ORIGINAL ARTICLE

An Environmental Disinfection Odyssey: Evaluation of Sequential Interventions to Improve Disinfection of *Clostridium difficile* Isolation Rooms

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OBJECTIVE.   Effective disinfection of hospital rooms after discharge of patients with *Clostridium difficile* infection (CDI) is necessary to prevent transmission. We evaluated the impact of sequential cleaning and disinfection interventions by culturing high-touch surfaces in CDI rooms after cleaning.

DESIGN.   Prospective intervention.

SETTING.   A Veterans Affairs hospital.

INTERVENTIONS.   During a 21-month period, 3 sequential tiered interventions were implemented: (1) fluorescent markers to provide monitoring and feedback on thoroughness of cleaning facility-wide, (2) addition of an automated ultraviolet radiation device for adjunctive disinfection of CDI rooms, and (3) enhanced standard disinfection of CDI rooms, including a dedicated daily disinfection team and implementation of a process requiring supervisory assessment and clearance of terminally cleaned CDI rooms. To determine the impact of the interventions, cultures were obtained from CDI rooms after cleaning and disinfection.

RESULTS.   The fluorescent marker intervention improved the thoroughness of cleaning of high-touch surfaces (from 47% to 81% marker removal; $P < .0001$). Relative to the baseline period, the prevalence of positive cultures from CDI rooms was reduced by 14% ($P = .024$), 48% ($P < .001$), and 89% ($P = .006$) with interventions 1, 2, and 3, respectively. During the baseline period, 67% of CDI rooms had positive cultures after disinfection, whereas during interventions periods 1, 2, and 3 the percentages of CDI rooms with positive cultures after disinfection were reduced to 57%, 35%, and 7%, respectively.

CONCLUSIONS.   An intervention that included formation of a dedicated daily disinfection team and implementation of a standardized process for clearing CDI rooms achieved consistent CDI room disinfection. Culturing of CDI rooms provides a valuable tool to drive improvements in environmental disinfection.

Contaminated environmental surfaces are an important source for transmission of healthcare-associated pathogens, including *Clostridium difficile*, methicillin-resistant *Staphylococcus aureus* (MRSA), and vancomycin-resistant enterococci (VRE).[1-4] Unfortunately, environmental cleaning in healthcare facilities is often suboptimal.[5,6] In recent years, 2 promising strategies have been used to improve cleaning and disinfection. First, routine monitoring of cleaning with feedback to environmental services personnel has been effective in achieving sustained improvements in standard cleaning practices.[3,6,7] Methods of monitoring have included direct observation of cleaning, use of fluorescent markers to monitor the thoroughness of cleaning, and adenosine triphosphate (ATP) bioluminescence to evaluate for the presence of residual organic material after cleaning.[3,6,7] Second, automated

room disinfection devices have been developed as a means to reduce dependence on appropriate application of disinfectants by environmental services personnel.[8-13] For example, automated ultraviolet (UV) radiation devices have been shown to reduce levels of pathogens, including *C. difficile* spores, in hospital rooms.[8-12] Although these strategies are promising, limited data on their effectiveness in improving disinfection in real-world settings are available.

The Louis Stokes Cleveland Veterans Affairs (VA) Medical Center experienced a large outbreak of *C. difficile* infection (CDI) from 2002 through 2004 and subsequently has maintained a high endemic CDI incidence (~15 cases per 10,000 patient-days). In 2009, we demonstrated that environmental cultures collected from CDI rooms were often positive after completion of terminal room cleaning by environmental ser-

vices personnel. In response, we initiated an intervention to improve cleaning and disinfection of CDI rooms. Here, we report the impact of sequential interventions on the frequency of *C. difficile* environmental contamination in CDI rooms after completion of cleaning and disinfection. The goal of the intervention was to achieve consistently negative cultures from high-touch surfaces after cleaning of CDI rooms (ie, zero or close to zero positive cultures).

METHODS

The hospital's institutional review board approved the study protocol. The Louis Stokes Cleveland VA Medical Center includes a 215-bed hospital and 165-bed long-term care facility. During the study, diagnostic testing for CDI was performed using an enzyme immunoassay for glutamate dehydrogenase (Wampole C. DIFF CHEK-60; Inverness Medical) as an initial screen, with positive tests being confirmed with a commercial polymerase chain reaction assay (Xpert *C. difficile*; Cepheid). Clorox Clean-Up Cleaner with Bleach was used for terminal cleaning of CDI rooms. During a 21-month period, we implemented 3 sequential tiered interventions to improve cleaning and disinfection and evaluated the impact on the percentage of positive cultures from CDI rooms after terminal cleaning. No other changes in cleaning practices or products occurred during the study period.

Intervention Period 1 (Facility-Wide Fluorescent Marker Intervention)

The first intervention occurred from January 1, 2011, through February 28, 2012 (14 months). The primary goal of period 1 was to improve the thoroughness of cleaning on all medical and surgical wards. The intervention included education of environmental services personnel and use of fluorescent markers (Dazo; EcoLab) to provide monitoring and feedback on thoroughness of cleaning. Fluorescent marker was applied to 14 high-touch surfaces in patient rooms, and thoroughness of cleaning was assessed on the basis of marker removal, as described elsewhere.[6] Education and feedback were provided at monthly environmental services staff meetings, at small group meetings for housekeeping teams for specific wards, and to individual housekeepers. The education included general information on *C. difficile*, detailed information on recommended cleaning and disinfection practices, and information on how and where monitoring was being performed. For education of individual housekeepers, research staff directly observed and commented on cleaning practices in patient rooms and provided checklists of the sites being monitored. Feedback was provided as aggregate data on thoroughness of cleaning. For the initial 8 months of period 1, monitoring and feedback included only thoroughness of cleaning after patient discharge. Cultures of high-touch surfaces after cleaning and disinfection were collected during a 3-month baseline period prior to the intervention (all avail-

able rooms sampled) and after the sixth month of period 1 (about half of available rooms sampled).

For the final 6 months of period 1, monitoring and feedback was expanded to include daily cleaning in CDI rooms using the same fluorescent marker method. Education on the importance of daily cleaning of CDI rooms was provided at monthly environmental services meetings and to individual housekeepers.

Intervention Period 2 (Adjunctive UV Device Use for CDI Rooms)

The second intervention period occurred from March 1, 2012, through June 30, 2012 (4 months). In addition to the period 1 interventions, 2 portable UV room disinfection devices (Tru-D; Lumalier) were used as an adjunct to standard cleaning and disinfection in CDI rooms. The goal was to determine whether use of the UV devices would significantly reduce *C. difficile* contamination to below levels achieved by the initial intervention. Housekeepers used the devices and were informed that they should not alter their standard cleaning and disinfection practices. The devices were used on 2 medical wards during the first month of period 2 and then for CDI rooms throughout the facility. Cultures of high-touch surfaces were obtained after standard terminal cleaning of all available CDI rooms and again after operation of the UV device.

Intervention Period 3 (Enhanced Daily and Terminal Disinfection of CDI Rooms)

The final intervention period occurred from July 1, 2012, through September 30, 2012 (3 months). In addition to the period 1 and 2 interventions, we formed a dedicated team of 3 housekeepers to provide daily disinfection of high-touch surfaces in CDI rooms and implemented a process requiring that terminally cleaned CDI rooms be "cleared" for the next patient by environmental services supervisors and/or infection control staff. Daily disinfection of high-touch surfaces was performed using Clorox Germicidal Wipes. The process for clearing rooms included direct observation of housekeeper cleaning and disinfection with immediate feedback (when feasible) and/or evaluation based on visual assessment and ATP bioluminescence (CleanTrace; 3M) readings from 3 sites (bed rail and table, call button and telephone, and toilet seat and bathroom hand rail). For the ATP readings, the entire surfaces of the sites were contacted with swabs, and values above 250 required recleaning and disinfection of the surfaces. Cultures of high-touch surfaces were obtained from all available rooms after standard terminal cleaning of CDI rooms and again after operation of the UV device.

Microbiology

Cultures were collected in a standardized manner from high-touch surfaces (bed rail and bedside table, call button and telephone, and toilet seat and bathroom hand rail) throughout the study. The surfaces were first contacted with pre-
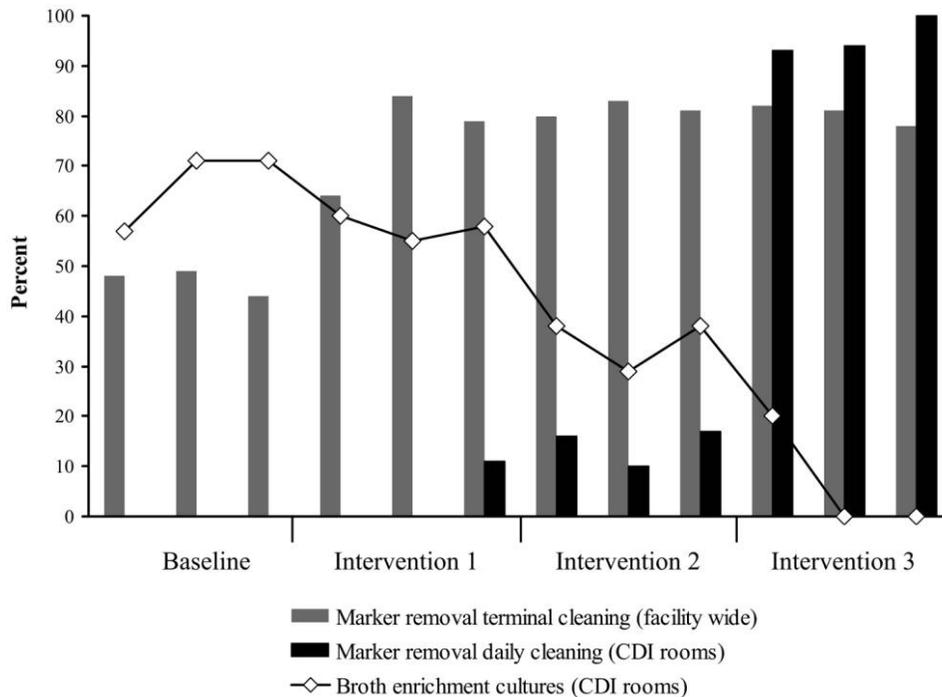
FIGURE 1.   Effect of sequential environmental cleaning and disinfection interventions on thoroughness of cleaning (determined on the basis of fluorescent marker removal) and on disinfection of *Clostridium difficile* infection (CDI) rooms (determined on the basis of environmental cultures for *C. difficile*). Intervention 1 (January 1, 2011, through February 28, 2012; 14 months) involved education in combination with monitoring of fluorescent marker removal from high-touch surfaces with feedback to housekeepers; intervention 2 (March 1, 2012, through June 30, 2012; 4 months) included addition of an automated ultraviolet radiation device for disinfection of CDI rooms; intervention 3 (July 1, 2012, through September 30, 2012; 3 months) included enhanced standard cleaning through formation of a 3-person dedicated daily disinfection team for high-touch surfaces in CDI rooms and implementation of a process requiring that terminally cleaned CDI rooms be "cleared" for the next patient by environmental services supervisors and/or infection control staff. Each intervention was divided into 3 time periods, which are indicated by separate bars.

moistened swabs (BD BBL CultureSwab; Becton Dickinson); the entire surface areas of the sites were contacted. After collection of swabs, a 2 cm × 2 cm gauze pad moistened in sterile water was applied to the same areas and placed into a sterile container. The swabs were cultured by direct plating onto prereduced *C. difficile* Brucella agar plates, and the gauze specimens were cultured by broth enrichment, as described elsewhere.[14] All isolates were tested for in vitro toxin production using *C. difficile* Tox A/B II (Wampole Laboratories); isolates that did not produce toxin were excluded from the analysis.

Statistical Analysis

The Pearson χ^2 and Fisher's exact tests were used for categorical data. The proportions of positive cultures were compared for sites and rooms that had markers removed or not removed. The proportions of marker removal were compared overall and by site during the baseline period versus the fluorescent marker intervention period. Log-binomial regression with robust variance estimation was used to model the prev-

alence of positivity by broth enrichment cultures for each of the intervention periods relative to baseline.

RESULTS

Figure 1 provides an overview of the results for fluorescent marker removal and *C. difficile* cultures. In period 1, the intervention resulted in a significant increase in the thoroughness of cleaning of high-touch surfaces (376/800 [47%] vs 2,680/3,272 [81%]; $P < .0001$) that was maintained in intervention periods 2 and 3. As shown in Figure 2, all of the sites that were assessed showed a significant improvement in the thoroughness of cleaning ($P < .0001$ for each comparison). There was considerable variation in baseline thoroughness of cleaning for alternate sites on single surfaces being assessed (eg, marker removal occurred less frequently on the side versus the top surface of the table), but all sites were consistently cleaned during the intervention at the time of terminal cleaning. However, despite multiple group and individual educational sessions on the importance of daily disinfection of CDI rooms and feedback regarding low rates of
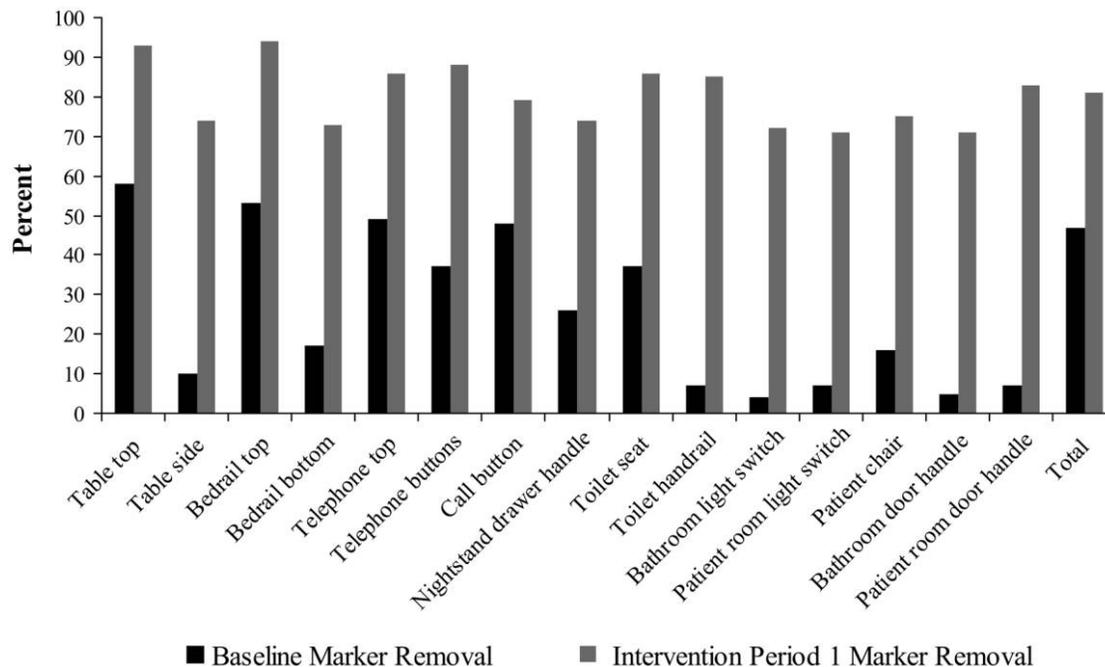
FIGURE 2. Improvement in thoroughness of cleaning of high-touch surfaces with the fluorescent marker intervention.

compliance with the recommendation, daily disinfection of CDI rooms remained at low levels during the final 6 months of period 1, when the efforts to improve daily disinfection occurred.

The broth enrichment method using gauze to sample surfaces consistently yielded about twice as many positive results as the direct plating method using swabs, and all sites that were positive by direct plating were also positive by broth enrichment. Therefore, broth enrichment culture results were used for all comparisons. Relative to the baseline period, the period 1 intervention resulted in a statistically significant 14% decrease in the prevalence of CDI rooms with positive cultures (14/21 [67%] vs 16/28 [57%]; prevalence ratio, 0.86 [95% confidence interval (CI), 0.76–0.98]; $P = .024$; Figure 1). For individual sites, the percentage of positive cultures was significantly lower if the marker was removed versus not removed (27/97 [28%] vs 10/11 [91%]; $P < .0001$).

Relative to the baseline period, the addition of the UV device resulted in a statistically significant 48% decrease in the prevalence of CDI rooms with positive cultures (14/21 [67%] vs 8/23 [35%]; prevalence ratio, 0.52 [95% CI, 0.43–0.62]; $P < .001$). Several steps were taken to assess potential reasons for the lower-than-anticipated effectiveness of the UV devices in eradicating *C. difficile*. First, we tested the devices in a laboratory setting to confirm that they were functioning appropriately; the results were similar to those from our previous assessment of the device.[8] Second, we assessed whether there was a decrease in the effectiveness of standard cleaning and disinfection. Although the housekeepers had repeatedly been informed that the devices were only an adjunct to room

disinfection and that standard cleaning should be performed according to usual protocols, it was observed that standard room cleaning and disinfection was often performed suboptimally when the UV devices were used during the first 2 months of period 2 (ie, less than 50% removal of fluorescent markers and visible soiling in several rooms after use of the device). Further efforts were made to educate the housekeepers about the importance of completing standard cleaning and disinfection before running the device. Finally, to assess whether the frequency of positive cultures was attributable to reduced effectiveness of the device in shaded areas, cultures were obtained from shaded and unshaded areas of the high-touch sites. For 3 sites with positive cultures, all were positive from shaded areas and negative from areas in direct line of UV exposure.

In period 3, the enhanced daily and terminal disinfection measures resulted in an immediate and dramatic reduction in the percentage of rooms with positive cultures. Relative to the baseline period, there was a statistically significant 89% decrease in the prevalence of CDI rooms with positive cultures (14/21 [67%] vs 1/14 [7%]; prevalence ratio, 0.11 [95% CI, 0.02–0.53]; $P = .006$). All of the cultures that were negative after operation of the UV device were also negative before operation of the device, suggesting that eradication of *C. difficile* from the surfaces being sampled was attributable to the improvements in standard cleaning and disinfection. For 10 rooms, more extensive cultures were collected to assess a wider range of high-touch surfaces (eg, light switches, bathroom fixtures, television controls, drawer handles, chair arm-

rests, and vital signs equipment); all of these cultures were negative.

In period 3, the dedicated CDI team reported that daily disinfection with bleach wipes was well tolerated by patients, with only 1 patient refusing daily disinfection due to dislike of the bleach odor. The process of clearing CDI rooms required approximately 1–2 hours per week (approximately 5 rooms per week) for environmental services supervisors and/or infection control personnel. The housekeepers did not express any concerns regarding the process of clearing rooms and uniformly stated that it was beneficial to receive immediate feedback on their performance through ATP readings and observation.

DISCUSSION

The ultimate goal of environmental cleaning and disinfection interventions is to reduce levels of pathogenic microorganisms to a sufficient degree to prevent transmission. It is possible that there is an acceptable level of residual *C. difficile* spore contamination that presents a relatively low risk of transmission to subsequent room occupants. For other pathogens, reductions in transmission have been achieved with cleaning interventions that reduced but did not eliminate environmental contamination.[3,4] However, given the low inoculum of spores required to produce disease in antibiotic-treated animals and the demonstration that spores on surfaces can easily be acquired on hands,[2,15] the goal of our intervention was to achieve consistently negative cultures from high-touch surfaces after cleaning of CDI rooms. The lessons learned in achieving this goal have important implications for healthcare facilities seeking to optimize environmental disinfection.

The fluorescent marker intervention greatly improved thoroughness of terminal cleaning but had only a modest impact on residual spore contamination after terminal cleaning and disinfection of CDI rooms. Although cultures were more likely to be negative if markers were removed, it is notable that *C. difficile* was cultured from many rooms that had 100% removal of marker from all sites and 28% of all sites with complete marker removal. Others have similarly reported that fluorescent marker interventions may not provide assurance that pathogens will be removed from surfaces. Alfa et al[16] cultured *C. difficile* from 33% of toilet seats in CDI rooms with complete marker removal, and Goodman et al[4] found that an effective fluorescent marker intervention significantly reduced but did not eliminate contamination after cleaning of isolation rooms (ie, 27% of rooms were contaminated with MRSA or VRE after terminal cleaning during the intervention, compared with 45% prior to the intervention). In our facility, the failure to reduce contamination was not due to lack of education of housekeepers; the intervention included multiple educational sessions on appropriate application of bleach and numerous individual sessions that included direct input on how and where bleach

was to be applied. Although we did not specifically monitor individual housekeepers, our observations suggested that a major factor contributing to suboptimal room disinfection was variability in the performance and motivation of individual housekeepers, as has been reported by Boyce et al.[17] Despite the limitations of the marker method, our impression was that it was a very helpful and easy-to-use tool to improve cleaning that might be most effective if used in conjunction with cultures to drive efforts to optimize disinfection.

Our findings provide support for the use of automated UV devices as an adjunct to room disinfection, but they also provide a cautionary note. In a real-world setting, we found that 35% of CDI rooms had residual spores detectable by culture after standard terminal cleaning and operation of the devices. This may have been due in part to a substantial decline in attention to standard cleaning by housekeepers when the device was initially implemented, based on an overly optimistic belief that the devices would eradicate all environmental contamination. However, we continued to culture *C. difficile* from rooms after use of the device even when standard cleaning was reemphasized. One potential explanation is that the devices are more effective in eradicating pathogens from areas receiving direct versus indirect exposure to UV (ie, 2–4-log reduction in *C. difficile* spores with direct exposure vs 1–2.4-log reduction with indirect exposure).[10-12] In contrast, bleach achieves a 6-log reduction in spores with sufficient exposure time. Our experience highlights an important issue for all facilities that purchase automated devices for room disinfection: there are currently no simple and efficient methods to monitor the effectiveness of the devices in real-world settings.

The intervention that was ultimately effective in achieving consistently negative cultures involved 2 strategies to improve standard cleaning and disinfection. First, we formed a dedicated CDI daily disinfection team. We have previously reported that daily disinfection of high-touch surfaces in isolation rooms may be beneficial because it removes an important source of contamination of healthcare workers' hands.[18] It is likely that daily disinfection contributed to our finding of negative cultures after terminal cleaning by providing multiple opportunities for elimination of environmental contamination. Moreover, formation of a dedicated team of highly motivated housekeepers eliminated the problem of variability in housekeeper performance. Others have also used dedicated housekeeping teams to improve effectiveness of room disinfection.[19-21] Second, we implemented a process by which supervisory housekeeping staff and/or infection control personnel cleared CDI rooms. The process required relatively little time (1–2 hours per week) and provided an opportunity to directly observe individual housekeeper performance and provide immediate feedback. ATP readings appeared to be a useful component of the clearance process because they provided an objective measure of the effectiveness of cleaning. Notably, although use of the UV device was continued, it did not contribute to the effectiveness

of the intervention (ie, all negative cultures were negative both before and after operation of the UV device).

Our study had some limitations. First, we have not yet demonstrated that it is possible to maintain the intervention for a prolonged period. Second, although the UV device did not appear to be necessary to achieve negative cultures in the sites sampled, the use of the devices may be beneficial if they contribute to eradication of spores from other sites in CDI rooms. Third, it is not known, as noted previously, whether achieving consistently negative cultures after disinfection of CDI rooms is essential to reduce transmission. In our facility, the incidence of healthcare-associated CDI remained stable at approximately 10 cases per 10,000 days of care during the study until period 3, when the incidence decreased to 6 cases per 10,000 days of care. Future studies will be necessary to evaluate whether the current CDI room disinfection intervention results in a sustained reduction in CDI. Finally, environmental cultures for *C. difficile* were crucial to the success of our intervention, but they are currently not feasible for most healthcare facilities.

In summary, we found that an intervention including education as well as monitoring and feedback improved thoroughness of cleaning but did not significantly improve CDI room disinfection. The adjunctive use of an automated UV device improved disinfection, but 35% of rooms remained culture positive for *C. difficile* after use of the devices. Ultimately, disinfection was dramatically improved through formation of a dedicated daily disinfection team and implementation of a standardized process for clearing CDI rooms. Our experience suggests that culturing of CDI rooms after terminal cleaning could provide a valuable means to assess the effectiveness of cleaning interventions.

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