patient

Table I Environmental cleaning thoroughness and contamination before and after a housekeeping cleaning improvement intervention

	Counts of rooms or sites measured for environmental cleaning thoroughness			Counts of rooms or sites measured for environmental contamination, before cleaning			Counts of rooms or sites measured for environmental contamination, after cleaning		
	Period[a]			Period			Period		
	1	2	3	1	2	3	1	2	3
Rooms (*N*)	53	160	160	34	35	33	34	35	33
Rooms housing VRE-colonised patients, no contact precautions (*N*)	14	30	15	13	14	11	13	14	11
Rooms housing VRE-colonised patients, contact precautions (*N*)[b]	22	35	32	21	21	22	21	21	22
Rooms housing non-VRE-colonised patients, no contact precautions (*N*)	13	72	96	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]
Rooms housing non-VRE-colonised patients, contact precautions (*N*)	4	23	17	0[c]	0[c]	0[c]	0[c]	0[c]	0[c]
Sites observed or cultured (*N*)	415	1240	1246	519	482	471	519	482	471
Category 1 sites[d]	—	—	—	36	29	27	36	29	27
Category 2 sites[d]	156	455	448	255	236	239	255	236	239
Category 3 sites[d]	259	785	798	228	217	205	228	217	205
Sites measured by housekeeper (*N*)									
Housekeeper A	343	626	674	444	278	298	444	278	298
Housekeeper B	72	24	257	75	—	29	75	—	29
Housekeeper C	—	156	106	—	73	56	—	73	56
Housekeeper D	—	252	94	—	117	58	—	117	58
Other housekeepers[e]	—	182	115	—	14	30	—	14	30
Sites measured by room type (*N*)									
Single room	199	824	664	219	430	186	219	430	186
Double room	184	288	316	244	26	184	244	26	184
Room with anteroom[f]	32	128	266	56	26	101	56	26	101
Sites measured by unit (*N*)									
RCSU	80	432	357	75	190	102	75	190	102
MICU	335	808	889	444	292	369	444	292	369
Sites measured by census (*N*)									
Above average	280	1087	475	312	396	244	312	396	244
Below average	135	153	771	207	86	227	207	86	227

	Thoroughness of environmental cleaning (% cleaned)			Environmental contamination with VRE, before cleaning (% contaminated)			Environmental contamination with VRE, after cleaning (% contaminated)		
Overall	49	85	84	21	8	10	13	8	6
By site category									
Category 1[d]	—	—	—	28	17	22	31	34	33
Category 2	46	85	82	24	11	13	14	11	6
Category 3	51	86	86	17	3	5	9	1	1
By VRE and contact precautions status									
Rooms housing VRE-colonised patients, no contact precautions	48	89	86	12	12	6	11	12	3
Rooms housing VRE-colonised patients, contact precautions	50	83	81	28	5	12	14	5	7

(*continued on next page*)

Table I (*continued*)

	Thoroughness of environmental cleaning (% cleaned)			Environmental contamination with VRE, before cleaning (% contaminated)			Environmental contamination with VRE, after cleaning (% contaminated)		
Rooms housing non-VRE-colonised patients, no contact precautions	50	86	86	—[c]	—[c]	—[c]	—[c]	—[c]	—[c]
Rooms housing non-VRE-colonised patients, contact precautions	42	83	79	—[c]	—[c]	—[c]	—[c]	—[c]	—[c]
By housekeeper									
A	54	91	93	22	6	9	14	5	5
B	24	75	77	13		10	7		3
C		90	86		7	16		7	11
D		70	80		7	2		15	2
Other[e]		86	51		43	23		14	13
By room type									
Single room	42	84	84	25	8	11	14	9	9
Double room	55	87	84	20	0	10	15	0	4
Room with anteroom[f]	59	94	86	7	4	9	4	4	4
By unit									
RCSU	24	82	81	13	7	5	7	12	6
MICU	55	87	86	22	8	12	14	5	6
By census									
Above average	48	84	78	29	8	13	17	8	8
Below average	51	92	88	8	8	7	8	8	4

VRE, vancomycin-resistant enterococcus; MICU, medical intensive care unit; RCSU, respiratory care step-down unit.

[a] Period 1, 58 day baseline period without intervention; period 2, 58 day intervention period; period 3, 57 day 'washout' period, without intervention.

[b] Results of rectal swab surveillance for VRE were not revealed to medical staff or housekeepers, and patients whose swabs grew VRE were not placed on contact precautions. Patients with a clinical culture growing VRE were placed on contact precautions if they had a clinical culture growing VRE or for other indications (e.g. MRSA, *C. difficile*, or appropriate clinical features).[16,17]

[c] Only rooms housing VRE-colonised patients were included in this analysis.

[d] Category 2, site within 0.91 m (3 feet) of the patient but not touching the patient; Category 3, site farther than 0.91 m (3 feet) from patient.

[e] Represents ≥2 housekeepers used sporadically, aggregated together.

[f] Rooms with anterooms were usually occupied by patients on reverse or airborne isolation.

discharge.[15] A quaternary ammonium detergent disinfectant was used for cleaning (Virex, 8.19% *n*-alkyl benzyl and 8.704% didecyl dimethyl ammonium chloride, S.C. Johnson, Sturtevant, WI, USA) (see Appendix).

Measurement of environmental cleaning

Observations of environmental cleaning were conducted throughout the study but increased in frequency in periods 2 and 3 as part of the intervention. Observations occurred for each of eight environmental sites (bed rails; over-bed tables; infusion pumps; clean countertops where intravenous medications and solutions were prepared; soiled countertops adjacent to sinks; soap dispensers; drawer handles; and inside handles of room doors). An observed site was classified as 'cleaned' if the housekeeper applied a disinfectant-soaked cloth to a site, and 'not cleaned' if the housekeeper did not apply a disinfectant-soaked cloth to a site; durations of applications were not measured. We observed cleaning of rooms housing both VRE-colonised and non-VRE-colonised patients. Observations were not concealed; housekeepers were aware that their performance was being monitored, and if, after being observed, a housekeeper asked about his or her performance, research staff provided immediate, specific feedback (e.g. 'You forgot to clean the countertop').

Assessment of VRE colonisation of patients, and patient isolation procedures

Rectal swab cultures were obtained from each patient at admission and daily to determine VRE colonisation. Housekeepers and the medical staff were not informed of study surveillance culture results. Rather, contact isolation was instituted based on CDC guidelines (i.e. presence of clinical findings or clinical isolates of organisms warranting barrier isolation, particularly *C. difficile* and multidrug-resistant organisms such as MRSA, VRE, or antibiotic-resistant Gram-negative rods).[16,17]

Measurement of environmental contamination

Twice weekly, environmental sites in up to six rooms of selected VRE-colonised patients as well as rooms of non-VRE-colonised patients were cultured before and after daily cleaning, and the prevalence of contamination was calculated. For the purposes of this study, only rooms occupied by VRE-colonised patients were analysed. The eight environmental sites subject to observation were tested for contamination by rubbing dual rayon swabs moistened with liquid Stuart's medium (Copan Diagnostics, Murrieta, CA, USA) over a 50 cm^2 area or over the entire surface if <50 cm^2. One swab was placed into 5 mL of bile esculin azide broth (BBL, Cockeysville, MD, USA) and 6 μg/mL of vancomycin; the second swab was plated directly onto bile esculin azide agar (BBL) plus vancomycin. Both media were incubated for 48 h at 35°C in ambient air.[8] VRE were confirmed as described previously.[13]

Classification of environmental sites

All observed and cultured sites were categorised based on proximity to the patient (Figure 1).[18] The blood pressure cuff, the only monitored environmental site in contact with the patient, was designated category 1. Sites within 0.91 m (3 feet) of the patient, but not touching the patient (bed rails, over-bed table, and infusion pump) were designated category 2, while sites farther away (clean and soiled countertop, soap dispenser, drawer handles, and inside door handle) were designated category 3. The sites selected for culture and cleaning observations and the site categories were based on previously described rates of VRE contamination.[18]

Additional data elements measured

Other data elements measured during the study were the daily point prevalence of VRE (colonisation pressure), calculated from daily rectal swab screening of all MICU patients as described elsewhere;[8,19] whether patients were on contact precautions; type of patient room (room with anteroom, 2-bed, or single-bed); daily MICU census; and hand hygiene compliance as measured by unobtrusive observation of a sample of healthcare workers twice weekly. In contrast with housekeeping observation, which was a component of the intervention, hand hygiene observation was not a part of the intervention and was covert.

Statistical methods

Count data were compared using χ^2-tests. Univariate and multivariate analyses were performed using the Generalised Estimating Equation. Data were entered using Microsoft Access 2000 (Redmond, WA, USA); data analyses were performed with SAS version 9 (Cary, NC, USA), using proc genmod and a Poisson distribution. Observations were analysed using an exchangeable correlation structure and identifying repeated measures at the room level.

Predictors of housekeeper cleaning thoroughness were assessed using proportion of sites cleaned in a room each day, grouped by category, as the outcome variable, and using the study period (baseline, intervention or washout) as the primary predictor variable. All observations were included in analysis of environmental cleaning. The role of contact precautions in environmental cleaning was assessed by comparing combinations of VRE-colonisation status and presence of contact precautions on quality of cleaning in the final multivariable model.

To determine predictors of environmental contamination after cleaning, the prevalence of VRE environmental contamination by site category was the outcome variable, and the proportion of environmental sites cleaned in that room was the main predictor. Because more environmental cleaning observations than environmental cultures were performed, only rooms in which environmental cleaning observations and environmental cultures occurred on the same day were used to estimate predictors of environmental decontamination.

Univariate and multivariate results are reported as prevalence ratios. All factors tested in univariate analyses were included in the initial multivariate models. Factors were removed sequentially by backward elimination. Data for census and colonisation pressure of VRE were aggregated by week and dichotomised as either above or below their mean values.

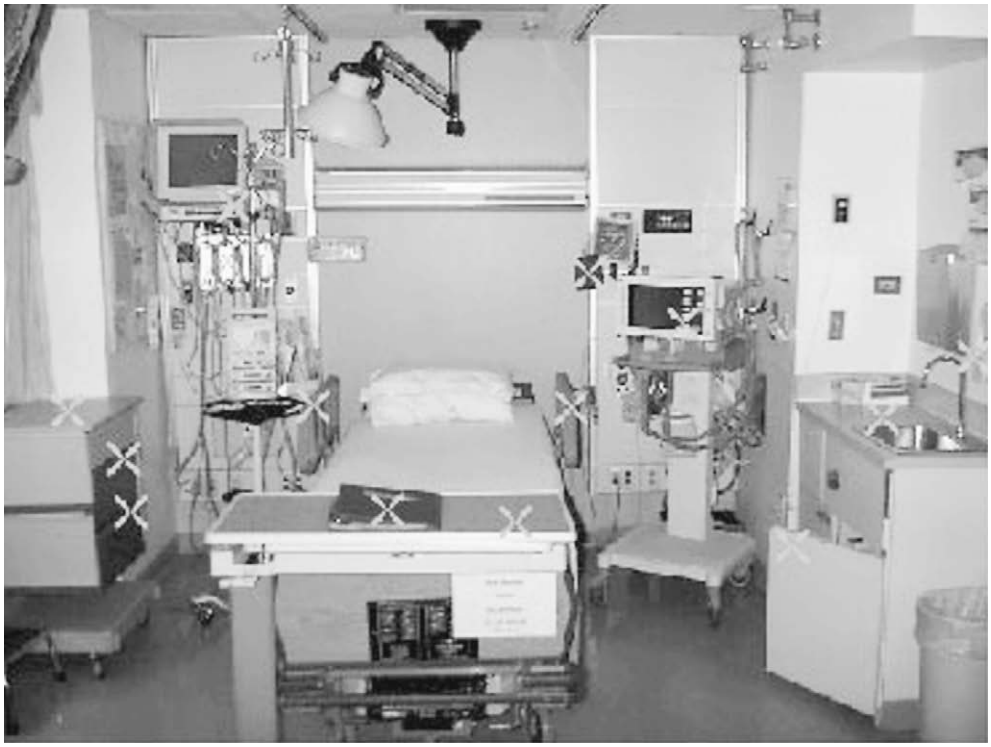

Figure 1 Typical environmental sites contaminated with vancomycin-resistant enterococcus (VRE) in rooms of patients colonised with VRE. 'X' symbols: contaminated sites.

Results

Cleaning thoroughness

During 25 weeks, we observed 2901 sites for appropriate cleaning; 1059 sites (36.5%) were category 2 and 1842 (63.5%) were category 3. Overall, the proportion of sites cleaned improved from 49% to 85% from period 1 to period 2 ($P < 0.001$) with no decline during washout (period 3; 84%, $P = 0.50$ vs period 2) (Table I, overall thoroughness of environmental cleaning). Handwashing or glove use occurred at a rate of 61% overall (63% among nurses, 54% among physicians, and 68% among other staff) and was stable over the three study periods (data not shown). In addition, antibiotic use was similar for the three time periods in number of antimicrobials given per patient, and number of patients on multidrug regimens. Use of individual antimicrobial agents was similar with the exception of clindamycin, which was prescribed more frequently in period 1 (9% vs 5–6%; $P = 0.05$).[13]

In univariate and multivariate analyses (Table II), the education/observation intervention was associated with improved cleaning, with greater improvement in the RCSU, which had less thorough cleaning at baseline. Both above-average unit census and the presence of contact precautions were independently associated with reduced proportion of sites cleaned.

Environmental contamination

We cultured 1472 environmental sites before and after housekeepers cleaned rooms housing VRE-colonised patients; 92 sites (6%) were category 1, 730 (50%) were category 2, and 650 (44%) were category 3. From period 1 to 2, contamination of environmental sites declined from 21% to 8% ($P < 0.0001$) prior to cleaning and from 13% to 8% ($P < 0.0001$) following cleaning; the lower contamination rates persisted in period 3 (Table I, overall environmental contamination before and after cleaning). There was an inverse correlation between proportion of sites observed to have been cleaned and environmental contamination with VRE.

The results of a multivariate analysis examining predictors of environmental contamination for rooms housing VRE-colonised patients are shown in Table III. After adjustment for proportion of contaminated sites before cleaning, the proportion of sites cleaned remained a strongly protective factor, with a 6% decline in prevalence of VRE with every 10% increase in percentage of sites cleaned, even following adjustment for other factors. Category 3 sites were less likely to be contaminated than category 2 sites, and rooms with anterooms were

Table II Multivariable predictors of environmental site cleaning in all intensive care unit rooms

	Prevalence ratio (95% CI)	*P* value
Period 1		
MICU	Referent	
RCSU	0.55 (0.41–0.73)	<0.0001
Period 2		
MICU	1.69 (1.58–1.82)	<0.0001
RCSU	2.02 (1.81–2.25)	<0.0001
Period 3		
MICU	1.62 (1.50–1.75)	<0.0001
RCSU	1.90 (1.71–2.11)	<0.0001
Category of site[a]		
2	Referent	
3	1.04 (1.00–1.08)	0.068
Housekeeper		
A	Referent	
B	0.77 (0.70–0.85)	<0.0001
C	0.82 (0.73–0.92)	<0.0001
D	0.70 (0.62–0.78)	<0.0001
Other[b]	0.72 (0.62–0.83)	<0.0001
Census		
Below average	Referent	
Above average	0.95 (0.91–1.00)	0.049
No contact precautions	Referent	
Contact precautions	0.96 (0.92–1.00)	0.05

[a] Category 1, site touching patient (blood pressure cuff only); category 2, site within 0.91 m (3 feet) of the patient but not touching the patient; category 3, site farther than 0.91 m (3 feet) from patient.
[b] Represents ≥2 housekeepers used sporadically, aggregated together.

Table III Multivariable predictors of environmental contamination after cleaning in rooms of VRE-colonised patients

	Prevalence ratio (95% CI)	*P* value
Throughness of environmental cleaning (per 10% increase)	0.94 (0.90–0.99)	0.0107
Contamination prior to cleaning (per 10% increase)	1.22 (1.14–1.30)	<0.0001
Category of site[a]		
1	Referent	
2	0.51 (0.32–0.82)	0.0055
3	0.25 (0.10–0.61)	0.0022
Room type		
Private or double room	Referent	
Room with anteroom[b]	0.49 (0.31–0.78)	0.0025

[a] Category 1, site touching patient (blood pressure cuff only); category 2, site within 0.91 m (3 feet) of the patient but not touching the patient; category 3, site farther than 0.91 m (3 feet) from patient.
[b] Rooms with anterooms were usually occupied by patients on reverse or airborne isolation.

less likely to be contaminated than other types of rooms.

Discussion

Following the introduction of a multifaceted cleaning intervention in a MICU and step-down unit, environmental cleaning increased significantly, the effect persisted, and the intervention was strongly associated with less VRE environmental contamination. The decreased level of contamination was independent of other factors such as contamination before cleaning, the specific housekeeper performing cleaning and the location within a room or the type of room being cleaned. Major strengths of this study include the pre- and post- (i.e. non-intervention washout) periods, which strengthen the quasi-experimental study design, and careful attention to potential confounders, such as specific housekeeper and type of room.[20]

Although there is a growing body of evidence implicating surface contamination in hospitals as a source of cross-transmission of selected pathogens to patients, the best means for reducing the environmental reservoir has been less clear.[1–6,8–12] The unresolved issue has been whether residual surface contamination is a consequence of inadequate adherence to existing cleaning guidelines, a failure of these techniques, or inadequate products.[15] The findings of our study suggest that surface contamination with VRE is due to a failure to clean rather than to faulty cleaning methods or products, and support the notion that cleaning education and compliance monitoring may reduce environmental contamination.[21–23]

Other factors were also independently associated with environmental contamination or with diminished cleaning. Environmental sites near the patient were more often contaminated with VRE than more accessible sites further from the patient. In addition, perhaps reflecting housekeeper discomfort with perceived self-risk or the inconvenience associated with gowning and gloving for room entry, rooms with patients in contact precautions were cleaned less thoroughly. These observations suggest that educational efforts should emphasise thorough cleaning of all sections of a unit and all portions of a patient room, as well as the meaning and purpose of contact precautions. The less

thorough cleaning of rooms of patients on contact isolation may need to be addressed in policies for use of screening cultures and isolation of colonised patients.

Rooms with anterooms (e.g. for airborne isolation) were less densely contaminated with VRE. This may reflect less dissemination of VRE via contaminated healthcare worker hands due to healthcare workers' decreased contact with isolated patients, as has been documented in other ICUs.[24–26]

Our study should be considered in light of certain limitations. The results reflect observations in two units in a single hospital, and the degree of baseline adherence among housekeeping staff may vary significantly depending on housekeeper workload and training. It is striking, however, that rates of cleaning high-touch objects before (44–64%) and after (76–92%) an educational and targeting-method intervention carried out at three other hospitals were quite similar to ours.[22] Other centres with lower baseline contamination rates may have even greater success, since our housekeeping staff was able to effectively decontaminate the environment despite high baseline contamination. Rates of hand hygiene and compliance with barrier precautions also vary between institutions and probably influence the degree of contamination of environmental surfaces.

Improved environmental decontamination reduces VRE transmission.[13] Our data demonstrate that the degree of contamination can be reduced significantly by enabling more thorough cleaning through an intervention targeting housekeepers and using standard methods and materials such as education and monitoring of behaviour. Persistent environmental contamination reflects personnel, rather than procedure or product, failures.

Appendix: enhanced cleaning procedures

Daily cleaning

1. Wash hands thoroughly and put on gloves.
2. Place wet floor sign at door.
3. Discard disposable items and remove waste and soiled linen.
4. Sanitise waste can and linen hamper with detergent disinfectant solution.
5. Sanitise all horizontal, vertical and contact surfaces with a clean cotton cloth saturated with the detergent disinfectant solution. These surfaces include, but are not limited to:
   - Bed rails
   - Overbed table
   - Infusion pumps
   - IV poles
   - Hanging IV poles
   - Vacuum regulator
   - Nurse call box
   - Monitor cables
   - Telephone
   - Countertops
   - Soap dispenser
   - Paper towel dispenser
   - Cabinet fronts including handles
   - Visitor chair
   - Door handles inside and outside
   - Sharps container
   - Television.
6. Spot clean walls and windows with glass cleaner.
7. Clean and sanitise sink and toilet.
8. Stock soap and paper towel dispensers.
9. Dust mop floor.
10. Inspect work.
11. Damp mop floor with detergent disinfectant solution.
12. Remove gloves and wash hands.

Notes:

(i) The quaternary ammonium detergent disinfectant used was Virex, 8.19% *n*-alkyl benzyl and 8.704% didecyl dimethyl ammonium chloride (S.C. Johnson, Sturtevant, WI, USA).
(ii) Clean isolation rooms last.
(iii) Change mop water containing disinfectant every 3 rooms and after every isolation room.
(iv) Change mop head after isolation room and after blood or body fluid spills.
(v) Change surface cleaning/disinfectant solution after every room.
(vi) Change cleaning cloths after every room and use at least 3 cloths per room; typically, 8–12 cloths should be used to clean a standard room.
(vii) Do not place cleaning cloth back into cleaning solution after using it to wipe a surface.
(viii) Daily cleaning of ventilator contact surfaces is the responsibility of the respiratory therapy department. Surfaces should be wiped with a clean cloth soaked in cleaning/disinfectant solution.
(ix) 'Terminal cleaning' of non-isolation rooms consisted of the same procedures listed above plus cleaning and disinfection of bed mattresses.

(x) 'Terminal cleaning' of isolation rooms additionally includes: wash walls, strip and wax floors, remove and clean curtains, and discard disposable supplies left in drawers.

Conflict of interest statement
None declared.

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