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Major article

Evaluation of a pulsed xenon ultraviolet light device for isolation room disinfection in a United Kingdom hospital

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Background: Pathogen transmission from contaminated surfaces can cause hospital-associated infections. Although pulsed xenon ultraviolet (PX-UV) light devices have been shown to decrease hospital room bioburden in the United States, their effectiveness in United Kingdom (UK) hospitals is less understood.
Methods: Forty isolation rooms at the Queens Hospital (700 beds) in North London, UK, were sampled for aerobic bacteria after patient discharge, after manual cleaning with a hypochlorous acid–troclosene sodium solution, and after PX-UV disinfection. PX-UV device efficacy on known organisms was tested by exposing inoculated agar plates in a nonpatient care area. Turnaround times for device usage were recorded, and a survey of hospital staff for perceptions of the device was undertaken.
Results: After PX-UV disinfection, the bacterial contamination measured in colony forming units (CFU) decreased by 78.4%, a 91% reduction from initial bioburden levels prior to terminal cleaning. PX-UV exposure resulted in a 5-log CFU reduction for multidrug-resistant organisms (MDROs) on spiked plates. The average device turnaround time was 1 hour, with minimal impact on patient throughput. Ward staff were enthusiastic about device deployment, and device operators reported physical comfort in usage.
Conclusions: PX-UV use decreased bioburden in patient discharge rooms and on agar plates spiked with MDROs. The implementation of the PX-UV device was well received by hospital cleaning and ward staff, with minimal disruption to patient flow.

Health care–associated infections are estimated to cost the UK National Health Service (NHS) >£1 billion a year.[1] Infections caused by multidrug-resistant organisms (MDROs) and other hospital-associated infections (HAIs) are associated with increased morbidity and mortality and are among the many challenges faced by hospitals striving for better patient safety.[2] Despite the successes in the UK over the last decade in reducing the burden of some infections, such as *Clostridium difficile* infection and methicillin-resistant *Staphylococcus aureus* (MRSA) bloodstream infection, infection prevention and control continues to be challenging in hospitals. Austerity measures, increasing population demands for care, and emerging infection threats, such as from carbapenemase-producing *Enterobacteriaceae* (CPE), require innovative approaches to maintain quality and safety.

The environment provides a reservoir for pathogenic organisms and plays an important role in the transmission of infections, particularly in outbreak situations.[3,4] Therefore, decontamination of patient care areas is now considered to be vital in a comprehensive infection prevention and control program[5] and is critical in preventing transmission of norovirus and *C difficile*.[6]

There may be significant variation in the way manual cleaning with chemicals is performed and its effectiveness, partly because of the complexity of the environment in which these activities take

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place.[6-8] For instance, a study showed that up to 50% of high-touch surfaces within patient areas are often missed during chemical cleaning because of inaccessibility and human error.[9] Therefore, new technologies have begun to be investigated to help supplement the cleaning process with the intention of achieving better assurance of environmental decontamination.[10-13]

Multiple no-touch disinfection devices have been developed for environmental decontamination, and many of these systems are being suggested for adoption in health care facilities in the United States as part of standard decontamination protocols.[14,15] One such no-touch disinfection method involves ultraviolet in the C spectrum light-emitting devices, which use ultraviolet-C light between the wavelengths of 200 and 320 nm, the biocidal spectrum.[16]

Pulsed xenon ultraviolet (PX-UV) light devices (Xenex, San Antonio, TX) have been described previously and studies in the United States indicate microbiologic efficacy of the PX-UV device,[17-19] but the health care environment in the UK is challenging, with a decreasing hospital bed base and a need for faster patient discharges, less single rooms, and significant financial constraints. Therefore, the purpose of the current study was to evaluate the environmental efficacy and feasibility of using this no-touch technology within daily patient care activities in a UK hospital.

METHODS

This prospective study was conducted from July 2014-November 2014 at Queens Hospital (700 beds), a NHS hospital in the Barking, Havering, and Redbridge University Hospitals group in North London, UK, serving a population with a significant elderly proportion with many comorbidities. The study was approved by the hospital's research board. A convenience sample of 40 hospital rooms was selected for this study. Three main outcomes were studied: microbiologic efficacy of the PX-UV device on aerobic bacterial counts, time taken for disinfection, and staff attitudes to the new technology.

Microbiologic efficacy

A comparative study was designed to evaluate the efficacy of the PX-UV device in reducing environmental contamination in postdischarge patient isolation rooms by sampling 5 high-touch surfaces before standard terminal cleaning, after standard terminal cleaning, and after PX-UV disinfection. Patient rooms were selected from acute medical assessment units A and B (there were 6 rooms in each unit). The study rooms were identified through the infection prevention and control database and were selected for use by infection prevention and control staff. The inclusion criteria specified for the study rooms were as follows: (1) it must have been a single occupancy room, (2) it must have been occupied for a minimum of 48 hours, (3) it must have been recently vacated on the same day as the sample collection, and (4) it must have been used as a contact isolation room.

Once the room was identified, baseline microbiologic samples were collected after patient discharge but before standard terminal cleaning. Five high-touch surfaces (bedrail, bathroom handrail, tray table, toilet seat, and bathroom faucet handle) were sampled using 5-mm diameter Trypticase Soy Agar contact plates (Oxoid, Basingstoke, UK). For flat surfaces the press plate method was used,[20] and for curved surfaces a rolling plate technique was used to ensure coverage of the appropriate surface area. After the initial sampling, hospital cleaners performed standard terminal cleaning, using a 1,000 ppm (0.1%) chlorine disinfectant (Actichlor Plus; Ecolab, Cheshire, UK), prepared using 1 effervescent tablet mixed with 1 L of water to produce a hypochlorous acid disinfectant solution with detergent (troclosene sodium). Once the terminal cleaning was completed and surfaces were dry, the second set of environmental samples was collected. Finally, the PX-UV device was deployed and then subsequent environmental samples were taken from the same 5 surfaces. PX-UV device operators and cleaning staff were blinded to the chosen sampling surfaces to prevent any bias or changes in cleaning practices. After sample collection, the Trypticase Soy Agar contact plates were returned to the laboratory, incubated in air at 37°C for 48 hours, and enumerated per the manufacturer's recommendations with the number of colony forming units (CFU) being recorded. Aerobic bacteria, including MRSA, vancomycin-resistant enterococci (VRE), and CPE, will form colonies on Trypticase Soy Agar contact plates, but anaerobic bacteria such as *C difficile* will not.

In each hospital room, the PX-UV device was deployed for 3 cycles: two 5-minute cycles in the living room (1 cycle on each side of the patient bed) and one 5-minute cycle in the bathroom.

The efficacy of the PX-UV device was also evaluated by seeding agar plates with hospital clinical isolates of MRSA, VRE, multidrug-resistant *Acinetobacter*, and CPE. Suspensions of each organism were produced by inoculating the isolate into 5 mL of saline to McFarland turbidity 0.5-1.0. The Miles and Misra method[21] was used for dilution so that the CFUs postincubation could be counted by eye. Agar plates were divided into 6 equal sectors, and 20 μL of each dilution of organism was dropped onto the surface of separate sectors (ie, 1 agar plate had 6 dilutions for one of the test organisms.) Each drop was allowed to spread naturally, and plates were left upright on the bench to air-dry before inversion. In total, 3 sets of plates for each organism were prepared. One set of plates for each organism was immediately incubated once air-dried for 24 hours in air at 37°C as a control. The other 2 sets of plates for each organism were immediately taken to a sluice room (used for body fluid discard; also called a dirty utility room). The agar plates were placed at a surface 20 in above floor level adjacent to each other and at 1.2 m distance from the PX-UV device in the line of sight. One set of plates for each organism was kept covered (further control plate); the other was uncovered (test plate). All plates were exposed to PX-UV light for a 10-minute cycle. All plates were then incubated in air at 37°C for 24 hours.

Analysis of microbiologic samples

Means and frequencies described the total number CFU before and after standard terminal cleaning and after using the PX-UV device, overall and by surface location. Wilcoxon signed-rank tests were used to assess a change in CFU between baseline and after standard terminal cleaning for each surface location. Similarly, a change in CFU after standard terminal cleaning and after the PX-UV device use was assessed (Table 1). To examine a reduction in the presence of CFU with standard terminal cleaning versus no cleaning, or PX-UV disinfection versus standard terminal cleaning, the McNemar test was used to test the null hypothesis of marginal homogeneity. Evidence supporting the alternative hypothesis would suggest that one cleaning method was superior to the other (Table 2). For the seeded agar plates, CFU were recorded and CFU per milliliter were calculated (CFU/mL = number of colonies of a dilution × 50 × dilution factor).

Time studies

To determine the impact of the PX-UV device on isolation room decontamination times (and hence room availability), time studies of the movement and use of the device were conducted. A standard log was used to record when the device was collected from the storage area, how long the device was left waiting at the room before use, device in-use time, and device return time to storage.

Device transport time was standardized to represent the time it takes for the operator to walk from the storage area to the targeted

Table 1
CFU at baseline, after standard terminal cleaning, and after PX-UV disinfection, overall and by surface location (39 rooms)

Surface location	No. of pairs	Baseline, mean CFU ± SD, median (min-max)	Terminal clean, mean CFU ± SD, median (min-max)	PX-UV disinfection, mean CFU ± SD, median (min-max)	Terminal clean, reduction mean CFU ± SD, median (min-max), *P* value*	PX-UV disinfection, reduction mean CFU ± SD, median (min-max), *P* value†
Bedrail	28	16.2 ± 20.1, 9.0 (0-100)	1.6 ± 3.9, 0.0 (0-20)	0.5 ± 2.0, 0.0 (0-10)	14.6 ± 20.5, 6.0 (−2 to 100), <.01	1.1 ± 4.5, 0.0 (−10 to 20), .05
Tray table	39	9.6 ± 15.1, 3.0 (0-70)	2.6 ± 4.8, 0.0 (0-23)	0.5 ± 2.7, 0.0 (0-17)	7.0 ± 14.2, 2.0 (−6 to 67), <.01	2.1 ± 3.5, 0.0 (0 to 16), <.01
Bathroom handrail	39	11.6 ± 11.5, 9.0 (0-48)	9.6 ± 22.6, 3.0 (0-100)	1.5 ± 4.0, 0.0 (0-20)	1.9 ± 18.5, 2.0 (−73 to 28), .06	8.2 ± 22.1, 2.0 (−10 to 100), <.01
Toilet seat	39	31.2 ± 33.2, 19.0 (0-100)	12.4 ± 22.1, 4.0 (0-100)	5.0 ± 17.3, 0.0 (0-100)	18.8 ± 31.1, 10.0 (−40 to 100), <.01	7.4 ± 16.9, 1.0 (−23 to 70), <.01
Bathroom faucet	39	27.9 ± 33.9, 15.0 (0-100)	10.1 ± 15.4, 5.0 (0-70)	0.8 ± 2.1, 0.0 (0-8)	17.8 ± 29.7, 8.0 (−30 to 100), <.01	9.3 ± 15.4, 4.0 (−2 to 70), <.01
Combined	184	19.5 ± 26.1, 10.0 (0-100)	7.6 ± 16.8, 2.0 (0-100)	1.7 ± 8.5, 0.0 (0-100)	11.9 ± 24.6, 5.0 (−73 to 100), <.01	5.9 ± 15.0, 1.0 (−23 to 100), <.01

CFU, colony forming units; *max*, maximum; *min*, minimum; *PX-UV*, pulsed xenon ultraviolet.
*Change in CFU assessed with Wilcoxon signed-rank test, assuming a type I error of $\alpha = 0.05$ comparing baseline with post-terminal cleaning.
†Change in CFU assessed with Wilcoxon signed-rank test, assuming a type I error of $\alpha = 0.05$ comparing post-terminal cleaning with post-PX-UV disinfection.

Table 2
Proportion of samples with CFU present at baseline, after terminal cleaning, and after PX-UV disinfection, overall and by surface location (39 rooms)

Surface location	No. of pairs	Baseline, n (%)	Terminal clean, n (%), *P* value*	PX-UV, n (%), *P* value*
Bedrail	28	26 (92.9)	10 (35.7), <.01	2 (7.1), .01
Tray table	39	29 (74.4)	17 (43.6), <.01	3 (7.7), <.01
Bathroom handrail	39	32 (82.1)	23 (59.0), .02	7 (18.0), <.01
Toilet Seat	39	35 (89.7)	26 (66.7), .01	12 (30.8), <.01
Bathroom faucet	39	36 (92.3)	27 (69.2), .01	6 (15.4), <.01
Combined	184	158 (85.9)	103 (56.0), <.01	30 (16.3), <.01

CFU, colony forming units; *PX-UV*, pulsed xenon ultraviolet.
*Change in presence assessed with McNemar test, assuming a type I error of $\alpha = 0.05$.

Table 3
Description of CFU counts per sample

Surface	Status	n	Mean ± SD	Median (min-max)
Bedrail	Baseline	28	16.2 ± 20.1	9.0 (0-100)
	Manual	28	1.6 ± 3.9	0.0 (0-20)
	PX-UV	28	0.5 ± 2.0	0.0 (0-10)
Tray table	Baseline	39	9.6 ± 15.1	3.0 (0-70)
	Manual	39	2.6 ± 4.8	0.0 (0-23)
	PX-UV	39	0.5 ± 2.7	0.0 (0-17)
Bathroom handrail	Baseline	39	11.6 ± 11.5	9.0 (0-48)
	Manual	39	9.6 ± 22.6	3.0 (0-100)
	PX-UV	39	1.5 ± 4.0	0.0 (0-20)
Toilet seat	Baseline	39	31.2 ± 33.2	19.0 (0-100)
	Manual	39	12.4 ± 22.1	4.0 (0-100)
	PX-UV	39	5.0 ± 17.3	0.0 (0-100)
Bathroom faucet	Baseline	39	27.9 ± 33.9	15.0 (0-100)
	Manual	39	10.1 ± 15.4	5.0 (0-70)
	PX-UV	39	0.8 ± 2.1	0.0 (0-8)
Combined	Baseline	184	19.5 ± 26.1	10.0 (0-100)
	Manual	184	7.6 ± 16.8	2.0 (0-100)
	PX-UV	184	1.7 ± 8.5	0.0 (0-100)

CFU, colony forming units; *max*, maximum; *min*, minimum; *PX-UV*, pulsed xenon ultraviolet.

ward area with the PX-UV device. This transport time was recorded for every device deployment from storage facility to the target ward or room. In-room device use time was taken to also include any arranging of furniture. Of the sampled rooms, 31 had valid times recorded for each of the steps noted (Table 3).

Staff perceptions

A survey component was used to gauge staff attitudes toward the use of the new technology, including 3 device operators and 12 clinical ward staff members. Each of the surveys (one for operators and a separate survey for other staff) contained 4 Likert scale questions, ranging from responses of strongly disagree (or very difficult) to strongly agree (very easy). Agree-type responses (agree and strongly agree) were combined to denote whether or not staff agreed with the statement. Similarly, easy responses (easy and very easy) were combined to determine the ease of use for the PX-UV machine (Table 4). A type I error of $\alpha = 0.05$ was assumed throughout. All analyses were performed using SAS version 9.2 (SAS Institute, Cary, NC).

RESULTS

Patient rooms

One room was discarded from analysis for not having PX-UV disinfection information, reducing the sample to 39 rooms. Table 1 provides a summary of the recovered bioburden from the patient environment postdischarge, after standard terminal cleaning, and

Table 4
Time for PX-UV device deployment (31 rooms)

Process	Mean ± SD (min)	Median (min-max) (min)
Transport to room time	24.8 ± 17.9	20 (10-100)
Retrieval time	7.1 ± 3.2	5 (0-15)
Waiting time for use	17.7 ± 17.6	10 (5-90)
In-room use time	21.4 ± 15.4	20 (5-86)
Return to storage time	13.2 ± 16.8	6 (0-70)
Total time	59.4 ± 27.7	50 (35-135)

max, maximum; *min*, minimum; *PX-UV*, pulsed xenon ultraviolet.

Table 5
Survey responses from device operators (n = 3) and other clinical ward staff (n = 12)

Question	Agree
Device operator	
Q1. Moving machine (easy)	2 (66.7)
Q2. Set-up process (easy)	1 (33.3)
Q3. Comfortable using	3 (100)
Q4. Others commented	3 (100)
Clinical ward staff	
Q1. Use caused noise disturbance	0 (0.0)
Q2. Use caused disruption	0 (0.0)
Q3. Use impacted turnaround time	1 (8.3)
Q4. Patients commented on machine	7 (58.3)

NOTE. Values are n (%).
Q, question.

after PX-UV disinfection for the surface locations of bed rail, tray table, bathroom handrail, toilet seat, and bathroom faucet. The greatest reduction was observed for the toilet seat (median reduction, 10 CFU; $P < .01$), followed by the bathroom faucet (reduction, 8 CFU; $P < .01$). The use of PX-UV disinfection further reduced bioburden for the tray table, bathroom handrail, toilet seat, and bathroom faucet. The greatest reduction with PX-UV disinfection after terminal cleaning was observed for the bathroom faucet (median reduction, 4 CFU; $P < .01$), followed by the bathroom handrail (reduction, 2 CFU; $P < .01$).

Both standard terminal cleaning and PX-UV disinfection after terminal cleaning appeared to be effective in the reduction of rooms with any CFU present (Table 2). The greatest proportion of contaminated rooms at baseline was observed for bedrail surfaces (93%), which was reduced the most after terminal cleaning to 36%. PX-UV disinfection after terminal cleaning appeared to further decrease the proportion of rooms contaminated by at least half for all 5 surfaces (ranging from 54% for the toilet seat to 82% for the tray table).

Table 3 provides a description of CFU per sample. Average CFU for all sample sites were 19.5 (median, 10) CFU per contact plate (55 mm in diameter) at discharge. On standard terminal cleaning, average CFU per plate decreased 61% to 7.6 (median, 2) CFU per contact plate. After disinfection with the PX-UV device, the average CFU per plate decreased by 78% to an average of 1.7 (median, 0) CFU per plate, a 91% reduction from the initial levels.

Spiked plates in the sluice room

The control plates incubated directly at 37°C in air showed confluent growth of colonies. Similarly, the covered inoculated plates that were exposed to PX-UV disinfection (the cover blocks exposure to PX-UV) as previously described also showed confluent growth; however, the plates that were not shielded from PX-UV disinfection showed 1 colony of MRSA, 6 colonies of VRE, 7 colonies of multidrug-resistant *Acinetobacter*, and 3 colonies of CPE, indicating a 5-log reduction in colony counts on exposure to PX-UV light in the sluice room.

Time studies

Table 4 provides the time breakdown for specific tasks involved in PX-UV device use in room decontamination. The results recorded are from the perspective of the PX-UV device user and summarized by mean, median, and range. The median time for total PX-UV device deployment from retrieval to storage was 50 minutes. Retrieving and returning the device took approximately 5-6 minutes. Another 10 minutes were generally used for waiting to use the device. The actual PX-UV treatment time was approximately 20 minutes, which included rearranging furniture in the room and 3 locations for device use, taking up roughly one-third of the entire process.

Staff perceptions

Overall, cleaning staff were enthusiastic about PX-UV device usage and were willing to make adjustments to their existing schedules to accommodate its use. PX-UV operators all agreed that they felt comfortable using the device; two-thirds found moving the device easy, and one-third found the setup process to be easy (Table 5). Other hospital staff and patients were curious about the PX-UV device when it was seen in the clinical area, and they were supportive of its use after being given an explanation of its purpose.

None of the clinical ward staff felt the machine caused a noise disturbance or that it was disruptive to staff or patients. However, 1 staff member (8.3%) felt turnaround time was affected.

DISCUSSION

Increasingly, innovative no-touch disinfection devices are being used throughout health care arenas to provide more assurance of the cleanliness of hospital environments. The PX-UV device is one such no-touch disinfection device that is in use in the United States. However, there is limited published research on its implementation in the UK health care system. Our results demonstrate 3 main findings:

1. The failure of standard terminal cleaning (combined manual cleaning and chemical disinfection) of isolation rooms to adequately remove microbial contamination from the environment.
2. The PX-UV system significantly reduced microorganisms from common high-touch surfaces within patient isolation rooms and associated bathrooms.
3. The PX-UV device was easily incorporated into terminal decontamination protocols for isolation rooms within busy clinical areas and did not adversely affect patient throughput.

It is now accepted that a cleaner patient environment can reduce HAIs by reducing microbial contamination with less transmission of pathogens including MDROs to patients.[5] This is of particular importance when considering an isolation room because a new occupant may acquire pathogens from the environment whose original source was a previous occupant.[22] Our findings show that the initial bioburden recorded at 5 high-touch surfaces was reduced by terminal cleaning and further reduced by PX-UV application. When all sample locations were compiled, bioburden was reduced from a mean precleaning level of 19.5 CFU per contact plate to 7.6 after terminal cleaning and to 1.7 after PX-UV use, equivalent to a 61% reduction by terminal cleaning alone and a 78% reduction after PX-UV disinfection. The toilet seat and bathroom faucet showed the greatest reduction in bioburden overall. These findings could have particular significance when considering patients displaying symptoms of *C difficile* infection because these high-touch areas would

be suspected to be contaminated with the bacteria and spores; however, *C difficile* was not investigated as part of this study. The activity of the PX-UV device against MDROs was undertaken in a sluice room where the environment was expected to be heavily contaminated prior to exposure, rather than a patient care area, as in another study,[23] which could compromise patient safety through exposure to live cultures. There was a 5-log reduction in MDRO bacterial counts after the use of the PX-UV device for 10 minutes, highlighting the potential effectiveness against these significant causes of HAI that could contaminate the hospital environment.

The enhanced level of disinfection was achieved during everyday hospital operations with negligible interruption to patient care and flow. Hospital cleaning staff were able to effectively incorporate the PX-UV device as a no-touch disinfection approach into daily routine practice.

There are a few unique aspects to this study. Most previous studies conducted with PX-UV devices have been performed in the United States; this one however was conducted in the UK. This creates distinctive variables when compared with previous studies, including differences in hospital room layout, cleaning protocols, and hospital populations. With all of these local variables, the PX-UV device was shown to be effective at decreasing the bioburden in hospital isolation rooms. The results experienced in our study are similar to bioburden decrease seen in U.S. studies.[14,15,18,19,24,25] The pressure for beds in the UK NHS also necessitates that isolation room decontamination must be both quick and effective to maintain patient flow without compromising patient safety. Therefore, rapid and effective decontamination of an empty patient room was a key consideration of hospital ward staff as part of this study, particularly when considering, generally, isolation rooms are fewer in number in UK hospital wards compared with the United States.

Previous studies have discussed the time taken to run the device, but this study was able to record total retrieval to storage time as approximately 1 hour, with the PX-UV device use taking 20 minutes of the total time. The utilization of the device did not significantly increase the time taken to terminally decontaminate isolation rooms, and this was supported by the feedback from clinical ward staff with overall opinion of the device being relatively high—only 1 staff member reported that room turnaround time was affected on what were the most busy hospital wards.

Improvements could focus on strategic placement of devices to reduce transport time and nondisinfection and idle time if incorporation into standard hospital practice was considered. *C difficile* was not included as a specific pathogen in this study; when considering the demographics of the population the study hospital serves, this could provide valuable data. The use of the PX-UV device in multioccupancy ward settings should also be investigated, particularly in outbreaks when patients are cohorted into 4-6 patient occupancy ward bays. Our study is limited in the number of staff surveyed, and this is an area for future exploration. This study shows that no-touch, PX-UV device usage could be translated to a different health setting, which may bear consideration because MDROs pose an international threat.

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