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Major Article

Effect of pulsed xenon ultraviolet disinfection on methicillin-resistant *Staphylococcus aureus* contamination of high-touch surfaces in a Japanese hospital

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Background: The hospital environment is an important source of multidrug-resistant organisms such as methicillin-resistant *Staphylococcus aureus* (MRSA). Here, we evaluated the efficacy of pulsed xenon ultraviolet (PX-UV) disinfection in addition to manual cleaning in a Japanese hospital.

Methods: Environmental samples were collected from inpatient rooms that had been occupied for at least 48 hours by patients infected or colonized with MRSA. High-touch surfaces from 11 rooms were sampled before and after manual cleaning and then after PX-UV disinfection. Changes in bacterial counts and in the number of aerobic bacteria (AB)- and MRSA-positive samples between sampling points were assessed. The time taken to complete PX-UV treatment of patient rooms was also recorded.

Results: A total of 306 samples were collected. PX-UV disinfection resulted in a significant decrease in abundance of AB and MRSA (mean colony-forming units 14.4 ± 38.7 to 1.7 ± 6.1, $P < .001$ and 1.1 ± 3.9 to 0.3 ± 2.0, $P < .001$, respectively) and in the number of AB- and MRSA-positive samples (58.8%-28.4%, $P = .001$ and 19.6%-3.9%, $P < .001$, respectively) compared with manual cleaning. The median time of in-room use of the PX-UV device was 20 minutes.

Conclusions: The addition of PX-UV disinfection to the manual cleaning process significantly reduced AB and MRSA contamination of high-touch surfaces in hospital inpatient rooms.

Multidrug-resistant organisms such as methicillin-resistant *Staphylococcus aureus* (MRSA) and *Clostridioides difficile* are common causes of health care–associated infections that negatively affect patient outcomes, including length of hospital stay and mortality.[1-4] In Japan, MRSA is the most common multidrug-resistant nosocomial pathogen.[5] The hospital environment is a major reservoir of bacterial pathogens and plays an important role in their transmission.[6,7] Admission to a room previously occupied by a patient harboring a multidrug-resistant organism significantly increases the risk of acquisition of these pathogens.[8-10] Furthermore, manual cleaning using chemical disinfectants, which is the standard cleaning procedure used in most hospitals, may be inadequate if not carried out correctly.[11,12]

There are an increasing number of reports regarding no-touch disinfection in health care environments using ultraviolet light or hydrogen peroxide vapor.[13] The microbiological and clinical efficacy of pulsed xenon ultraviolet (PX-UV) light devices has been described previously, mainly in the United States.[14-17] However, health care environments can vary greatly between countries, and there are no

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reports about PX-UV disinfection in Japanese hospitals. Therefore, in this study, we evaluated the microbiological efficacy of PX-UV disinfection in addition to manual cleaning for elimination of aerobic bacteria (AB) and, more specifically, MRSA from high-touch surfaces in a Japanese hospital.

METHODS

Study design

Samples were collected from the intensive care unit (ICU), emergency intensive care unit (EICU), and high care unit (HCU) of Hiroshima University Hospital, Hiroshima, Japan, from February to June 2019. Hiroshima University Hospital is a 740-bed tertiary care hospital. As part of the standard infection prevention and control measures undertaken by the hospital, all patients admitted to the ICU or EICU undergo nasal swab culture at the time of admission or transfer to determine their MRSA status (positive or negative). The rooms selected for inclusion in the study were identified using medical records by infection prevention and control staff. The inclusion criteria were as follows: (1) single occupancy room, (2) occupied for at least 48 hours by a patient with MRSA colonization or infection, and (3) weekday and daytime discharge.

Initial baseline microbiological samples were collected immediately after patient discharge. After initial sampling, ward nurses performed standard manual cleaning as per ward protocols. Standard manual cleaning included cleaning visible dirt and surface cleaning. Surface cleaning was performed using disposable ready-to-use cleaning-disinfecting wipes containing 0.5% benzalkonium chloride (Seifukipu; Kao Corporation, Tokyo, Japan). Manual cleaning of high-touch surfaces in patient rooms with this type of wipe was performed daily. After manual cleaning and once environmental surfaces were dry, the second set of microbiological samples were collected. No-touch disinfection using the PX-UV device was then performed as per the manufacturer's instructions. Final microbiological samples were collected at the completion of no-touch disinfection. Nurses who performed manual cleaning and no-touch disinfection using the PX-UV device were aware that samples were being collected but were blinded to the chosen sampling surfaces to prevent any bias or changes in standard cleaning procedures. It was confirmed that PX-UV disinfection was carried out with appropriate cycles and irradiation time in the investigated rooms. The patients who were in the investigated rooms were blinded to this study to prevent any bias or variation in their activity.

PX-UV disinfection

A PX-UV device (Xenex Healthcare Disinfection Services, San Antonio, TX), containing a xenon flash lamp that emits a broad spectrum of light covering the germicidal spectrum (200-280 nm, UV-C) as well as the visible light spectrum, was used in this study. The ICU, EICU, and HCU wards are located on the same floor of the hospital. During the study period, the PX-UV device was stored on the same floor. Ward nurses were trained on the appropriate use of the PX-UV device. Single rooms without a separate bathroom and measuring 18 m^2 were the most common type of patient room on these wards. PX-UV disinfection was conducted in 5-minute cycles, with 1 cycle conducted on each side of the patient bed. If the patient room had a separate bathroom, preparation room, or waste treatment room, one 5-minute cycle was conducted in each additional room.

Sample collection

Samples were collected from the following 8 high-touch surfaces in each of 11 patient rooms: bed rails, bed control panels, overbed tables, vital sign monitor control panels, infusion pump control panels, bedside tables, door handles, and sink counters. Samples were collected at each of the sampling stages, that is, before manual cleaning (baseline), after manual cleaning, and after PX-UV disinfection. If the room had a toilet, additional samples were collected from the toilet seat at each of the sampling stages. In cases in which a suction machine or a treatment cart were used prior to discharge, samples were also collected from the suction machine control panel and treatment cart at each of the sampling stages. Microbiological sampling was performed using 25-cm^2 trypticase soy agar with lecithin and polysorbate Replicate Organism Detection and Counting Contact Plates (Becton, Dickinson and Company, Franklin Lakes, NJ). For flat surfaces, the contact plate was firmly pressed onto the surface for 10 seconds. For nonflat surfaces, a rolling plate technique was used to ensure coverage of the appropriate surface area. The resident microbiologist was blinded to the sample site and the timing of the sample.

Bacterial culture and identification

After sample collection, the contact plates were immediately transferred to the clinical laboratory at Hiroshima University Hospital and incubated for 48 hours at 36°C. Plate counts were then conducted to estimate the total number of colony-forming units (CFUs) for all AB present in each sample. Putative MRSA colonies on the sample plates, identified based on unique color and morphology and on the results of *S aureus*-selective latex agglutination tests (PS Latex; Eiken Chemical Company, Tokyo, Japan), were subcultured and identified using standard microbiological methods. CFU counts for MRSA were then estimated for each sample.

Time study

Studies to determine the amount of time required to carry out disinfection using the PX-UV device were also conducted. The most common patient room type, consisting of single room in which the PX-UV device was deployed for two 5-minute cycles, was selected for the time study. The PX-UV device use time was defined as the period from completion of manual cleaning to completion of PX-UV disinfection. The PX-UV device use time included the time required for additional setup, including setting up the PX-UV device, rearranging any furniture and medical devices, and attaching and removing blackout curtains over the door. Because patient room doors contained a transparent window, a blackout curtain was attached to the outside of the doors during PX-UV disinfection. The time studies were conducted in patient rooms in which environmental samples were not collected.

Ethics

Ethical approval was not sought because this study evaluated the performance of manual cleaning and PX-UV disinfection and did not require patient involvement or collection of human samples.

Statistical analysis

Because of the nonparametric distribution of the microbiologic data, the Wilcoxon rank-sum tests were used to determine differences in AB and MRSA CFU counts before and after manual cleaning, and before and after PX-UV disinfection. The McNemar test was used to determine differences in the number of AB- and MRSA-positive samples before and after manual cleaning, and before and after PX-UV disinfection. Data were analyzed using JMP version 13.0 (SAS Institute Inc, Cary, NC), and $P < .05$ was considered statistically significant.

RESULTS

Samples

Microbiological plate samples were collected from the bed rail, bed control panel, overbed table, vital sign monitor control panel, infusion pump control panel, bedside table, door handle, and sink counter in 11 patient rooms at each of the sampling stages. In addition, environmental samples were collected from toilet seats (1 sample from each of 9 rooms), suction machine control panels (1 sample from each of 2 rooms), and treatment carts (1 sample from each of 3 rooms) at each of the sampling stages. In total, 102 plate samples were collected at each of the 3 sampling stages.

Effects of PX-UV on the abundance of microbial contaminants

A summary of the total AB and MRSA bioburden for all samples prior to manual cleaning (baseline), after manual cleaning, and after PX-UV disinfection is shown in Table 1. Results are presented as the mean (± SD) and median (range) CFU counts of all plates at each sampling point. PX-UV disinfection resulted in a significant decrease in total CFU counts per plate for both AB and MRSA compared with manual cleaning ($P < .001$ and $P < .001$, respectively) (Table 1). PX-UV disinfection also caused a significant decrease in the overall number of AB- and MRSA-positive samples compared with manual cleaning alone ($P = .001$, $P < .001$, respectively), with 58.8% of plates still positive for AB after manual cleaning compared with 28.4% after additional PX-UV disinfection, and 19.6% of plates positive for MRSA after manual cleaning compared with only 3.9% after PX-UV disinfection (Table 1). Compared with the baseline, manual cleaning reduced mean MRSA counts by 80.7%, whereas the addition of PX-UV disinfection reduced this by a further 72.7% (Table 1).

A summary of CFU counts and percentage of positive samples by sampling site is shown in Table 2. Results showed that across all patient rooms, bed rails and infusion pump control panels were the surfaces most likely to remain contaminated with MRSA after manual cleaning. After PX-UV disinfection, MRSA was still recovered from bed rails, bed control panels, vital sign monitor control panels, and suction machine control panels.

Time study

The mean (± SD) and median (range) in-room use times for the PX-UV device were 20.9 ± 3.1 and 20.0 minutes (17-30 minutes), respectively. This time period included only two 5-minute cycles. Therefore, setting up the device, arranging furniture and medical devices, and attaching and removing blackout curtains took almost 10 minutes. The use time did not include retrieving and returning the device or wait time for use.

DISCUSSION

This study showed that the addition of PX-UV disinfection to the manual cleaning procedure significantly reduced AB and MRSA contamination of high-touch surfaces in patient rooms in a Japanese hospital. This finding is consistent with several previous reports.[15-17] High residual MRSA colony counts were observed in samples collected from bed rails and infusion pump control panels after manual cleaning. This may be the result of human error regarding which parts of the room had been cleaned. One of the major limitations of

Table 1
Overall CFU counts and proportion of samples with CFU present at baseline, after manual cleaning, and after PX-UV disinfection for aerobic bacteria and MRSA

Aerobic bacteria Number of pairs		Baseline	Manual cleaning	PX-UV disinfection
102	Mean CFU ± SD	29.8 ± 58.6	14.4 ± 38.7	1.7 ± 6.1
	median CFU (min-max)	4.0 (0-245)	1.0 (0-200)*	0 (0-48)†
	proportion of samples with CFU present (%)	84/102 (82.4)	60/102 (58.8)*	29/102 (28.4)‡
MRSA Number of pairs		Baseline	Manual cleaning	PX-UV disinfection
102	mean CFU ± SD	5.7 ± 2.1	1.1 ± 3.9	0.3 ± 2.0
	median CFU (min-max)	0 (0-190)	0 (0-25)*	0 (0-17)†
	proportion of samples with CFU present (%)	43/102 (42.2)	20/102 (19.6)*	4/102 (3.9)†

CFU, colony-forming units; *min-max*, minimum-maximum; *MRSA*, methicillin-resistant *Staphylococcus aureus; PX-UV*, pulsed xenon ultraviolet.
*P <.001 (comparing baseline with manual cleaning).
†P <.001 (comparing manual cleaning with PX-UV disinfection).
‡P = .001 (comparing manual cleaning with PX-UV disinfection).

Table 2
Total number of positive plates and colony counts per site for AB and MRSA at baseline, after manual cleaning, and after PX-UV disinfection of high-touch surfaces

	AB positive plates (total colony count)			MRSA positive plates (total colony count)		
Surface location	Baseline	Manual cleaning	PX-UV disinfection	Baseline	Manual cleaning	PX-UV disinfection
Bed rail	11/11 (431)	9/11 (227)	4/11 (60)	8/11 (252)	5/11 (23)	1/11 (10)
Bed control panel	10/11 (769)	9/10 (363)	5/11 (17)	8/11 (85)	2/10 (3)	1/11 (2)
Over table	11/11 (341)	5/11 (12)	1/11 (1)	6/11 (76)	2/11 (3)	0/11 (0)
Vital sign monitor control panel	7/11 (101)	3/10 (27)	1/11 (7)	2/11 (5)	1/11 (2)	1/11 (4)
Infusion pump control panel	11/11 (379)	6/11 (270)	3/11 (3)	6/11 (67)	5/11 (46)	0/11 (0)
Bedside table	6/11 (36)	6/11 (10)	3/11 (9)	3/11 (15)	0/11 (0)	0/11 (0)
Door handle	8/11 (80)	6/11 (21)	3/11 (3)	1/11 (8)	1/11 (4)	0/11 (0)
Sink counter	11/11 (578)	10/11 (454)	4/11 (21)	4/11 (20)	2/11 (6)	0/11 (0)
Toilet seat	4/9 (122)	3/9 (28)	4/9 (25)	3/9 (19)	1/9 (2)	0/9 (0)
Other sites*	5/5 (205)	3/5 (55)	1/5 (28)	2/5 (34)	1/5 (25)	1/5 (17)
Combined	84/102 (3,042)	60/102 (1,467)	29/102 (174)	43/102 (581)	20/102 (114)	4/102 (33)

AB, aerobic bacteria; *MRSA*, methicillin-resistant *Staphylococcus aureus; PX-UV*, pulsed xenon ultraviolet.
*Other sites included suction machine control panel (n = 2) and treatment cart (n = 3).

PX-UV disinfection is that treatment is less effective in areas of shadow, which receive a lower UV dose compared with areas directly exposed to the light source.[18] In addition, the effectiveness of PX-UV was shown to dramatically decrease as the distance from the device increased.[19] Therefore, effective PX-UV disinfection requires appropriate placement of the device within each room and rearrangement of furniture and medical devices to reduce areas of shadow on high-touch surfaces, which should also be moved close to the device, for optimal exposure to the radiation. In an acute care unit, as examined in the current study, there are more medical devices than in general wards, and the controllers or control panels of these devices are high-touch surfaces. Therefore, the PX-UV and medical devices need to be carefully positioned to reduce areas of shadow. Feedback of the results of environmental sampling to medical staff who operate the PX-UV device may be helpful to improve and maintain the efficacy of PX-UV disinfection.

Studies on the efficiency of PX-UV devices for reducing environmental contamination have been performed worldwide, especially in the United States.[14-17] However, to our knowledge, there are no reports examining PX-UV disinfection in a Japanese hospital. Our results showed that the addition of PX-UV disinfection to manual cleaning can significantly reduce the burden of both general AB and MRSA in a Japanese hospital. Because medical environments, including medical practices, staff, patients, patient room layouts, and cleaning protocols, vary widely by country, we believe this study provides valuable data for infection prevention and control.

ICUs tend to be the busiest hospital wards; therefore, rapid and effective decontamination of patient rooms is vitally important. In this study, the mean and median in-room use times (including two 5-minute cycles) for the PX-UV device were 20.9 and 20.0 minutes, respectively, and included the time taken to arrange furniture and medical devices and to attach and remove blackout curtains. These times are also consistent with previous reports from the United Kingdom.[16,19] However, we did not evaluate or include the time required to transport the device to the room or the wait time for the use of the device. In the current study, these times would have been minimal because a PX-UV device was stored on the same floor as the wards included in the study and was restricted to this floor for the duration of the study.

In general, the total time for PX-UV disinfection includes transport time, wait time for use, and time required for setup, and is thus dependent on the hospital layout, the number of available PX-UV devices, and the staff who perform PX-UV disinfection. Therefore, these factors should be considered when deciding whether PX-UV disinfection should be integrated into routine hospital cleaning procedures. In addition, practical difficulties such as bed turnover and time pressure to fill rooms, training on devices for medical staff, how often the devices are used, the cost of devices, and the number purchased, can be barriers to introducing this technology into real-world clinical settings.

Our study has several limitations. First, the study was conducted only in the ICU, EICU, and HCU of a single center, and included only weekday and daytime discharge, and the number of sampled surfaces was relatively small. However, the number of samples was sufficient for statistical analysis. Second, ward nurses conducted the cleaning of patient rooms in our study. In normal circumstances, assistant nurses perform manual cleaning of high-touch surfaces in patient rooms after discharge, which may affect the outcome. Third, because we focused on AB using trypticase soy agar plates, our results may not be entirely representative of the true level of bacterial contamination on each of the surfaces. In addition, the manual cleaning quality was not examined and could have influenced the outcome. Finally, we did not assess the impact of PX-UV disinfection on the rates of MRSA transmission to patients, or on the incidence of nosocomial MRSA infections in the hospital wards. Therefore, future studies are needed to examine the impact of PX-UV treatment on patient outcomes in Japanese hospitals.

CONCLUSIONS

Our study demonstrated that PX-UV disinfection in addition to manual cleaning significantly reduced AB and MRSA contamination of high-touch surfaces in a Japanese hospital. We believe this non-touch disinfection procedure might improve the standard of infection control practices in Japan. Additional studies are needed to determine the impact of PX-UV disinfection on the incidence of health care–associated infections. As such, outcome studies are being conducted to assess the clinical impact of PX-UV disinfection at our institution.

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