American Journal of Infection Control 44 (2016) 1089-94

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Major Article

Evaluating the effectiveness of ultraviolet-C lamps for reducing keyboard contamination in the intensive care unit: A longitudinal analysis

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Key Words:
Disinfection
UV light
UVC
bioburden
hospital-acquired infections
MRSA
VRE
hospital equipment

Background: Ultraviolet (UV) spectrum light for decontamination of patient care areas is an effective way to reduce transmission of infectious pathogens. Our purpose was to investigate the efficacy of an automated UV-C device to eliminate bioburden on hospital computer keyboards.

Methods: The study took place at an academic hospital in Chicago, Illinois. Baseline cultures were obtained from keyboards in intensive care units. Automated UV-C lamps were installed over keyboards and mice of those computers. The lamps were tested at varying cycle lengths to determine shortest effective cycles. Delay after use and prior to cycle initiation was varied to minimize cycle interruptions. Finally, 218 postinstallation samples were analyzed.

Results: Of 203 baseline samples, 193 (95.1%) were positive for bacteria, with a median of 120 colony forming units (CFU) per keyboard. There were numerous bacteria linked to health care–associated infections (HAIs), including *Staphylococcus*, *Streptococcus*, *Enterococcus*, *Pseudomonas*, *Pasteurella*, *Klebsiella*, *Acinetobacter*, and *Enterobacter*. Of the 193 keyboards, 25 (12.3%) had gram-negative species. Of 218 postinstallation samples, 205 (94%) were sterile. Of the 13 that showed bacterial growth, 6 produced a single CFU. Comparison of pre- and post-UV decontamination median CFU values (120 and 0, respectively) revealed a >99% reduction in bacteria.

Conclusions: The UV lamp effectively decontaminates keyboards with minimal interruption and low UV exposure. Further studies are required to determine reduction of HAI transmission with use of these devices.

Health care–associated infections (HAIs) represent a common complication for hospitalized patients with significant financial implications for the health care system. An estimated 721,800 HAIs were reported in acute care hospitals in the United States in 2011, with a financial impact of $33 billion.[1,2] In one study of 778 patients admitted to the intensive care unit (ICU), the total cost of care for an individual with a nosocomial infection was $10,354 compared with $3,985 for patients without an associated infection.[3] HAIs secondary to methicillin-resistant *Staphylococcus aureus* (MRSA) alone are responsible for close to $9.7 billion in excess medical expenses.[4] Although many sources of these pathogens have been identified, including patients' respiratory and gastrointestinal flora, contaminated surfaces in the hospital represent the most insidious mode of secondary transmission. Common pathogens include *Clostridium difficile*, vancomycin-resistant enterococci (VRE), MRSA, norovirus, and numerous multidrug-resistant gram-negative rods.[5,6] These organisms can persist on hospital surfaces for days, weeks, and in the case of *C difficile*, even months.[7-14] A study of 40 patients colonized with MRSA revealed that caregiver hand contamination was as likely after contact with common surfaces in the patient's room as it was after contact with the patient.[15] Environmental surface disinfection reduces HAIs and pathogen transmission in the hospital.[16]

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Funding/Support: This study was funded in its entirety by the UV Partners Company of Livonia, Michigan.

Disclaimer: None of the authors have any financial or equity interest in the success of UV Partners or the outcomes of this analysis.

Conflicts of Interest: A.G. has served as a paid consultant to UV Partners but derived no remuneration related to participation in this study.

http://dx.doi.org/10.1016/j.ajic.2016.06.012

Terminal cleaning is performed by wiping items and surfaces in a patient's room with liquid chemical agents (eg, chlorhexidine, sodium hypochlorite, hydrogen peroxide) once it is no longer occupied. Disinfection success depends on the pathogen and the type, concentration, and duration of exposure of the chemical agent.[17] Effective disinfection by these methods depends on staff compliance and training. There is ample evidence that contamination risk remains, despite terminal cleaning. A patient's risk of acquiring an infection is increased up to 250% if their room had been occupied by an individual with a positive bacterial culture, referred to as prior room occupancy risk.[18-21]

Recently, ultraviolet (UV) disinfection by way of either mercury bulb or pulsed xenon bulb devices has been introduced in an effort to reduce HAIs. UV-C (UVC) disinfection technologies use light in the range of 200-280 nm to eliminate microorganisms on exposed surfaces through the formation of pyrimidine dimers in DNA and RNA.[22] When the molecular burden of dimer formation exceeds the microorganisms capacity to repair the cellular damage, organism death ensues. The total accumulated dose of UVC radiation depends on the intensity of the source, duration of exposure, and distance from the source to the surface of interest.[23] Several studies evaluating the use of terminal cleaning devices to disinfect patient rooms and operating rooms have had promising results, with significantly decreased contamination by major pathogens such as VRE, MRSA, and *C difficile*. One study reported a 53% decrease in *C difficile* cases in a community hospital setting, a second study found a 20% overall decline in hospital-acquired multidrug-resistant gram-negative rods plus *C difficile* in an acute care setting, and a third study reported a 93% reduction in MRSA and VRE culture positivity in hospital rooms.[24-26] The devices used in these studies required significant staff training and could only be used as part of the terminal cleaning process in empty patient rooms.

No study to date has evaluated the use of a point-of-care device that provides timed, intermittent UV disinfection of surfaces routinely used by health care providers. In the era of mandated electronic records, a caregiver's hands are frequently interacting with both the patient and a variety of computer peripherals (eg, keyboards, mice, barcode scanners) after hand hygiene protocol has been performed. This workflow has turned computer peripherals into potent fomites.

The UV Angel (UV Partners, Livonia, MI), which is positioned above the computer keyboard, provides real-time monitoring of surface use and automatically delivers mercury bulb UV light disinfection when the device is not in use. In this study, we evaluated the effectiveness of this novel point-of-care cleaning device in an academic hospital setting.

MATERIALS AND METHODS

Location

This study took place in the medical ICU (15 beds) and surgical ICU (15 beds) of Presence Resurrection Medical Center, a 360-bed, acute care, academic medical center located in Chicago, Illinois, from May 2014-October 2015.

Collection of baseline data

After obtaining institutional review board approval, baseline keyboard cultures were taken from all fat client computers (ie, nonthin client computers) used in direct patient care within the ICUs (22 in-room computers and 18 hallway computers). Per hospital protocol, all ICU keyboards were to undergo routine daily cleaning with chemical disinfectants between 7:00 AM and 5:00 PM. Chlorhexidine wipes were located throughout the facilities for additional cleaning by caregivers as needed. Cultures were obtained by 6:00 AM to determine the maximum level of contamination.

Using the eSwab liquid-based collection and transport system kit (Copan Diagnostics, Murrieta, CA), cultures were obtained from the keyboards. To obtain the samples, saline solution was applied to the tip of each swab using saline-soaked gauze. The saline-dampened swab was then rolled over each alphabetical key (A-Z), the enter key, and the space bar. The swab was finally placed in a sterile vial provided in the eSwab kit. Negative control samples were obtained at the end of the culturing process by rolling a swab on only the sterile saline gauze to confirm that sterility was maintained during the culturing process. All samples were sent by 10:15 AM courier to PCL Alverno Laboratory in Hammond, Indiana, for same day plating for bacterial culture, species identification, and antibiotic sensitivities.

A total of 203 baseline cultures were obtained over the course of 2 months, before installation of the UV lamps. In-room keyboards were only sampled within occupied patient rooms.

UV disinfection protocol design

After baseline testing was completed, UV Angel Desktop lamps were installed per the manufacturer's guidelines over the keyboards and mice of all computers sampled during baseline testing. The UV Angel software package was then installed on the computers. The program allows the user to set 3 of the UV lamp function parameters: the delay between cessation of keyboard use and UVC light initiation; the total disinfection cycle length; and whether to have periodic deep-cleanings independent of those initiated by keyboard use. Analysis was conducted to optimize the first 2 parameters.

Light cycle length optimization

To increase the longevity of the mercury bulbs, which are limited to 8,000 hours of use, and to minimize the probability of staff interruptions (ie, a staff member using the keyboard before completion of the cleaning cycle), the shortest effective cycle time was experimentally derived. The UV Angel lamps were set to 3-, 5-, 6-, and 10-minute cycle lengths, in sequential order over the course of 3 months, and keyboards cultures were obtained as previously described. At least 30 samples from each group were sent for bacterial culture, species identification, and antibiotic sensitivities. The results were analyzed and compared based on the average number of colony forming units (CFUs), the percent reduction from baseline, and the percent of keyboards with no growth. Our group set the cycle time to achieve an internal benchmark of at least a 99% reduction in the average number of CFUs.

Light cycle delay optimization

Although the lamps are designed with a protective cover to focus UVC light only on the contaminated surface of interest, care providers can interrupt the lights during a cleaning cycle if keyboard use is required. As a safety mechanism, the lights are programmed to turn off following keyboard use, mouse input, or motion under the lamp. High-speed camera analysis was used to determine the longest duration of exposure before light termination after these actions and was observed to be a maximum of 1 second. Cycle delay analysis focused on extending the delay to minimize serial interruptions, which occur when staff occupy a computer terminal for extended periods of time, thereby reducing total exposure.

We conducted an extensive analysis of >106,000 cleaning cycles over 3 months, with the goal of minimizing the average UVC light exposure time during an 8-hour period. This analysis revealed much about the usage pattern of keyboards in the ICU. Staff members tended to batch computer activities and therefore interrupted cleaning cycles that were initiated after their own use (ie, serial interruptions). Extending the delay, therefore, resulted in fewer interruptions. The delay was extended to the point of diminishing returns, defined by our group as the point on the interruption curve where the logarithmic relationship between interruptions and cycle length appeared linear (Fig 1). The total observed exposure time was compared with the 8-hour limit set forth by the National Institute for Occupational Safety and Health (NIOSH) and the American Conference of Governmental Industrial Hygienists (ACGIH) in order to ensure regulatory compliance.

Collection of postdisinfection data

After light cycle length and delay optimization, the UV Angel lamps were programmed with a 90-second delay followed by a 6-minute use-initiated cycle and a 6-minute periodic deep clean every hour. With this protocol in place, the keyboards were swabbed by 6:00 AM, after the culturing procedure previously described, to obtain 218 postinstallation samples over a 3-month period. All samples were collected from keyboards that had completed a full disinfection cycle, as indicated by the UV Angel's status indicator light. All samples were sent via courier by 10:15 AM, to Dr. Curtis Donskey's laboratory at the Veterans Affair Medical Center in Cleveland, Ohio, for bacterial culture, species identification, and antibiotic sensitivities.

Statistical analysis

We used descriptive statistics to describe the baseline and post-UV light installation keyboard cultures. Because the culture results were non-normally distributed, median values for the total colony counts were compared. The χ^2 2-sided test of zero difference was used to compare the sterility rate between the 2 sets of cultures by treating the keyboard culture results as binary (ie, keyboards were either sterile or contaminated). A 2-sided significance level of .05 was used for statistical significance.

RESULTS

UV disinfection protocol design

Two important factors were considered when programming the cleaning cycles: delay before cycle initiation and cycle duration. The ultimate goal when considering the cycle delay was to initiate a cleaning cycle as soon as possible after a keyboard was no longer in use, but still accommodate any natural pauses that may occur when a staff member was using the keyboard. Similarly, the length of the cycle had to be long enough for sufficient elimination of bacteria but capped at the point when further exposure produced no additional gains.

The results of the cultures taken during sequential elongation of the cycle duration are shown in Figure 2. Incremental increases in cycle length resulted in progressive improvements in bactericidal activity until a ceiling effect was reached at a 6-minute cycle. Moving beyond a 6-minute cycle (99.2% reduction) to a 10-minute cycle (99.6%) resulted in an absolute improvement of 0.47% at the expense of a 66% increase in cycle length.

Our initial lamp cycles called for a 30-second delay in order to minimize the likelihood that a new staff member would use a dirty keyboard. With a 30-second delay and a 6-minute cleaning cycle, a full 74.9% of cycles were interrupted before completion. This means that a staff member began using the keyboard before the cleaning cycle finished. Analysis of the plot of the interruptions occurring during sequential 60-second intervals revealed that nearly 48% of all interruptions occurred in the first 60 seconds of keyboard disinfection (Fig 1). Therefore, the cycle delay was extended to a total of 90 seconds. Lengthening the cycle delay to 90 seconds resulted in an improved interruption rate of 54.6%. This optimization helped minimize the average daily UVC exposure time of the keyboards.

Comparison of keyboard sterility at baseline versus post-UV light installation

Of the 203 baseline samples, 193 (95.1%) were positive for bacteria, with a median of 120 CFUs per keyboard (Table 1). There were 218 post-UV light installation cultures and 28 negative controls sent for evaluation of the effectiveness of the UV lights. Of the 218 keyboard samples, 205 (94%) were sterile, with a median of 0 CFUs

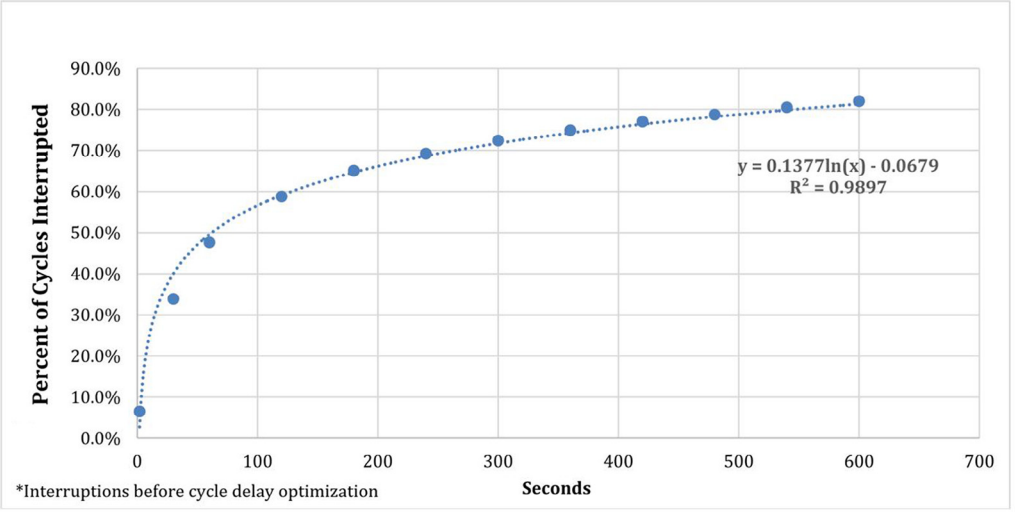

Fig 1. Percent of cleaning cycle interruptions (after a 30-second delay).

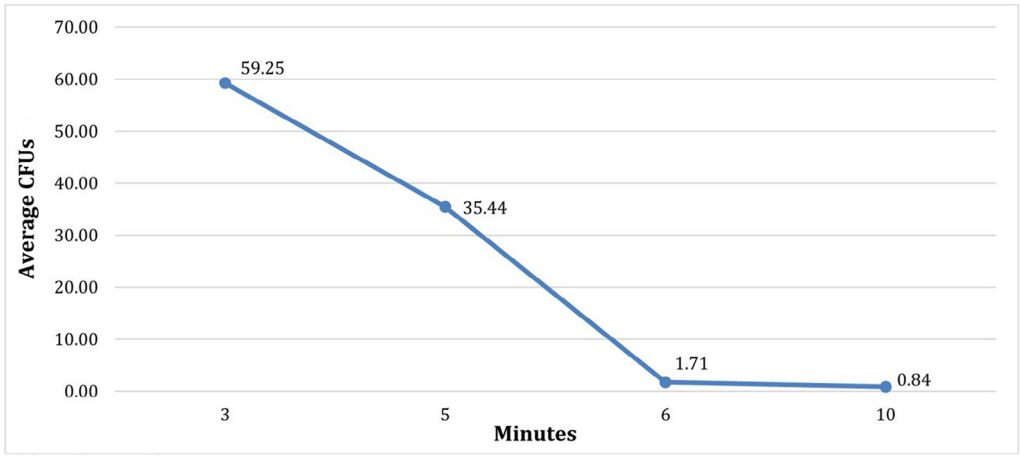

Fig 2. Average number of CFUs post ultraviolet disinfection by cycle length. *CFU*, colony forming unit.

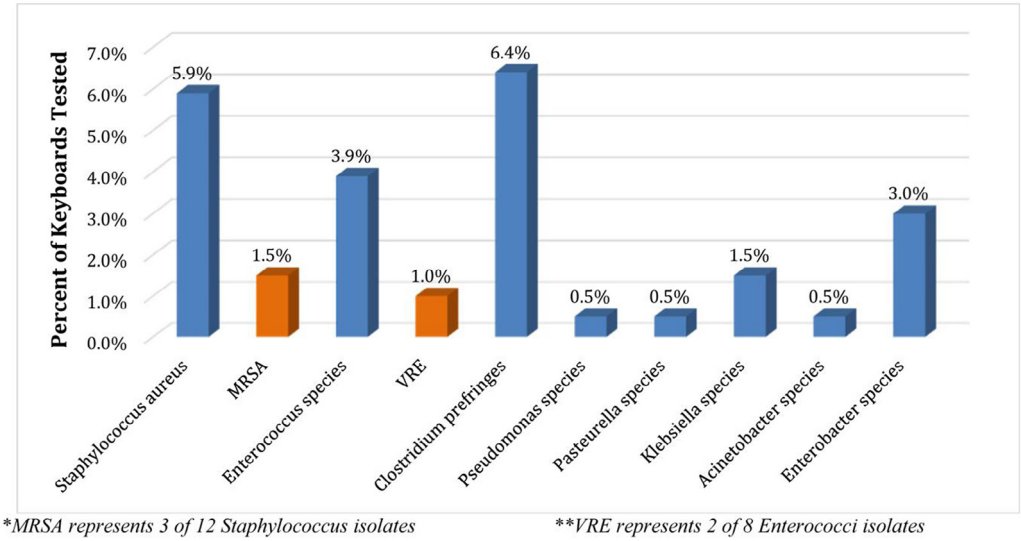

Fig 3. Percent of keyboards at baseline with various bacterial isolates. MRSA, methicillin-resistant *Staphylococcus aureus*; *VRE*, vancomycin-resistant enterococci.

Table 1
Descriptive statistics of baseline and post-UVC light installation cultures

Keyboard culture variable	Baseline	Post-UVC exposure
Sample count	203	218
Mean CFUs	203.729	1.95
Median CFUs	120	0
Minimum CFUs	0	0
Maximum CFUs	1,024	300
Percent sterile	4.90	94.04

CFU, colony forming unit; *UVC*, ultraviolet-C.

(Table 1). All negative controls showed no growth, validating the sterility of the culturing process. Using the χ^2 2-sided test of zero difference, we compared the sterility proportions between the baseline cultures and the post-UV light installation cultures for significance. We observed a large significant difference of 0.8911 between the proportions of sterile keyboards between the 2 groups ($P < .0001$), with a 95% confidence interval for the difference of 0.8391-0.9269.

There were also striking differences between the bacterial species cultured at baseline versus after installation of the UV lights. Although most baseline samples contained bacterial species considered part of the normal skin flora (eg, coagulase-negative *Staphylococcus*, *Micrococcus* spp, *Propionibacterium* spp), numerous bacteria associated with HAIs were also identified. Of the 203 baseline samples, 12 (5.9%) keyboards were positive for *S aureus*, 3 (1.5%) were positive for MRSA, 8 (3.9%) were positive for *Enterococcus*, 2 (1%) were positive for VRE, 6 (3%) were positive for *Enterobacter*, 3 (1.5%) were positive for *Klebsiella*, 1 (0.5%) was positive for *Pasteurella*, 1 (0.5%) was positive for *Pseudomonas*, and 1 (0.5%) was positive for *Acinetobacter* (Fig 3).

Comparison of the pre- and post-UVC decontamination median CFU values (120 and 0, respectively) revealed a >99% reduction in keyboard bioburden. Of the 13 post-UVC keyboard cultures that revealed growth of at least one colony, the bacteria identified were *Micrococcus* spp (6 keyboards), coagulase-negative *Staphylococcus* (5 keyboards), *Streptococcus* spp (2 keyboards), *Diphtheroid* spp (1 keyboard), and MRSA (1 keyboard). No gram-negative or *C difficile* spores were recovered in the post-UVC samples.

Table 2
UVC exposure calculation

Metric	6-min cycle/90-s delay
Average daily cycles initiated	83.51 cycles
Average cycle interruption rate, %	54.64
Average daily interruptions	45.63 cycles
Average interruptions per 8-h period	15.21 cycles
Maximum UVC exposure per interruption, s	1
Average UVC exposure per 8-h period, s	15.21
NIOSH UVC (60 μW/cm^2) limit per 8-h period, s	100
Percent of NIOSH limit	15.21% of NIOSH limit

NIOSH, National Institute for Occupational Safety and Health; *UVC*, ultraviolet-C.

Safety

The exposure of staff or patients to UVC is the primary safety concern regarding the use of the UV Angel lamps. Measured intensity of UVC at the surface of the spacebar is 60 μW/cm^2. The NIOSH and ACGIH have set the evidence-based limit for the exposure to this intensity of UVC at 100 seconds for an 8-hour shift.[27]

Analyzing the data from 106,000 lamp cycles during which a 90-second delay was followed by a 6-minute use-initiated cleaning cycle and a 6-minute periodic cleaning every hour, 54.6% of the 83.5 average cycles per day were interrupted (Table 2). The high-speed video evaluation determined that the maximum UVC exposure before cessation of light was 1 second. With an average of 45.6 cycle interruptions per 24 hours, this resulted in 45.6 seconds of exposure during a 24-hour shift. In a given 8-hour shift, this yields an average exposure of 15.2 seconds of UVC exposure, roughly 15% of the maximum dosage set by the NIOSH and ACGIH (Table 2).

DISCUSSION

Although contaminated surfaces were initially thought to have a negligible role in the spread of infection within a hospital, they are now proven vectors for the spread of pathogens implicated in hospital-acquired infections. According to recent studies on HAIs, a contaminated environment is responsible for approximately 12% of hospital-wide outbreaks.[28] In most modern hospitals, all charting and patient data are entered into a computer during the patient encounter. If keyboards or other frequently used instruments, such as vital signs monitors, ventilators, or intravenous pumps, within a patient's room harbor bacteria, a caregiver's hands may become contaminated despite practice of proper hand hygiene on entering the room.

UV light exposure is an effective mechanism to eliminate contamination on surfaces within a hospital through mutation of bacterial DNA and inhibition of bacterial proliferation. Use of a UVC-emitting device reduces both the presence of vegetative bacteria and *C difficile* by 99.9% and 99.8%, respectively.[29] Furthermore, UVC disinfection dramatically reduces bacterial burden even in the absence of manual cleaning. Jinadatha et al found a reduction from 398 to 100 MRSA colonies after the use of UV light disinfection without prior manual cleaning.[30] Although we do not suggest abandoning manual surface cleaning, the use of UV decontamination is a promising adjunct to daily cleaning. In this study, UVC disinfection, in addition to normal surface cleaning, yielded a considerable reduction in bacteria per keyboard, with a statistically significant number found to be without any bacterial growth. Although baseline samples were not analyzed for *C difficile* spores, no spores were detected on the keyboards after UV Angel installation.

The use of passive UVC lamps represents a novel method for decontaminating high-risk devices and surfaces. Beyond the initial installation, the lights used in this study required no maintenance or input by clinical staff members. Because the lights are programmed to initiate a cleaning cycle in response to normal keyboard use and once hourly regardless of use, they function completely independent of staff effort. This combination eliminated any interruptions or changes to clinical workflow and therefore to patient care as well. With the lamps' redundant mechanisms for UVC cessation (keyboard entry, mouse movement, infrared motion sensor) in response to staff use, there was no need for providers to alter their use of the computer terminals before, during, or after cleaning, an observation supported by the safety analysis (Table 2). This was also reflected by a high overall interruption rate of 54.6%, which still allowed for an average of 319.3 minutes of UVC exposure per 24-hour period.

There is an established need for a streamlined environmental surface cleaning modality that is automated, requires little to no staff participation, and is affordable for hospitals and private offices. A device that could be used safely within an occupied patient room, without disruption of the daily workflow, deserves further examination. Our results echo those found in previous studies of UV decontamination (ie, a significant reduction in bacterial contamination).[31] In addition, cultures grown from keyboards sampled after installing the UV Angel device have shown no growth of most pathogens linked to hospital-acquired infections.

CONCLUSIONS

This study demonstrates the feasibility of using the UV Angel lamp for reducing bacterial burden on one of the most frequently encountered surfaces in a patient's room, the computer keyboard. In addition, this novel device emits a relatively low dose of UVC radiation to the target area, and the disinfection cycle can proceed many times during the day without disruptions to patient care from interruptions to normal staff workflow. Further study is warranted to examine a direct association between the use of an automated keyboard disinfection device and a reduction in hospital-associated infections.

Acknowledgments

We thank Dr. Curtis Donskey, Jennifer Cadnum, and Amit Shah for growing and analyzing our cultures. In addition, we thank Michael Avram, PhD, for his help and guidance with the statistical analysis. Finally, we thank Rosemarie Semar, Sylvia Chen, and all of the intensive care unit staff at Presence Resurrection Medical Center for your help in making this study possible.

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