

## ORIGINAL ARTICLE

# Comparison of the Microbiological Efficacy of Hydrogen Peroxide Vapor and Ultraviolet Light Processes for Room Decontamination

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**OBJECTIVE.** To compare the microbiological efficacy of hydrogen peroxide vapor (HPV) and ultraviolet radiation (UVC) for room decontamination.

**DESIGN.** Prospective observational study.

**SETTING.** 500-bed teaching hospital.

**METHODS.** HPV and UVC processes were performed in 15 patient rooms. Five high-touch sites were sampled before and after the processes and aerobic colony counts (ACCs) were determined. Carrier disks with  $\sim 10^6$  *Clostridium difficile* (CD) spores and biological indicators (BIs) with  $10^4$  and  $10^6$  *Geobacillus stearothermophilus* spores were placed in 5 sites before decontamination. After decontamination, CD log reductions were determined and BIs were recorded as growth or no growth.

**RESULTS.** 93% of ACC samples that had growth before HPV did not have growth after HPV, whereas 52% of sites that had growth before UVC did not have growth after UVC ( $P < .0001$ ). The mean CD log reduction was  $>6$  for HPV and  $\sim 2$  for UVC. After HPV 100% of the  $10^4$  BIs did not grow, and 22% did not grow after UVC, with a range of 7%–53% for the 5 sites. For the  $10^6$  BIs, 99% did not grow after HPV and 0% did not grow after UVC. Sites out of direct line of sight were significantly more likely to show growth after UVC than after HPV. Mean cycle time was 153 (range, 140–177) min for HPV and 73 (range, 39–100) min for UVC ( $P < .0001$ ).

**CONCLUSION.** Both HPV and UVC reduce bacterial contamination, including spores, in patient rooms, but HPV is significantly more effective. UVC is significantly less effective for sites that are out of direct line of sight.

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Environmental contamination makes an important contribution to the transmission of pathogens in hospitals.<sup>1</sup> Some of the most compelling evidence that contaminated surfaces contribute to transmission is the increased risk of acquiring multidrug-resistant organisms in rooms where the previous occupant was colonized or infected with the organism.<sup>2-6</sup> Standard methods of cleaning and disinfecting surfaces in hospitalized patients' rooms are often suboptimal.<sup>7,8</sup> Therefore, there has been a recent focus on "no touch" automated room disinfection systems, which do not rely on the operator for the correct application and contact time of the active agent.<sup>9,10</sup> Novel technologies used to more reliably decontaminate patient rooms include hydrogen peroxide vapor (HPV) and ultraviolet radiation (UVC).<sup>9,10</sup>

HPV is an Environmental Protection Agency-registered sporicidal sterilant with *in vitro* and *in situ* efficacy against nosocomial pathogens<sup>11,12</sup> that has demonstrated utility in outbreak remediation<sup>13,14</sup> and has been linked with reductions in acquisition of healthcare-associated pathogens and infection.<sup>15-17</sup> UVC has proven microbiological efficacy *in vitro*

and was shown to reduce contamination with nosocomial pathogens *in situ*.<sup>18-20</sup>

We evaluated an HPV system and a UVC system separately.<sup>17,20</sup> However, this does not allow for direct comparison of the impact of the systems.<sup>10</sup> Therefore, we conducted a prospective observational study to compare the microbiological efficacy of a HPV system with that of a UVC system for room decontamination in a 500-bed university-affiliated community teaching hospital.

## METHODS

A convenience sample of 15 patient rooms was selected for the study. The rooms were located in 8 different wards and the bathrooms and showers were located directly off the patient rooms. In 2 of the rooms sampled from 1 ward, the shower was located at a right angle from the bathroom. The size of the rooms ranged from 46 to 86 m<sup>2</sup>. Each room was decontaminated once using HPV and once with UVC, separated by a period of at least 2 months. The length of time to complete the process was recorded and the average time

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was calculated. For HPV, the process time included taping the room, running the decontamination process, removing the tape, and exiting the room. For UVC, the process time included only the time that the instrument was running, because the set-up time is very short.

### HPV Decontamination Process

Selected rooms were first cleaned using either a quaternary ammonium compound (Virex 256, JohnsonDiversy) or a 10% bleach wipe (Dispatch, Caltech Industries), bed linens and trash bags were removed, and the bathroom and shower doors were fully opened before decontamination was performed using HPV (Bioquell), as described by French et al.<sup>21</sup> Briefly, all heating, ventilation, and air conditioning ducts were sealed with tape. A remotely controlled generator was used to convert 30% hydrogen peroxide liquid into HPV, which was dispersed into the room until approximately 1  $\mu\text{m}$  was deposited on all exposed surfaces. The in-room HPV concentration, temperature, and humidity were monitored during the decontamination process. The HPV was catalytically converted to oxygen and water vapor, leaving a residue-free surface.

### UVC Decontamination Process

Selected rooms were first cleaned using either a quaternary ammonium compound or a 10% bleach wipe, bed linens and trash bags were removed, and the bathroom and shower doors were fully opened before decontamination was performed using UVC (Tru-D, Lumalier), as described by Boyce et al.<sup>20</sup> Briefly, the UVC device was placed in the center of the patient room and the door was closed. The dose of UV light was set at 22,000  $\mu\text{W sec/cm}^2$  to eradicate bacterial spores.<sup>20</sup> Once activated by a handheld device outside of the room, the device emitted UVC in the 254-nm range until all sensors on the instrument reached the desired dose of reflected light and the instrument turned itself off.

### Aerobic Bacterial Growth

Five standardized high-touch surfaces in each room were sampled using D/E neutralizing contact agar plates (Rodac plates; Remel or Becton Dickinson) before and after the decontamination process. The 5 sites included the bedside rail, the overbed table, the television remote, the bathroom grab bar, and the top of the toilet seat. The plates were incubated at 37°C for 48 hours and aerobic colony counts (ACCs) were determined. The efficacy of the decontamination processes against aerobic vegetative bacteria was expressed by comparing the number of sites with bacterial growth before the decontamination process with the number of those sites with bacterial growth that remained after the decontamination processes for all 5 sites. The mean, median, and range of ACCs were calculated for all 5 sites.

### Sporicidal Activity

To evaluate the efficacy of the decontamination processes against spores, 3 different carrier disk tests were used: *Clostridium difficile* (CD) spores at a concentration of  $\sim 10^6$  produced in-house, as previously described,<sup>20</sup> and *Geobacillus stearothermophilus* biological indicators (BIs) at concentrations of  $10^4$  and  $10^6$  (Apex Laboratories). These commercially available BIs are enclosed in Tyvek pouches. For the purposes of this study, the pouches were opened and the disks were placed with the inoculated side of the disk faceup to allow for the greatest amount of exposure during the process. All 3 disk types were placed in sterile petri dishes, which were then placed in 5 sites in each of the rooms before decontamination was performed. The 5 sites included the overbed table, the chair, the floor under the bed (often out of direct line of sight), and the toilet seat and shower floor in the bathroom. The latter 3 sites were chosen because they were not in a direct line of sight from the device and are areas that are at risk for CD contamination. The disks were evaluated for viable spores after the decontamination processes were performed, as follows.

### CD Log Reductions

In order to evaluate the efficacy of the decontamination processes against CD spores, the log reductions achieved were determined, using a modification of the ASTM E-2197 quantitative disk carrier method as previously described by Boyce et al.<sup>20</sup> A modification of the ASTM E-2197 was used because there is currently no standardized method with which to evaluate the antimicrobial efficacy of UVC or HPV technologies. After the decontamination process, CD spore log reductions were determined by comparing the concentration of spores recovered from the test disks from each of the 5 sites with 3 disks unexposed to the decontamination process.

### *Geobacillus stearothermophilus* BIs

BIs seeded with spores are often used to ensure the efficacy of automated sterilization and disinfection systems in hospitals.<sup>22</sup> BIs containing  $10^6$  *Geobacillus stearothermophilus* spores are typically used to validate HPV cycles in health care and other industries.<sup>17,21,23</sup> Six-log BIs may not be useful indicators for systems with a lower level of microbial inactivation, and so we evaluated the efficacy of the decontamination processes against commercially available BIs at concentrations of  $10^4$  and  $10^6$  spores per disk. After the decontamination processes, each of the BIs were placed into trypticase soy broth and incubated in a water bath at 60°C for 5 days. The results of the BIs were recorded as growth or no growth, and the percentages that achieved a 4-log and a 6-log reduction were calculated for each of the 5 sites.

### Statistical Analysis

Univariate analyses of dichotomous variables were performed by using  $\chi^2$  tests. Differences in cycle times were compared

by using an unpaired *t* test. Continuous ACC data were compared using the Wilcoxon signed ranks test. For multivariate analysis of continuous ACC data, a 5 (sample site) × 2 (time [before, after]) × 2 (HPV vs UVC) repeated-measures general linear model with Greenhouse-Geisser adjustment was used in SPSS (ver 18, IBM-SPSS).

## RESULTS

### Univariate Analysis

Of the 75 sites sampled before HPV decontamination was performed, 70 (93%) yielded aerobic bacteria growth. After decontamination with HPV, 65 (93%) of the 70 sites yielded no growth ( $P < .0001$ ). Of the 5 sites that yielded growth, there was a range of growth from 1 to 4 colony-forming units (CFUs) per plate (Figure 1). For UVC decontamination, 68 (91%) of the 75 sites sampled yielded bacterial growth before decontamination and 35 (51%) of the 68 sites yielded no growth after decontamination ( $P < .0001$ ). Of the 33 sites that yielded growth, there was a range of 2 to 160 CFUs per plate (Figure 1). There was a significant difference in the percentage of sites that grew bacteria after HPV decontamination (7%) compared with after UVC decontamination (49%;  $P < .0001$ ). Eleven of the 33 sites (33%) that yielded bacteria after UVC decontamination were samples taken from sites located in the patient's room, while 22 of the 33 sites (67%) were located in the patient's bathroom, out of direct line of sight of the UVC device ( $P < .0001$ ). There was no difference for HPV decontamination.

The mean, median, and range values for the ACCs for each site are shown in Table 1. The median ACC from the samples collected in the patients' rooms following decontamination was 0.0 for both HPV and UVC. The median ACC for samples collected in the patients' bathrooms was 0.0 for HPV, while it was 6.0 for the grab bar and 2.0 for the toilet seat for UVC. ACCs after room decontamination were reduced significantly at each of the 5 sample sites after HPV treatment ( $P < .001$  for all sites). ACCs after decontamination with UVC were significantly reduced for samples collected from bed rails, overbed tables, television remotes, and bathroom grab bars (each  $P = .001$ ), but not for those from toilet seats ( $P = .155$ ).

### Multivariate Analysis

A repeated-measures general linear model of continuous ACC data revealed that ACCs were significantly different for the 5 sample sites ( $P = .008$ ) and by time (significantly lower after room decontamination [ $P < .001$ ]), and they also revealed a significant interaction ( $P = .041$ ). However, there was no significant main effect difference observed between HPV and UVC decontamination.

HPV decontamination achieved a 6-log reduction in CD spores in 100% of samples taken from all 5 sites. UVC decontamination achieved an average log reduction of 2.2 for all 5 sites, with a range of 1.7–3.0 (Figure 2). For the  $10^4$  BIs,

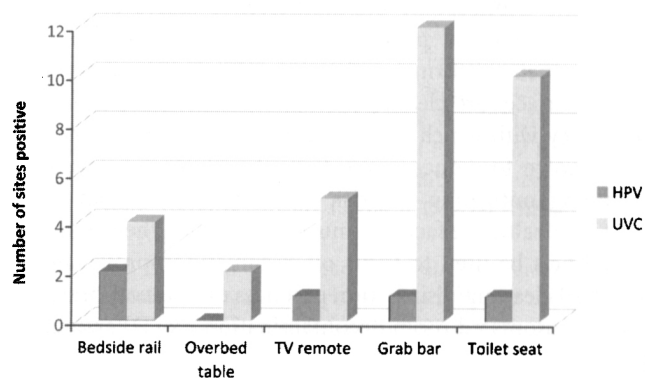


FIGURE 1. Number of samples positive for bacterial growth after decontamination with hydrogen peroxide vapor (HPV) and ultraviolet radiation (UVC) for each of the 5 sites.

HPV achieved a 4-log reduction in 100% of the BIs from all 5 sites, whereas UVC achieved a 4-log reduction in 29% of the BIs, with a range of 7%–53% for the 5 sites (Figure 3). Overall, there was a significant difference between HPV as compared with UVC for the percentage of BIs achieving a 4-log reduction ( $P < .0001$ ). Two (7%) of 30 BIs placed in the bathroom out of direct line of sight of the UVC device achieved a 4-log reduction, compared with 20 (44%) of 45 BIs placed in the room ( $P = .0006$ ). There was no significant difference with HPV. For the  $10^6$  BIs, HPV achieved a 6-log reduction in 99% of the sites sampled, with growth being detected in only 1 BI, which was placed on a toilet seat. For UVC, a 6-log reduction was achieved in 0% of the sites.

The mean length of time to complete the HPV decontamination process was 153 minutes, with a range of 140–177 minutes. UVC decontamination had a mean length of time of 73 minutes and a range of 39–100 minutes ( $P < .0001$ ).

## DISCUSSION

Given the recent focus on “no touch” automated room disinfection systems, a number of studies have been conducted to evaluate their performance.<sup>17–20,25</sup> Recently, Holmdahl et al<sup>25</sup> published the first head-to-head comparison of HPV and aerosol room decontamination systems. We believe that our study is the first head-to-head comparison of the HPV and UVC decontamination methods.

The HPV system was more effective than the UVC system in eliminating aerobic bacteria from surfaces in patient rooms. Unlike HPV, UVC was affected by line of sight. The UVC system was significantly faster and easier to use than the HPV system.

There are several ways to improve environmental hygiene in hospitals. Assigning responsibility for cleaning various equipment to specific healthcare workers helps housekeepers and nurses understand who is responsible for cleaning environmental surfaces.<sup>26</sup> Monitoring housekeeper performance by using methods such as fluorescent marking systems or

adenosine triphosphate bioluminescence assays or by performing ACCs and providing personnel with feedback regarding their performance can increase the frequency with which surfaces are cleaned and disinfected.<sup>8,27</sup> Increasing the frequency with which surfaces are cleaned by personnel has been shown to reduce acquisition of pathogens by patients, including mitigating the risk from the prior room occupant.<sup>2,24</sup> Healthcare facilities must decide when their resources would best be used to focus on systematic improvement of standard cleaning/disinfection practices or to incorporate “no touch” automated room decontamination (NTD) systems. A key benefit of NTD systems is that they do not rely on the operator to ensure adequate distribution and contact time of the disinfectant. A few studies of HPV decontamination have shown reduced acquisition of pathogens by patients and mitigation of the risk from the prior room occupant.<sup>15-17</sup> No UVC studies with a clinical outcome have been published to date. Head-to-head studies are needed to compare the efficacy of the various NTD systems, such as the study conducted by Holmdahl et al.<sup>25</sup>

In our study, sampling sites were chosen that were in and out of direct line of sight of decontamination equipment, to represent the complex topography of the healthcare environment. HPV decontamination achieved a higher level of microbiological inactivation than UVC and was not affected by line of sight, which concurs with the results of other studies.<sup>25</sup> In contrast, UVC decontamination using the spore inactivation cycle achieved a lower level of inactivation and was affected by line of sight, which concurs with the results of other studies.<sup>18-20</sup> Although the level of decontamination of surfaces in hospital rooms that is required to reduce transmission of pathogens is currently unknown, there is limited evidence that the risk of transmission from contaminated

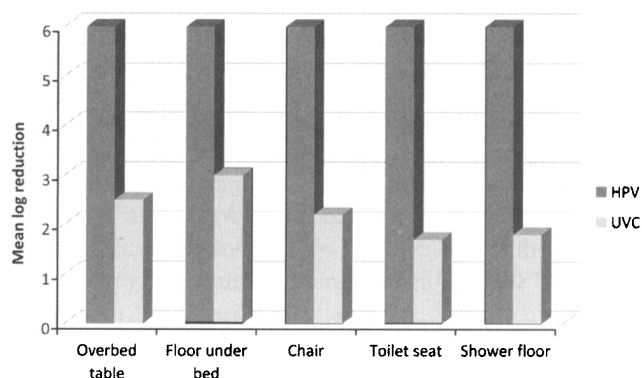


FIGURE 2. Mean *Clostridium difficile* log reductions for each of the 5 sites after decontamination with hydrogen peroxide vapor (HPV) and ultraviolet radiation (UVC).

surfaces is proportional to the amount of contamination remaining.<sup>28</sup>

UVC decontamination was easier to use and had significantly shorter cycle times, can be administered by personnel with only limited training, and does not require monitoring by personnel during the process. However, UVC cycles were longer here than in previously published studies.<sup>19</sup> Running multiple cycles for UVC, such as operating the device in the patient’s bathroom followed by placing the device in the center of the patient’s room, can achieve a higher level of inactivation but requires increased hands-on time.<sup>20</sup> Commercially available spore BIs do not appear to be useful in validating the UVC system, and currently there is no standardized method to evaluate the microbiological efficacy of this technology. It should be noted that the numbers of spores

TABLE 1. Aerobic Colony Counts per Rodac Plate before and after Decontamination for the 5 High-Touch Surfaces

	Patient room			Patient bathroom		Overall
	Bedside rail	Overbed table	TV remote	Grab bar	Toilet seat	
<b>Before HPV</b>						
Mean	17.7	12.0	36.7	53.4	45.5	33.1
Median	17.0	7.0	15.0	30.0	22.0	18.2
Range	2-46	0-47	0->200	1->200	0->200	0->200
<b>After HPV</b>						
Mean	0.1	0.0	0.1	0.3	0.18	0.1
Median	0.0	0.0	0.0	0.0	0.0	0.0
Range	0-1	0	0-2	0-4	0-2	0-4
<b>Before UVC</b>						
Mean	25.4	7.9	31.7	97.0	40.9	40.6
Median	18.0	5.0	10.0	90.0	3.0	25.2
Range	0-95	1-28	0-30	0->200	0->200	0->200
<b>After UVC</b>						
Mean	1.7	0.4	1.3	24.1	7.3	6.9
Median	0.0	0.0	0.0	6.0	2.0	1.6
Range	0-14	0-4	0-12	0-160	0-4	0-160



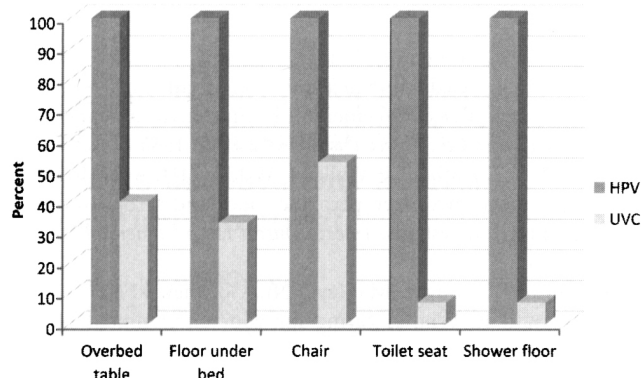


FIGURE 3. Percentages of samples achieving a 4-log reduction using the 4-log *Geobacillus stearothermophilus* biological indicators. HPV, hydrogen peroxide vapor; UVC, ultraviolet radiation.

on the carrier disk BIs are much greater than would be present on surfaces in patient rooms, which presents a difficult challenge for decontamination processes.

Our study has several limitations. First, it was conducted in a single hospital and the number of rooms sampled was relatively small. There was also a limited number of surfaces sampled in each room, and this may not accurately reflect the level of contamination on other surfaces that were not sampled. Although total ACCs were determined, identification of pathogens was not performed.

In conclusion, we found that both HPV and UVC decontamination reduce bacterial contamination in patient rooms. HPV was significantly more effective than UVC in rendering surfaces culture negative and was significantly more effective against spores. UVC is significantly less effective in areas that are out of direct line of sight. However, UVC is faster and easier to use than HPV. Further studies of UVC systems are warranted to establish their ability to reduce healthcare-associated infections. Additional studies of both HPV and UVC are needed to establish the situations in which the different technologies are most beneficial and cost effective.

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