Non-inferiority of pulsed xenon UV light versus bleach for reducing environmental *Clostridium difficile* contamination on high-touch surfaces in *Clostridium difficile* infection isolation rooms

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The standard for *Clostridium difficile* surface decontamination is bleach solution at a concentration of 10 % of sodium hypochlorite. Pulsed xenon UV light (PX-UV) is a means of quickly producing germicidal UV that has been shown to be effective in reducing environmental contamination by *C. difficile* spores. The purpose of this study was to investigate whether PX-UV was equivalent to bleach for decontamination of surfaces in *C. difficile* infection isolation rooms. High-touch surfaces in rooms previously occupied by *C. difficile* infected patients were sampled after discharge but before and after cleaning using either bleach or non-bleach cleaning followed by 15 min of PX-UV treatment. A total of 298 samples were collected by using a moistened wipe specifically designed for the removal of spores. Prior to disinfection, the mean contamination level was 2.39 c.f.u. for bleach rooms and 22.97 for UV rooms. After disinfection, the mean level of contamination for bleach was 0.71 c.f.u. ($P=0.1380$), and 1.19 c.f.u. ($P=0.0017$) for PX-UV disinfected rooms. The difference in final contamination levels between the two cleaning protocols was not significantly different ($P=0.9838$). PX-UV disinfection appears to be at least equivalent to bleach in the ability to decrease environmental contamination with *C. difficile* spores. Larger studies are needed to validate this conclusion.

BACKGROUND

Environmental contamination has been identified as an important factor for the transmission of *Clostridium difficile* (Cristina *et al.*, 2013; Weber *et al.*, 2013). According to current *C. difficile* control guidelines, rooms previously occupied by patients with *C. difficile* infection (CDI) should be cleaned with an Environmental Protection Agency-approved disinfectant that is registered as effective against *C. difficile* (Cohen *et al.*, 2010; Dubberke, 2012; Carrico *et al.*, 2013). Thorough cleaning of these rooms is essential, but is often difficult to achieve on multiple surfaces and complex equipment. *C. difficile* endospores have been found to survive up to 5 months in a hospital environment (Cohen *et al.*, 2010; Hacek *et al.*, 2010; Carrico *et al.*, 2013). *C. difficile* has also been shown to be resistant to alcohol-based disinfectants and quaternary ammonium compounds, and some detergents may even encourage sporulation of this organism (Fraise, 2011).

The most common disinfectant used for *C. difficile* is a 1 : 10 dilution of sodium hypochlorite (bleach). Terminal cleaning with bleach of rooms once occupied by patients with CDI has shown a significant reduction in the rate of nosocomial CDI (Hacek *et al.*, 2010). Although effective when applied for the correct dwell times, long-term use of bleach may cause corrosion, harmful effects on some metals and pitting of equipment and other surfaces (Carrico *et al.*, 2013). Bleach also produces fumes that have led to respiratory complaints from environmental service workers and may also cause irritation to mucous membranes as well as emitting odour (Carrico *et al.*, 2013).

Germicidal UV irradiation has been shown to be effective in deactivating *C. difficile* endospores in laboratory and clinical settings (Nerandzic *et al.*, 2010; Rutala *et al.*, 2010; Stibich *et al.*, 2011). Specifically, the UV-C frequency, which ranges from 200 to 280 nm, is known to have germicidal properties through a variety of mechanisms, including photodimerization, photohydration, photo cross-linking, and photoseparation (Rutala *et al.*, 2010; Stibich *et al.*, 2011). Pulsed xenon UV (PX-UV) is a means of quickly producing

Abbreviations: CDI, *C. difficile* infection; PX, pulsed xenon.

germicidal UV that has been shown effective against *C. difficile* (Stibich *et al.*, 2011). PX-UV light may have greater efficacy than other forms of UV, such as mercury UV, against *C. difficile* because of the broad spectrum produced within the UV-C range and a greater intensity (Levin *et al.*, 2013; Qureshi & Yassin, 2013; Rutala & Weber, 2013). PX-UV technology has been associated with a reduction in facility-wide *C. difficile* rates (Levin *et al.*, 2013).

The purpose of the current study was to assess whether PX-UV cleaning and bleach were equivalent in terms of reducing environmental *C. difficile* contamination and to determine whether PX-UV could be an alternative to corrosive chemicals for the disinfection of *C. difficile* infection isolation rooms in the clinical setting.

METHODS

The study was conducted at a major comprehensive cancer centre in the United States. The environmental surfaces in 30 *C. difficile* infection isolation rooms were sampled immediately after patients with a CDI were discharged. Five surfaces in each room were sampled before being cleaned, and the same five surfaces were sampled after being cleaned via one of two protocols.

In the first arm of the study, 15 rooms were cleaned according to the standard protocol, which included bleach disinfection. In the second arm, 15 rooms were visually cleaned without bleach and then disinfected using a PX-UV device (Xenex Disinfection Services). After the samples were collected post PX-UV clean, these 15 rooms were again cleaned with bleach disinfection to be in accordance with the standard cleaning protocol. The samples were taken from the following five surfaces: (1) the bathroom handrail, horizontal/vertical surface facing into the room; (2) the bed control panel, on the side facing the door; (3) the bedrail, at the midpoint upper surface; (4) the top of the bedside table, near the centre; and (5) an IV pump control panel or other equipment control panel, when available.

Disinfection arm 1: bleach. Rooms were visually cleaned using an activated hydrogen peroxide disinfectant and then with bleach at a concentration of 10 % of sodium hypochlorite according to guidelines published by the Society for Healthcare Epidemiology of America (Cohen *et al.*, 2010).

Disinfection arm 2: PX-UV light. After a visual cleaning using an activated hydrogen peroxide disinfectant and without bleach, a PX-UV device was placed in the bathroom and on both sides of the bed and then run for 5 min in each position (Fig. 1).

Device description. The PX-UV device contains a xenon flash lamp that emits a broad spectrum of light covering the germicidal, or UV-C, spectrum of 200–280 nm as well as the visible light spectrum (Nerandzic *et al.*, 2010). The device weighs approximately 150 lb (68 kg) and has dimensions of 20 in (51 cm) wide by 30 in (76 cm) long by 38 in (97 cm) high. The PX-UV system produces a pulsed flash at a frequency of 1.5 Hz with an approximate output of 505 J per pulse and duration of less than 360 μs. The device is typically operated by housekeeping personnel and includes safety features such as motion sensors. The operating time for the device for *C. difficile* deactivation is 5 min per position for a total of three positions based on the average size of each room at our institution.

Laboratory analysis. Environmental samples were taken from five high-touch surfaces in rooms in which the previous occupant had been diagnosed with CDI. Briefly, sponges were moistened with 1 ml of sterile normal saline (0.9 %, w/v, NaCl) and used (with sterile gloves) to scrub the surfaces. The sponge was then placed in a 50 ml conical tube containing 10 ml sterile 10 % (v/v) Dey–Engley neutralizing broth (Difco, BD) and refrigerated. The contents of each tube were passed through a 0.45 μm membrane filter (EMD Millipore). Each tube was washed two additional times with 30 ml sterile PBS, and each wash volume was passed through the same membrane filter. The membrane filter was placed directly onto *C. difficile* agar supplemented with 7 % horse blood, 0.5 g l^{-1} cycloserine, 0.016 g l^{-1} cefoxitin, 1 g l^{-1} taurocholate and 10 mg l^{-1} lysozyme. All enumeration plates were incubated anaerobically for 48 ± 4 h at 36 ± 1 °C. Samples demonstrating growth were morphologically compared with *C. difficile* (ATCC 43598) grown on the same membrane filter type. Alternatively, samples demonstrating growth were subcultured onto supplemented *C. difficile* agar, incubated anaerobically, compared with *C. difficile* (ATCC 43598), and subjected to Gram staining for confirmation. The c.f.u. were determined by directly counting the colonies on each filter. Each filter represented one submitted sample (e.g. sponge), and more than 100 colonies were determined to be too numerous to count.

Ethics. Ethical approval was not sought because this was a study evaluating the performance of two cleaning protocols.

Statistical analysis. Because a non-parametric distribution of the data was likely, the Wilcoxon rank-sum test was used to compare the mean *C. difficile* colony counts for the bleach and PX-UV disinfected rooms.

RESULTS

In the pre-disinfection period, 26 of 74 samples were positive for *C. difficile* (mean 2.39 c.f.u.) in the bleach arm. After disinfection with bleach, 18 of 74 samples were positive (mean 0.71 c.f.u.), a decrease of 70 % ($P=0.1380$). In the PX-UV disinfection arm, 34 of 75 samples were positive (mean 22.97 c.f.u.). This decreased to 18 samples (mean 1.19 c.f.u.) after PX-UV disinfection, a significant reduction of 95 % in the level of environmental contamination as measured by bacterial load ($P=0.0017$).

Because five of the samples in the pre-group were outliers and created high leverage in favour of the UV device, an analysis was done with these outliers removed, and the
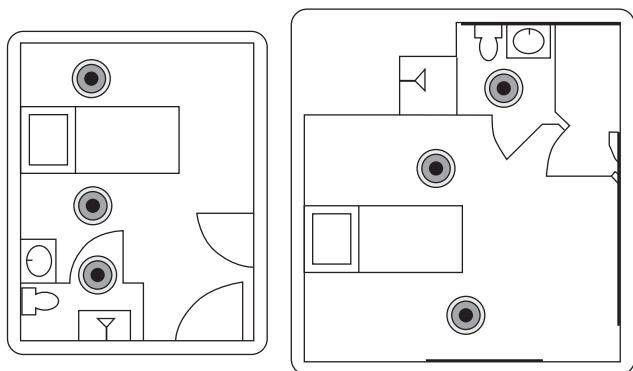

Fig. 1. PX-UV device positions.

Table 1. Impact of standard cleaning and PX-UV disinfection on *Clostridium difficile* counts in patient rooms

Room status	Samples taken (*n*)	Samples positive for *C. difficile* [*n* (%)]	c.f.u.					Reduction (%)	*P*-value
			Min.	Mean	Median	Max.	IQR		
Pre-bleach cleaning	74	26 (35)	0	2.39	0	81	11	70	0.13
Post-bleach cleaning	74	18 (24)	0	0.71	0	18	0		
Pre-PX-UV Cleaning	70	29 (41)	0	4.61	0	71	2	83	0.007
Post-PX-UV	70	16 (23)	0	0.80	0	13	0		

IQR, Interquartile range.

results are shown in Table 1. In the pre-disinfection period, 29 of 70 samples were positive for *C. difficile* (mean 4.61 c.f.u.) in the PX-UV (Table 1). After disinfection with PX-UV, 16 of 70 samples were positive (mean 0.80 c.f.u.), a decrease of 83 % (*P*=0.007).

Outcomes of the two methods of environmental cleaning were compared using the Wilcoxon–Mann–Whitney two-sample rank-sum test (12 observations in 2012 for bleach alone and 12 in 2013 for PX-UV alone), which confirmed the equivalence of these two methods of cleaning (*z*=0.058).

DISCUSSION

The current study shows that PX-UV disinfection appears to be equivalent to bleach in decreasing environmental contamination with *C. difficile* spores. The pre-disinfection *C. difficile* contamination level in the second arm was approximately 8.6 times higher than that in the bleach arm, although the reason for this difference in c.f.u. is unclear.

The study is limited by the small sample size and the targeted nature of the surface sampling. An additional limitation is the use of a customized laboratory protocol that, although validated in the laboratory, could have introduced additional variables.

In summary, both methods of disinfection, bleach and PX-UV light, produced equivalent results in reducing the level of *C. difficile* contamination in patient rooms. PX-UV technology may be an attractive alternative to bleach for the disinfection of *C. difficile* environmental surfaces. Other technologies, such as the use of hydrogen peroxide vapour (HPV) for decontamination, have also been investigated for decontaminating rooms occupied by patients with CDI (Boyce *et al.*, 2008; Zoutman *et al.*, 2011; Passaretti *et al.*, 2013). In spite of showing some promise in eliminating *C. difficile* from the room surfaces (Boyce *et al.*, 2008), the HPV method has some drawbacks. The time taken for disinfection is between 2 and 4.5 h, which may present a real challenge for routine use, especially when a rapid bed turnaround time is necessary (Otter *et al.*, 2009). Environmental cleaning with HPV is also an intensive procedure requiring specialized personnel and equipment, increasing the operational costs of using this method (Blazejewski *et al.*, 2011). On the other hand, one of the limitations of the UV technology when compared with HPV is that the former does not disinfect evenly throughout a room, with areas in shadow receiving a smaller dose than directly exposed areas. This could be lessened by manually moving the PX-UV device to two or three locations within each room.

PX-UV technology can be easily incorporated in routine environmental decontamination and has a potentially faster turnaround time than either HPV or bleach. In staff time, HPV costs approximately $175 per room (Doan *et al.*, 2012). It takes approximately 45 min to clean a room with bleach and 15 min with PX-UV, resulting in staff savings (Boschert, 2012). The PX-UV device costs approximately $3000 per month and can disinfect more than 30 rooms per day at a per-room cost of approximately $3 excluding labour costs. Five-year materials damage testing has not indicated that PX-UV causes any kind of damage to materials in hospital settings.

Additional studies on a larger scale are needed to verify these findings and to determine their impact on CDI rates.

ACKNOWLEDGEMENTS

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