

Article

Evaluating the Utility of UV Lamps to Mitigate the Spread of Pathogens in the ICU

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Featured Application: Pathogen transfer mitigation.

Abstract: Contaminated surfaces in a hospital serve as reservoirs for pathogen spread. The aim of this study was to evaluate UV lights in preventing the spread of a DNA tracer in an intensive care unit (ICU) through sterilization of highly touched surfaces. In a prospective trial, a non-pathogenic DNA virus was inoculated onto surfaces in an ICU patient room. Investigators swabbed frequently touched surfaces in non-inoculated ICU rooms at 24, 48, and 96 h post inoculation. Culture specimens were analyzed for the presence of viral DNA via PCR. After baseline data were obtained, UV lights were deployed in a standardized fashion onto vitals monitors, ventilators, keyboards, and intravenous (IV) pumps. Inoculation and culturing were then repeated. Prior to UV implementation, the DNA tracer disseminated to 10.10% of tested surfaces in non-inoculated rooms at 48 h. Post UV light deployment, only 1.20% of surfaces tested positive for the DNA tracer after 48 h. UV decontamination significantly retarded the spread of the virus DNA, with a relative reduction of 90% at 48 h from 10.10% of surfaces pre UV to 1.20% of surfaces post UV ($p < 0.0001$). UV decontamination holds the potential to confer protection to patients by reducing the number of surfaces that can serve as a nidus for transfer.

Keywords: UV light; tracer virus; UV-C; hospital acquired infection (HAI); UV sterilization

1. Introduction

The Center for Disease Control (CDC) estimates that 1 in 31 hospitalized patients suffers a healthcare-associated infection (HAI) annually [1]. The economic implications of HAIs are far-reaching and cost the medical system between \$35.7 and \$45 billion each year [2–4]. In one meta-analysis looking at additional hospital costs per case, central-line-associated bloodstream infections incurred an additional \$45,814 (95% CI, \$30,919–\$65,245) to the total hospital stay, followed by ventilator-associated pneumonias at \$40,144 (95% CI, \$36,286–\$44,220), surgical site infections at \$20,785 (95% CI, \$18,902–\$22,667), *Clostridium difficile* infections at \$11,285 (95% CI, \$9118–\$13,574), and catheter-associated urinary tract infections at \$896 (95% CI, \$603–\$1189) [5]. A commonality among many HAIs is their association with these devices: e.g., lines, catheters, and ventilators [6].

Portable equipment and other shared devices, e.g., keyboards, touchscreens, and pens, may be an underappreciated source of transfer of healthcare-associated pathogens; these items are often

contaminated by microbes and cleaning may be suboptimal [7]. In several outbreak investigations, shared equipment has been implicated as a reservoir for the transfer of pathogens [8]. One study from a laboratory at the University of Siena analyzed keyboards in a shared working space and found microbes in counts ranging from 6 colony-forming units/computer keyboard key (CFU/key) to 430 CFU/key, including *Staphylococcus*, *Streptococcus*, and *Enterococcus* species [9]. Thus, it is plausible that decreasing the rate of cross-contamination of hospital equipment might be an effective strategy to mitigate the spread of HAIs [10–12]. This paper explores the application of passive, real-time disinfection technology to high-risk surfaces within the hospital to reduce the prevalence of contaminated surfaces and protect against pathogen transfer between patient rooms.

Since first described in 1903 by Nobel Laureate Niels Finsen, ultraviolet (UV) light has been recognized as an effective decontamination technique [13,14]. UV light works by disrupting the structure of the microorganism's DNA [15,16] and is a well-validated sterilization tool. In one study looking at the role of UV light in stethoscope sterilization, short-wavelength ultraviolet light (UV-C) demonstrated the capacity to maintain high levels of disinfection against common HAI microorganisms [17]. Historically, the deployment of UV light in the presence of humans required significant measures to protect staff and patients from exposure. Recent developments in UV technology have yielded a new class of devices capable of monitoring for user input and delivering a low dose of UV-C light when human exposure is not detected. Each dose is set to a safe and optimal disinfection cycle to eliminate pathogens with minimal human exposure [17]. Should a human need to interact with the device being sterilized, the UV light automatically pauses its operation, waits for use to cease, then resumes the cleaning cycle.

A 2016 study in the *American Journal of Infection Control* demonstrated the utility of low-intensity UV-C devices in reducing the bioburden on hospital computer keyboards [18]. In the current study, we investigated the capacity of these UV-C devices in reducing the spread of a mosaic virus DNA tracer, i.e., a proxy for pathogens, across hospital rooms in the intensive care unit (ICU).

2. Materials and Methods

2.1. Study Site and Design

The trial was carried out via a pre–post experimental design. The study site was a single, 33-bed mixed medical and surgical intensive care unit at an academic medical center in Stanford, CA. Study approval was obtained from the Stanford University Human Subjects Panel (Institutional Review Board Protocol #45006). Faculty and staff were educated on the function of the UV lights prior to implementation; however, there was no instruction to alter staff behavior or decontamination practices within the ICU.

2.2. UV Light Installation and UV Treatment Protocol

The manufacturer (UV Partners, Inc., Grand Haven, MI, USA) installed the UV lights (UV Angel) on 140 high-touch devices in the ICU. These devices included: IV pumps (Alaris Pump, BD Medical, Franklin Lakes, NJ, USA), stationary computer keyboards, portable computer workstation surfaces and keyboards, touchscreen vitals monitors, ventilators, and Pyxis drug dispensers (Pyxis Medstation, BD Medical, Franklin Lakes, NJ, USA). The UV lights used were small, 3.2 cm deep by 30.5 cm wide, and were placed above high-touch items with the goal of providing fully automated decontamination cycles after each use. Detailed descriptions of the UV device have been published previously [18]. The UV lights were programmed to turn on 90 s after user input was no longer detected. The UV light remained on for an 18 min cycle. The cycle length was determined based on a previous analysis in which UV-C light was used to inactivate *C. difficile* spores [19]. The UV lights reported the number of cleaning cycles initiated and completed via their cloud connectivity. No other HAI reduction strategy, outside of the standard of care, was implemented during this analysis.

2.3. Mosaic Virus Transfer

Pathogen transfer analysis was performed using two genetically distinct mosaic virus DNA markers. These mosaic viruses have been studied extensively for modeling pathogen transmission in clinical environments [20]. Prior to installation of the UV lights, a standard quantity of cauliflower mosaic virus DNA was suspended in sterile saline. A standardized 1.15 mL volume was sprayed onto high-touch surfaces, including bed rails, touchscreen monitors, computer keyboards, and ventilators in 4 of the 33 ICU patient bays. Swabs from high-touch surfaces in the 29 non-inoculated bays were then obtained 24 h (n = 100 swabs), 48 h (n = 99 swabs), and 96 h (n = 78 swabs) post inoculation to demonstrate the baseline spread of this pathogen proxy throughout the ICU. A total of 277 baseline swabs, plus positive controls, were obtained and amplified via polymerase chain reaction (PCR). After deployment of the UV lights, the same protocol was followed with a second, genetically distinct, mosaic virus DNA marker to determine the impact on pathogen transfer to non-inoculated bays. A total of 261 swabs plus positive controls were collected post intervention at 24 h (n = 98 swabs), 48 h (n = 83 swabs), and 96 h (n = 80 swabs).

2.4. Viral Swabs and Processing

Viral swab collection throughout the study was performed by a trained operator using Copan eSwab collection kits (Copan Diagnostics, Inc., Murrieta, CA, USA). The swab tip was dipped in the kit's modified liquid transport medium inside the vial, and the remainder of the liquid was discarded to prevent dilution of the mosaic virus. The swab was passed multiple times in a wide pattern over the collection surface and inserted back into the collection tube. The applicator tip was broken off into the vial and the screw cap sealed. The specimen was then immediately labeled according to protocol. Researchers and lab staff were not blinded to the surface or whether or not the samples came from UV-protected devices.

Throughout both phases of the study, the swab processing was consistent in methodology. The same investigator conducted all portions of the collections. Storage and shipping, which consisted of insulated boxes with ice packs, were consistent for all swabs and expedited to the research lab for analysis at the earliest possible time. The swab collection technique, labeling, and volume of liquid culture medium used to gather samples were consistent throughout all phases.

2.5. Device Touch and Cycle Analysis

During the 96 h deployment of the UV lights on various high-touch surfaces, motion sensors in the UV lights recorded the number of unique touches on UV-protected devices. Based on a prior study from 2016, we defined a unique touch as occurring at least 90 s after the previous interaction was completed [18]. This length of time was chosen based on the plot of the percent of touches occurring versus length of time since the last touch. It revealed a logarithmic curve with slightly over 50% of touches occurring in the first 90 s. Beyond that point, the curve became approximately linear suggesting a uniform probability of device use after 90 s. The results of the protected device touches per 24 h period are displayed in Table 1 with an average of 64 touches per device class per 24 h period. Mobile workstation surfaces and keyboards were touched the most followed by Pyxis machines and IV pumps. Ventilators and vitals monitors were touched the least.

Table 1. Estimated Number of Unique Device Touches per 24-h Period.

Device	Average 24-h Touches
IV Pump	48.8
Keyboard	111.2
Pyxis	50.5
Ventilator	28.5
Vitals Monitor	29.5
Worksurface on Cart	112.7

2.6. Statistical Analysis

We used descriptive statistics for comparison, in charts and in graphs, to analyze viral transfer interruption. The Wilcoxon signed-rank two-tailed test was used to compare the pre and post-intervention results. Analysis was done using XLSTAT Version 2019.3.2 (Copyright Addinsoft (2019); XLSTAT and Addinsoft are Registered Trademarks of Addinsoft).

3. Results

Mosaic Virus Transfer

When analyzing the data of the mosaic virus dissemination in the absence of UV-C treatment, the virus disseminated to 2.00% ($n = 2$ of 100) of surfaces after 24 h, peaked at 10.10% ($n = 10$ of 99) after 48 h, and was found on 5.13% ($n = 4$ of 78) of tested surfaces after 96 h (Figure 1). Post UV deployment, 0.00% of surfaces tested positive for the mosaic virus DNA after 24 h, 1.20% ($n = 1$ of 83) of sites tested positive for the mosaic virus DNA after 48 h, and 2.50% ($n = 2$ of 80) tested positive after 96 h (Figure 1).

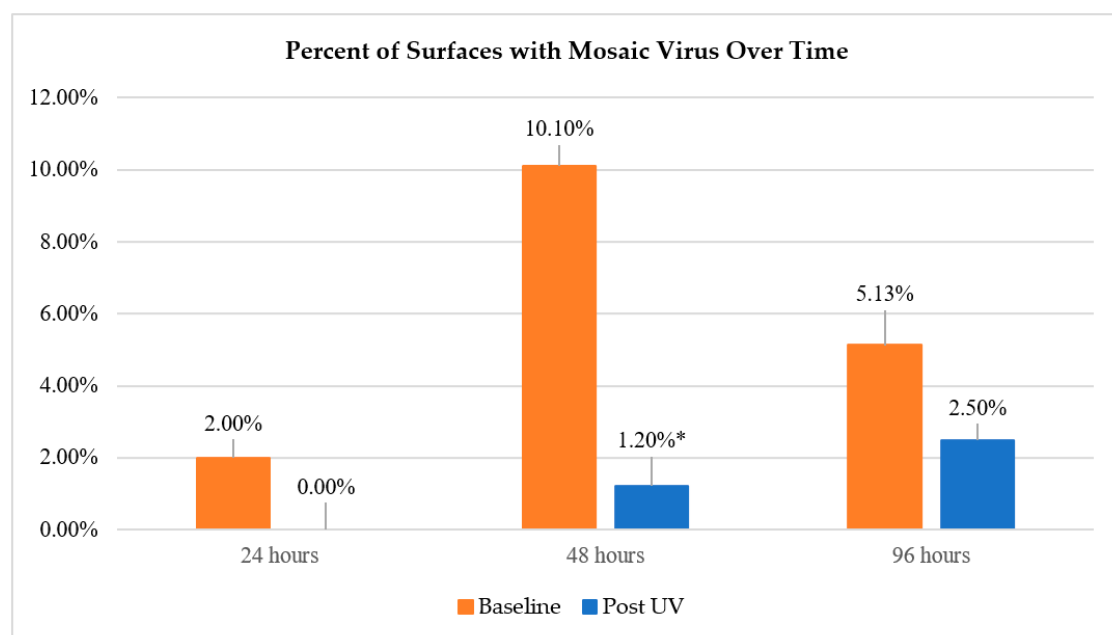


Figure 1. Percent of intensive care unit (ICU) Surfaces Contaminated with Mosaic Virus at Sequential Samplings. * Denotes a statistically significant reduction.

The greatest reduction in mosaic virus transfer post UV implementation was observed at 48 h with a 90% relative reduction ($p < 0.0001$) in mosaic virus spread across surfaces in the ICU (Table 2).

Table 2. Percent of Surfaces Bays Contaminated with Mosaic Virus at Sequential Samplings.

Hours Post Inoculation	24	48	96
Pre-UV Surfaces Positive (Percent)	2.00%	10.10%	5.13%
Pre-UV Surfaces Positive (Number)	N = 2	N = 10	N = 4
Post-UV Surfaces Positive (Percent)	0%	1.20%	2.50%
Post-UV Surfaces Positive (Number)	N = 0	N = 1	N = 2
Significance	$p = 0.125$	$p < 0.0001$	$p = 0.688$

4. Discussion

HAIs are commonly spread through contaminated hospital surfaces, air, water, or providers that serve to transport pathogens [21,22]. Countless surfaces in hospitals are reservoirs for viable pathogens including Methicillin-Resistant *Staphylococcus Aureus* (MRSA) and Vancomycin Resistant *Enterococcus* (VRE). In rooms of patients with diarrhea, viable MRSA has been collected from 59% of the room surfaces and viable VRE has been collected from 46% of room surfaces [23].

Despite the known prevalence of contaminated surfaces, current cleaning practices are inadequate [24]. Terminal room cleaning after patient discharge only reduced bacterial contamination to undetectable levels on 49% of surfaces, including less than 30% for toilet hand holds, bedpan cleaners, room doorknobs, and bathroom light switches [25]. Furthermore, these cleaning practices occur, at best, once per day [12]. These high-touch surfaces serve as potent sources for bacterial and viral transfer and are concerning given the ratio of touches to cleanings that they receive [26]. In one analysis, it was noted that while nearly two thirds of clinical staff touched surfaces within a patient's room, these same surfaces were only cleaned by environmental services a maximum of once per day [27]. Alarmingly, it is these same surfaces nearest to the patient that confer the highest infection risk [28–30].

Despite numerous studies demonstrating its utility, UV light use remains underutilized in the hospital, in part due to issues regarding costs, safety, or staffing needs [13]. The small UV devices used in the current study have some advantages and disadvantages over larger UV room decontamination devices. The devices are intended to be used when people are present and are fully automated. In a previous study, we found that the UV devices effectively decontaminated keyboards with no interruption of workflow, no additional staffing, and no adverse effects due to UV exposure. This follow-up study again demonstrated the capacity of UV light to reduce bacterial burden on some of the most commonly touched surfaces in the hospital.

It seems reasonable to conclude that UV treatment could help mitigate the spread of infectious agents by reducing cross-contamination from commonly used objects in the ICU, given the frequency with which these devices are used. Here, we sought to decontaminate as many device surfaces as possible post contact with staff via the application of passive UVC light. By providing real-time pathogen reduction technology to various surfaces, we reduced the probability that a mosaic virus was able to spread within the ICU. In combination with high handwashing rates, which were assumed to be constant throughout the study, as the probability of decontaminated surfaces in the hospital increases, the number of viable transfer routes between patients decreases [31]. Greater utilization of validated aseptic techniques like UV decontamination could enhance patient safety and improve outcomes, especially in critically ill and otherwise susceptible patients [32].

This study has limitations given the resources and time available to run the trial. While we significantly reduced the transfer of pathogens on the UV-protected devices, we do not know what percent of interactions those high-touch devices represent as it is impractical to count every touch that occurs in an ICU of this size. Given this limitation, we only tested known high-touch surfaces. These surfaces were identified by a review of time in motion studies [33]. Lastly, we were unable to consent patients for physical culturing, so it was not within the means of this analysis to provide direct evidence that the mosaic virus was transmitted to patients from the numerous in-room surfaces. Further study is needed to examine if this causal reduction in pathogen transfer leads to a reduction in specific healthcare-associated infections.

5. Conclusions

This study confirmed our hypothesis that UV decontamination significantly and meaningfully retarded the spread of the mosaic virus across ICU surfaces with a relative reduction of 90% at 48 h from 10.10% of tested surfaces to 1.20% of surfaces post UV ($p < 0.0001$). Realtime UV decontamination holds the potential to confer protection to ICU patients by reducing the number of surfaces that can serve as a nidus for infection transfer.

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