Clinical and microbiological effect of pulsed xenon ultraviolet disinfection to reduce multidrug-resistant organisms in the intensive care unit in a Japanese hospital: a before-after study

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Abstract

Background No-touch environmental disinfection using ultraviolet devices has been highlighted in the past several years to control the transmission of multidrug-resistant organisms (MDROs). However, its effectiveness in non-US healthcare settings is yet to be examined. This study aimed to evaluate the effectiveness of disinfection by portable pulsed xenon ultraviolet (PX-UV) devices in controlling transmission of MDROs in a non-US healthcare setting. Methods All patients admitted in the intensive care unit in a 629-bed tertiary referral hospital in Japan from August 2016 to February 2019 were enrolled. During the study period, PX-UV disinfection was added to manual terminal cleaning after every patient transfer/discharge. For microbiological evaluation, surfaces were selected for sampling by contact plates before/after manual cleaning and after PX-UV. After overnight incubation, colonies on the plates were counted. Results The incidence of newly acquired methicillin-resistant Staphylococcus aureus (MRSA) declined significantly (13.8 to 9.9 per 10,000 patient days, incidence rate ratio 0.71, p=0.002), as well as that of newly acquired drug-resistant Acinetobacter (48.5 to 18.1, 0.37, p<0.001). The percent reduction of the microbiological burden by manual cleaning was 81%, but a further 59% reduction was achieved by PX-UV. Conclusions PX-UV is effective in further reducing the microbial burden and controlling MDROs in a non-US healthcare setting.

Background

Infection remains a significant cause of morbidity and mortality in the healthcare setting, despite international initiatives in infection control and prevention. Pathogens such as *Clostridioides difficile*, vancomycin-resistant enterococci (VRE) and multidrug-resistant *Acinetobacter* are especially difficult to deal with. These pathogens can easily reside in the healthcare environment and are difficult to remove or eradicate by conventional environmental cleaning, typically by manual wiping with disinfectants and cloths. Ultraviolet light disinfection has recently been used as an adjunct to terminal cleaning, and many studies have shown its effectiveness in reducing healthcare-associated transmission of these pathogens. However, most studies have been performed in the United States, where most of the rooms are private. To our knowledge, there are no published studies investigating the clinical effectiveness of this novel technology in healthcare settings outside the United States.

In Yamagata University Hospital, there has been sporadic identification of two-drug resistant *Acinetobacter baumannii* (2DRA), which is resistant to two classes of antimicrobial: carbapenem and quinolone. In order to halt the transmission of this pathogen, interventions such as enhanced terminal cleaning by hypochlorous acid and strict contact precaution were implemented. This was partially successful; however, it did not lead to the eradication of transmission. Therefore, we decided to implement further intervention using pulsed xenon ultraviolet light (PX-UV).

The objective of this study is to evaluate the effect of PX-UV on the transmission of healthcare-associated pathogens and on the environmental contamination within a Japanese healthcare setting.

Methods

Study settings and design

This study was conducted at Yamagata University Hospital, a 629-bed academic tertiary referral hospital in Yamagata, Japan. The Yamagata University School of Medicine Institutional Review Board approved this study

with a waiver of informed consent.

Implementation and operation of the disinfection device

A PX-UV device (Xenex Disinfection Services, San Antonio, TX, USA) was introduced in the study hospital in November 2017. It was decided that this device would be used in the intensive care unit (ICU), since most of the newly detected 2DRA infections occurred in the ICU patient population. After education to clinical engineering staff, the device was deployed in the ICU environment. The ICU has six rooms and beds. One room has independent walls and positive/negative air pressure. The other rooms are in an open space separated by curtains. Portable drapes which protect UV and visible light from leaking outside the designated room were used, except when operating PX-UV in the private room. The device came into full operation by January 2018.

Terminal cleaning after every patient discharge or transfer to the ward was performed using cloths soaked with diluted sodium hypochlorite solution, which were then applied to every possible touchable surface in the room as well as portable and non-portable equipment. Next, the room was covered by portable drapes, which were hung inside of the curtains of the room. After hanging the portable drapes, two 5-minute disinfection cycles using PX-UV were run following the manufacturer's recommendation. The machine was operated by clinical engineering staff, and sequentially placed on two opposite corners of the room. For each operation, the operator's name, date and time, and duration (in seconds) of UV irradiation was recorded on the device's cloud-based reporting system.

Active surveillance of MDROs

Every patient admitted in the ICU was screened for methicillin-resistant *Staphylococcus aureus* (MRSA) and 2DRA colonization on the day of the admission and every Tuesday and Thursday, until transfer or discharge from the unit. New acquisition of MRSA or 2DRA was defined as the identification of these pathogens from the screening specimen or clinical culture specimen on or after the third day of admission to the ICU, with at least one preceding negative screening result.

Microbiological evaluation

Microbiological contamination of the environment was evaluated by using Rodac plates. Ten frequently touched surfaces were selected for sampling: the bed rail (inside and outside near patient's head, near patient's feet), touch panel of cardiopulmonary monitor, ventilator control panel, intravenous fluid pump control panel, glove hanger, workstation keyboard, workstation cart handle and water basin. Samples were collected by gently stamping Rodac plates onto the site for 10 seconds. The roll plate method was used for nonflat surfaces such as bedrails. Sampling occasions included (1) immediately after patient discharge, before terminal cleaning (2) immediately after terminal cleaning (3) after PX-UV disinfection. Plates were then cultured at 37 degrees Celsius for 18 hours. Colony-forming units (CFU) were counted and reported as CFU per $25cm^2$.

Statistical analysis

Poisson regression model analysis was used to estimate the incidence of MRSA and 2DRA infection, which were expressed as the number of acquisitions per 10,000 patient days. To do statistical analysis, we assume that the pre-intervention period is a baseline, which means the event (acquisition of MRSA or 2DRA) occurs in a probability calculated by using the data in the pre-intervention period. To analyze the CFU data a Shapiro-Wilk test was conducted to determine the skewness of the CFU data. The results suggested the CFU data were

skewed (p<0.001), indicating the need for a nonparametric test. The Dunn's Test of multiple comparisons using a rank sum was used to assess the difference between environmental sampling timepoints. This test is a nonparametric multiple comparison test, that uses a Wilcoxon Rank Sum that allows for more than a two-group comparison. The Dunn's Test used a Bonferroni correction to adjust for multiple comparisons. The statistical analyses were conducted using the Poisson and Dunn's Test package in STATA 15.1 (College Station, TX, USA).

Results

Change in the incidences of MDROs

The baseline incidence of MRSA and 2DRA in the ICU were 13.8 and 48.5 per 10,000 patient days, respectively. The incidence dropped to 9.9 and 18.1, resulting in a decrease of 29% and 63%, respectively (Table 1). The reductions in both MRSA and 2DRA were statistically significant (p=0.002 and p<0.001, respectively) (Table 2). Notably, in the intervention period, new acquisition of 2DRA in the ICU was observed only in the first six months, with no new acquisition for a seven month period. This also led to the eradication of new acquisition of 2DRA throughout the hospital in August 2018.

Microbiological effect

Environmental sampling was performed after 17 patient discharges. Some of the samplings were not performed due to time constraints by waiting patients or unique features of certain rooms. In total, 128 sites were sampled. The total colony count was: 3,336 (before manual cleaning), 669 (after manual cleaning, before PX-UV) and 280 (after PX-UV). Compared to pre-cleaning, a statistically significant decrease in colony count was observed after manual cleaning (p<0.0001, Wilcoxson rank sum test) (Table 3). Also, compared to post-manual cleaning, a statistically significant decrease in colony count was observed after PX-UV disinfection (p=0.0213) (Table 3).

Discussion

There are a number of studies which have demonstrated the effect of ultraviolet light disinfection in reducing environmental microbiological contamination[1-3] and healthcare-acquired infections by MRSA[4,5], VRE[5,6] and *Clostrisioides difficile*[5-10]. However, all but one study[3] was performed in the United States, where most of the patient rooms are private. Furthermore, that study[3] did not evaluate clinical outcomes.

Our study is the first hospital-acquired infection outcome study evaluating the clinical effectiveness of the PX-UV device in a non-US healthcare setting with an open-style ICU. In this setting, patient beds were separated by privacy curtains, not by walls. PX-UV emits intense visible light and creates a sound while disinfecting. The light and sound can be seen and heard outside the privacy curtains. This was initially not well tolerated by healthcare staff, some of whom raised concerns about sensitivity to the light and sound. We also experienced faults from the pulse oximeter when PX-UV was used adjacent to patient beds. To overcome these challenges, we provided goggles and earplugs to healthcare staff and ordered blackout curtains from the PX-UV vendor that hung inside

the privacy curtains during PX-UV operation. The blackout curtains worked well and eliminated the problems stated above.

Adding PX-UV disinfection to routine terminal cleaning after patient discharge increased the turn-around time of ICU beds by approximately 20 minutes. Manual cleaning by sodium hypochlorite solution took about 50 minutes, so the increase in time by adding PX-UV was not significant, and was well accepted by ICU staff and physicians as a routine workflow.

The effectiveness of PX-UV is expected to be maximized when environmental contamination is a major factor in transmission of the specific pathogen. In this context, pathogens such as *Clostridioides difficile* and multidrug-resistant *Acinetobacter* are more likely to be controlled. The effectiveness of PX-UV in controlling transmission of *Clostridioides difficile* is well studied and demonstrated[5-10], but that of *Acinetobacter* has not been well investigated.

Sporadic transmission of 2DRA has been observed in our ICU for the last five years. In Japan, antimicrobial resistance of *Acinetobacter* is not as serious. According to the Japanese national microbiological surveillance report, 97%, 97% and 87% of *Acinetobacter* isolates were reported to be susceptible to meropenem, amikacin and levofloxacin, respectively[11]. Therefore, most of the newly identified 2DRA in our hospital seemed to be acquired by horizontal transmission. Until mid-2018, this situation has not been well controlled, despite our efforts for elevated compliance to hand hygiene, strict contact precaution of patients with this pathogen, terminal cleaning using bleach, and in some occasions, restriction of new admission to the ICU. However, by introducing the PX-UV, transmission of 2DRA in the ICU halted. As of June 2019, no new isolation of 2DRA from patients in the ICU has been observed for 11 months (August 2018 to June 2019), nor in the non-ICU ward for 10 months (September 2018 to June 2019). We believe that PX-UV successfully decreased or eradicated the environmental *Acinetobacter* bioburden of not only the targeted ward (ICU), but also of the other wards. Anderson et al experienced a similar decrease in the transmission of MRSA and VRE throughout the ward by using ultraviolet light disinfection in only isolation rooms after patients with targeted pathogen were discharged[6].

The effectiveness of ultraviolet light disinfection is maximized when performed after every patient discharge from the targeted ward. In the only multicenter, randomized controlled study[6], ultraviolet disinfection was performed in only isolation rooms occupied by known MDRO or *C. difficile* colonization or infection. They did not observe any statistically significant effect on the incidence of MRSA and multidrug-resistant *Acinetobacter*. In contrast, we operated PX-UV after every patient discharge or transfer from the ICU, regardless of their colonization status, and obtained statistically significant reduction in the incidence of healthcare-associated transmission of MRSA and 2DRA. This difference may be because undetected carriers of MRSA or *Acinetobacter* could serve as a source of environmental contamination even under the operation of ultraviolet light disinfection in the targeted rooms.

Our study has several limitations. First, the effect of PX-UV was evaluated using historical controls when we were not using this technology. We have only one ICU in our hospital, so we were not able to have a non-intervention arm in this study. Second, not all MRSA or 2DRA identified were necessarily acquired in the ICU by horizontal transmission. However, we screened all patients on the day of their admission into the ICU and if they were positive for MRSA and/or 2DRA we regarded it as prior acquisition and excluded them from the acquisition in the ICU. Therefore, we believe that most of the identified MRSA and 2DRA in this study were acquired by horizontal

transmission. Third, the microbiological effect of PX-UV was evaluated by comparing the number of colonies from sampling the same frequently touched surface, but with different sites adjacent to each other. If there were significant differences in contamination between sites on the same surface, the result may not accurately reflect the effect of cleaning and PX-UV. We, however, believe that by sampling over 100 surfaces, we can minimize the effect by the heterogeneity of environmental contamination.

Conclusions

The addition of PX-UV to terminal cleaning successfully decreased the bioburden in the healthcare environment and led to the decrease of MRSA and drug-resistant *Acinetobacter* transmission in the ICU as well as in other wards of our hospital.

Abbreviations

multidrug-resistant organisms (MDROs)

pulsed xenon ultraviolet (PX-UV)

methicillin-resistant *Staphylococcus aureus* (MRSA)

vancomycin-resistant enterococci (VRE)

two-drug resistant *Acinetobacter baumannii* (2DRA)

intensive care unit (ICU)

colony-forming units (CFU)

Declarations

Ethics approval and consent to participate

The Yamagata University School of Medicine Institutional Review Board approved this study (reference number: H29-248) with a waiver of informed consent, based on this study's design which contains no direct intervention on patients and collects no data regarding patient identification.

Consent for publication

Not applicable

Availability of data and materials

The datasets generated and/or analysed during the current study are available in a GitHub repository, https://github.com/keitamorikane/BMCID.

Competing interests

KM declares that he has received honorarium from Terumo Corporation, which sells the PX-UV devices in Japan. The other authors declare that they have no competing interest.

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The Rodac plates were supplied from Xenex Disinfection Services.

Authors' contributions

KM collected and analysed all of the data in this manuscript. KM, SS, JY1 (Jun Yoshioka) and JY2 (Jun Yakuwa) established the operational logistics. JY1 and JY2 operated and maintained the PX-UV device. All authors read and approve the final manuscript.

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Tables

Table 1. MRSA and 2DRA Infection, by locations

– Jan 2018 period)	ICU MRSA	HCU MRSA	All Other Units MRSA	ICU 2DRA	HCU 2DRA	All other Units 2DRA
	4	5	44	14	13	17
ys	2852	6494	309512	2852	6494	309512
ncidence	13.84	7.64	1.23	48.5	20.2	0.55
– Feb ion	ICU MRSA	HCU MRSA	All Other Units MRSA	ICU 2DRA	HCU 2DRA	All other Units 2DRA
	2	3	31	4	3	7
ys	2102	4554	218907	2102	4554	218907
ncidence	9.89	6.60	1.41	18.10	6.46	0.31
hange	-28.5%	-13.6%	+14.6%	-62.6%	-68.0%	-43.6%

NOTE. ICU: intensive care unit, HCU: high care unit, MRSA: methicillin-resistant *Staphylococcus aureus*, 2DRA: two-drug resistant *Acinetobacter baumannii*

Table 2. Poisson models

	ICU MRSA	HCU MRSA	All Other Units MRSA	ICU 2DRA	HCU 2DRA	All other Units 2DRA
idence Rate io	0.71	0.86	1.14	0.37	0.31	0.56
% CI	0.57-0.88	0.65-1.12	0.62-2.12	0.32-0.43	0.25, 0.40	0.18-1.80
alue	0.002	0.283	0.663	<0.001	<0.001	0.338

NOTE. ICU: intensive care unit, HCU: high care unit, MRSA: methicillin-resistant *Staphylococcus aureus*, 2DRA: two-drug resistant *Acinetobacter baumannii*,

Table 3. Reduction in colony-forming units (CFU) from the environment

	Before Cleaning (A)	**After Cleaning** (B)	**After PX-UV** (C)
Total CFU	3,336	679	280
Median (IQR)	10 (2-30)	0 (0-2)	0 (0-1)
A vs B* (p-value)	—	79.6% (p<0.0001)	--
A vs C* (p-value)	–	--	91.6% (p<0.0001)
B vs C* (p-value)	—	—	58.7% (p=0.0213)

NOTE: IQR: Inter-quartile range, PX-UV: pulsed xenon ultraviolet

*Bonferroni correction used to adjust for multiple comparisons