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Pulsed-xenon ultraviolet light disinfection in a burn unit: Impact on environmental bioburden, multidrug-resistant organism acquisition and healthcare associated infections

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ABSTRACT

Portable pulsed xenon ultraviolet disinfection (PPX-UVD) may reduce healthcare associated infections (HAI). There is limited data to inform use in burn intensive care units (BICU), where multidrug-resistant organisms (MDRO), especially gram negative rods (GNR), commonly cause disease. We evaluated PPX-UVD effects on environmental bioburden and rates of HAI and MDRO acquisition in a BICU. PPX-UVD was used for 3 months after standard cleaning of patient and operating rooms (ORs). Settle and touch plates in patient rooms and ORs were obtained after standard cleaning, pre-and post-PPX-UVD. HAI and MDRO acquisition were evaluated 1 year prior to and for 3 month periods before, during, and after PPX-UVD. 110 touch and settle plates (33 pre- and 30 post-PPX-UVD) were obtained after standard cleaning, pre- and post-PPX-UVD. After PPX-UVD, environmental samples with any growth decreased (48% vs 31%, p=0.02), as did mean colony count/sample (2.8 pre- vs 1.6 post-, p=0.03). The 379 colonies largely represented skin commensals, without identified MDRO. Following PPX-UVD, no changes in device-associated infections, overall MDRO, or MDR GNR were seen, though a prolonged interval without healthcare-associated *Clostridium difficile* infection was observed. PPX-UVD in a BICU reduced overall environmental bioburden, without a statistically significant impact on HAI or MDRO.

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Abbreviations: PPX-UVD, portable pulsed xenon ultraviolet disinfection; HAI, healthcare associated infections; BICU, burn intensive care unit; MDRO, multidrug-resistant organisms; GNR, gram negative rods; CDI, *Clostridium difficile* infection; NHSN, National Healthcare Safety Network; UVC, Ultraviolet-C; MRSA, methicillin-resistant *S. aureus*; VRE, vancomycin-resistant enterococci; HA-CDI, healthcare-associated *Clostridium difficile* infections; CLABSI, central line associated bloodstream infection; CAUTI, catheter associated urinary tract infection; VAP, ventilator associated pneumonia; BAL, bronchoalveolar lavage; OBD, occupied bed days.

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1. Introduction

Healthcare associated infections (HAI) are a major cause of morbidity and mortality worldwide. Critical illness and disruption of host defense mechanisms place burn patients at high risk of infections, particularly with gram negative rods (GNR), including multidrug-resistant organisms (MDRO) [1]. Infections account for the majority of deaths in patients who survive initial resuscitation [2,3]. National Healthcare Safety Network (NHSN) data report higher baseline rates of HAIs in burn units compared to other types of intensive care units (ICUs) [4]. *Staphylococcus aureus* and GNR pathogens including *Pseudomonas aeruginosa*, *Acinetobacter baumannii*, and *Klebsiella pneumoniae* are commonly associated with infections in this population, with increasing rates of resistance over the course of hospitalization [5,6]. *Clostridium difficile* infection has historically been less common in this center's burn environment compared to other units, although rates have increased in recent years with introduction of PCR assays as well as changes in patient demographics to include more civilian transfer patients with complex wounds [7].

There has been much interest in the development of effective environmental disinfection strategies to prevent HAIs [8]. Contaminated surfaces act as reservoirs for pathogens, which can then be transmitted to patients. It is estimated that 20% of HAI may be driven by cross-transmission from the hospital environment, though these estimates may not apply to burn units, where patients' wounds and the widespread use of invasive devices lead to high colonization and infection rates [9]. In a previous evaluation of environmental bioburden in this center's burn unit, organisms have been cultured from 76% of environmental surfaces in occupied patient rooms [10]. A recent evaluation of airborne bacteria in a burn unit demonstrated significant dispersion created by bed and dressing changes, and numerous burn outbreak investigations have documented widespread environmental contamination with outbreak-strains of GNR including *A. baumannii* and *P. aeruginosa* [11–13]. Standard terminal cleaning involves manual application of chemicals to surfaces, which has numerous limitations, is prone to error, and up to 50% of surfaces may not be adequately disinfected during standard cleaning protocols [14]. Ultraviolet-C (UVC) light is broadly active against HAI pathogens, and no-touch devices using UVC generated by mercury or pulsed-xenon bulbs are becoming increasingly used as adjuncts to manual cleaning. Evaluations of UVC disinfection have demonstrated reductions in environmental pathogens, including methicillin-resistant *S. aureus* (MRSA), vancomycin-resistant enterococci (VRE) and *C. difficile* from hospital environment surfaces [15,16].

Clinical data have also demonstrated reductions in infectious complications following implementation of UVC disinfection. One evaluation of UVC light disinfection hospital-wide resulted in a 53% reduction in healthcare associated *C. difficile* infections (HA-CDI), and another demonstrated a 70% reduction in HA-CDI cases in the ICU [17,18]. Another study demonstrated an 87% reduction in ICU VRE rates, and a combined MDRO (including VRE, MRSA, and *C. difficile*) rate reduction of 61% [19]. However, no published data exist to date reporting on efficacy of portable pulsed-xenon ultraviolet disinfection (PPX-UVD) in burn units, either for reductions in environmental contamination or toward HAI or MDRO acquisition. Similarly, the role of PPX-UVD in reducing gram-negative infections has not been specifically evaluated.

2. Material and methods

The study entailed 2 aims. The primary aim was an evaluation of surface and air microbial contamination in inpatient rooms and ORs within an American Burn Association accredited burn center after standard cleaning, then before and after use of PPX-UVD. The secondary aim was an assessment of NHSN-defined HAI rates, MDRO acquisition, and clinical bioburden; the latter defined as all positive bacterial cultures from BICU patients in the time frames of interest. PPX-UVD was delivered after routine housekeeping disinfection via a device (Xenex Healthcare Services, San Antonio, TX) containing a xenon flash lamp emitting both the germicidal light spectrum of 200–280 nm UVC light as well as the visible light spectrum. Typical cycle lengths were five minutes, with four positions per patient room/anteroom/bathroom combination and two for shower rooms/ancillary areas. Cycle lengths were ten minutes for ORs with two positions per room. PPX-UVD was used in patient rooms when vacated for a procedure and after discharge, and in ORs/shower rooms/ancillary areas daily.

The burn unit contains 16 ICU patient beds and provides regional and referral burn care including patients transferred from overseas for their injuries. Patients predominantly are admitted for thermal injury, although there are occasional admissions for trauma or medical illness which undergo specialized wound care. Patients injured overseas generally arrive about 4 days after their injuries are sustained, while local and regional referrals present hours to days after burn. Standard care includes early resuscitation followed by wound excision and grafting. Vancomycin and amikacin are routinely used perioperatively, with topical antibiotics per staff discretion. Other routine infection control measures include private rooms, universal contact precautions, and strict hand hygiene. Central lines are routinely exchanged every five days or earlier if there is concern for infection. The burn center has dedicated housekeeping staff. Patient care equipment is cleaned after use with hospital approved disinfectants. Housekeeping cleans the room with approved disinfectants at least once per shift. At discharge or upon transfer to another unit, the patient room is cleaned in its entirety with a hospital approved disinfectant, including with a hospital approved bleach product if the occupying patient had CDI. Burn showers are also cleaned after each use.

2.1. *Assessment of environmental microbial contamination*

Inpatient rooms (n=9) and ORs (n=2) were evaluated at the beginning of a 3 month intervention period using PPX-UVD throughout the ICU. Bacterial contamination levels were assessed on 5 high-touch surfaces in inpatient rooms (bedrail, bathroom handrail, bedside monitor, documentation station, and door handle) and in ORs (OR table, back table, anesthesia machine, supply cabinet doors, and documentation station)

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after standard terminal cleaning and again after PPX-UVD. Microbiologic sampling using contact and settle plates was performed in inpatient rooms after terminal cleaning the day of discharge, with the discharged patient having occupied the room for a minimum of 48 h. In ORs, sampling with contact and settle plates occurred after terminal cleaning following ≥1 completed procedure within the previous 24 h.

The difference in organism recovery from high touch surfaces was examined using MacConkey agar contact plates (Hardy Diagnostics, Santa Maria, California, product number: P47). The contact plates were incubated for 48 h and read according to manufacturer's instructions. The difference in airborne contamination in inpatient rooms and ORs was evaluated using 3 TSA agar petri dishes ("settle plates") positioned as closely as possible to patient care spaces without disrupting provision of care. Each plate was left uncovered for 8–12 h, then covered and incubated for 48 h and read according to manufacturer's instructions.

Contact plates and settle plates were collected on-site and evaluated at Central Texas Veterans Health Care System, Olin E. Teague Veterans' Medical Center, Temple, Texas. Colonies were counted and underwent basic identification based on morphology/gram stain, with further workup (speciation, susceptibilities) performed if the isolate was consistent with a potential HAI pathogen, defined as *S. aureus*, *Enterococcus* spp., or any GNR.

2.2. Assessment of HAI rates, MDRO acquisition, and clinical bioburden

NHSN-defined HAI rates and MDRO acquisition in the burn ICU, as monitored routinely by infection prevention and without any links to individual patient information, were also assessed. The HAI data included all device associated infections, to include central line associated bloodstream infections (CLABSI), catheter-associated urinary tract infections (CAUTI), and ventilator-associated pneumonias (VAP), expressed as number of events per 1000 device days. MDRO acquisition was defined per NHSN criteria, including both incident colonization and infection, and both HAI rates and MDRO rates were collected via standard institutional surveillance policies [20,21]. A "clinical bioburden" endpoint (including positive cultures from the BICU, not excluding duplicates, and obtained during the study periods) was evaluated as an approximation of colonization and infection in BICU patients and as an assessment of pressures which might impact MDRO rates. These data were generated via electronic health record query of all BICU bacterial cultures from any site (surveillance, respiratory, bronchoalveolar lavage (BAL), wound, blood, body fluid, stool, urine, etc.) and *C. difficile* stool PCR results obtained from de-identified BICU patients during the study periods. Unit census data was obtained to generate a rate of positive cultures per 1000 occupied bed-days. In evaluation of HAI, MDRO acquisition, and clinical bioburden, 3 month study periods were assessed, to include a pre-intervention control period 1 year prior to the intervention (December 2013–February 2014), an immediate pre-intervention control (September 2014–November 2014), the intervention period itself from December 2014 to February 2015 (after a 2-week wash-in period during which device use was inconsistent, and including a 2-week wash-out period after discontinuation), and an immediate post-intervention control (March 2015–May 2015).

2.3. Primary data analysis

Basic descriptive statistics were used to summarize the findings. Categorical variables were compared by chi-squared testing or Fisher's exact test where appropriate. Statistical significance was set at $p < 0.05$ (two tailed). Statistical analysis was performed using existing software (SPSS, version 19.0, IBM SPSS).

3. Results

3.1. Microbiology data

Nine inpatient rooms and 2 ORs had air (n=63) and surface sampling (n=110) before and after PPX-UVD (Table 1). Prior to PPX-UVD, samples from bathroom hoppers, bedside monitors and door handles were most heavily contaminated. After PPX-UVD, total samples (including both touch and settle plates) with any growth significantly decreased (48% vs 31%, p=0.02), as did surface growth alone (51% vs 33%, p=0.05). Including both air and surface samples, mean microbial density (heterotrophic plate count) per sample was tabulated prior to PPX-UVD as 2.75 colonies/sample. After PPX-UVD, mean microbial density was reduced to 1.61 colonies/sample (p=0.03) (Fig. 1).

3.2. Environmental bioburden

A total of 379 colonies were isolated from air and environmental surfaces (Table 2). All but 4 bacteria were consistent with skin commensals. Two colonies of mold were grown. Neither of the 2 GNR, *Sphingomonas paucimobilis* and *Moraxella osloensis*, were common HAI pathogens or MDRO.

3.3. NHSN-defined HAI and MDRO

Comparing VAP, CLABSI, and CAUTI rates during the intervention period to combined rates from control periods, no statistically significant changes in the rates of these device-associated HAI were observed, either individually, or as a combined endpoint including total numbers of device-associated infections/1000 device-days (Table 3).

There was no significant decrease in the overall acquisition of MDRO or MDR GNR, following introduction of PPX-UVD (Table 4). However, after introduction of PPX-UVD, the BICU experienced the longest interval without HA-CDI between 2013 and 2015. The median time between HA-CDI cases from February 2013 through December 2014, when PPX-UVD began, was 65.5 days (range 2–148); following the PPX-UVD intervention, the next HA-CDI did not occur for 290 days following the previous case. During this time, HA-CDI cases in the rest of the hospital remained stable. Though no cases in the BICU were observed during the intervention and three month post-intervention period, this decrease did not achieve statistical significance.

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Table 1 – Review of number of colonies and percentages of plates with growth before and after portable pulsed-xenon ultraviolet light disinfection (PPX-UVD).

	Pre-PPX-UVD (# colonies)	N (%) with any growth	Post-PPX-UVD (# colonies)	N (%) with any growth	p value (any growth)
Surface samples (touch plates)					
Operating room (n=2)					
Anesthesia machine	0	0	0	0	
Back table	2	1 (50%)	0	0	
Cabinet	2	1 (50%)	5	2 (100%)	
Documentation station	1	1 (50%)	2	1 (50%)	
Table	2	1 (50%)	0	0	
Inpatient rooms (n=9)					
Bathroom hopper	37	6 (67%)	28	6 (67%)	
Bedrail	3	3 (33%)	3	2 (22%)	
Bedside monitor	97	2 (22%)	1	1 (11%)	
Documentation station	10	7 (78%)	6	3 (33%)	
Door handle	65	6 (67%)	78	3 (33%)	
Air samples (settle plates)					
Operating room (n=6)	2	2 (33%)	1	1 (17%)	
Inpatient rooms (n=27 before, n=24 after)	21	12 (44%)	13	7 (29%)	
Surface totals (n=110)	219	28 (51%)	123	18 (33%)	0.05
Air totals (n=63)	23	14 (42%)	14	8 (27%)	0.19
Total	242	42 (48%)	137	26 (31%)	0.02

3.4. *Clinical bioburden data*

All positive clinical bacterial cultures obtained from de-identified BICU patients were assessed during 3 month intervals 1year prior to, 3 months prior to, during, and after trial of PPX-UVD (Table 5). During the intervention period, there was a significant decrease in total MDRO per 1000 occupied bed days (OBD) (p=0.03), apparently largely driven by an unusually high number in the post-intervention period. During the intervention period, there were trends toward reductions in percentage of MDRO among all bacteria (p=0.07) as well as the rate of MDR GNR per 1000 OBD (p=0.07). There were 2 clinical samples positive for *C. difficile* in the initial 2-week wash-in period of PPX-UVD use, and another community-associated case halfway through the intervention period, with none in the post-intervention period.

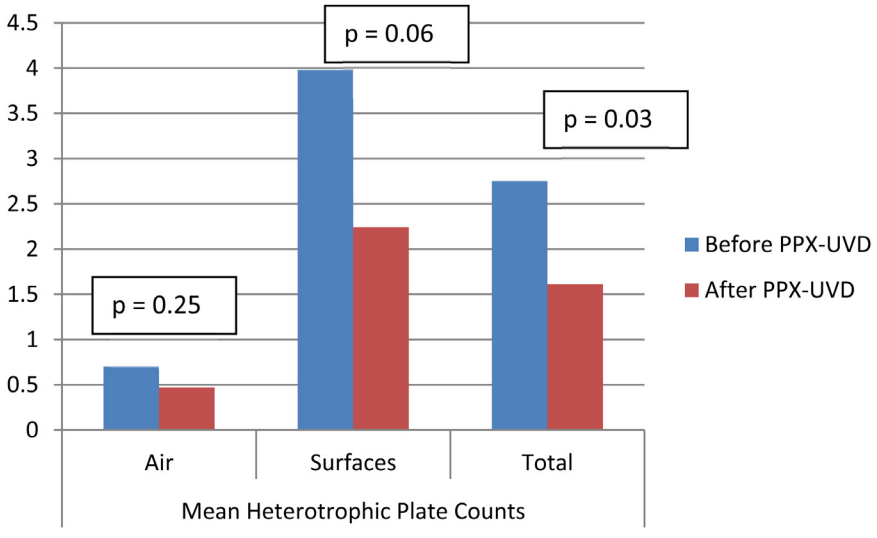

Fig. 1 – Mean heterotrophic plate counts pre- and post-PPX-UVD.
Mean heterotrophic plate counts from air (n=33 settle plates before portable pulsed-xenon ultraviolet light disinfection [PPX-UVD] and n=30 after PPX-UVD) and surfaces (n=55 touch plates both before and after PPX-UVD), as well as total plates (n=88 before PPX-UVD and n=85 after PPX-UVD).

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Table 2 – Organisms isolated from surfaces and air (touch and settle plates), total number of colonies of each organism, and source of cultures positive for each organism.

Organism	# Total colonies	Sites (n from each site)
Bacillus spp.	9	Air (3) Bathroom hopper (2) Bedrail (1) Documentation station (2) Door handle (1)
Coagulase negative staphylococci	329	Air (24) Bathroom hopper (57) Bedrail (2) Bedside monitor (98) Cabinet (1) Documentation station (12) Door handle (135)
Micrococcus spp.	8	Air (2) Door handle (6)
Corynebacterium aurimucosum	1	Air
Dietzia cinnamea	1	Documentation station
Moraxella osloensis	1	Air
Sphingomonas paucimobilis	1	Door handle
Mold	3	Air (1) Cabinet (2)
Other presumed environmental isolates (listed as large gram positive cocci, gram-positive rods, or unknown/not described)	26	Air (3) Back table (2) Bathroom hopper (6) Bedrail (3) Cabinet (5) Documentation station (5) Table (2)

Table 3 – Device-associated infections reported during 3 month control periods and trial of portable pulsed-xenon ultraviolet light disinfection (PPX-UVD).

	Control: 1year prior	Control: pre-PPX-UVD	Intervention: PPX-UVD	Control: post-PPX-UVD	p-Value[a]
Central line days (utilization ratio)	840 (0.89)	528 (0.80)	542 (0.85)	531 (0.88)	
CLABSI rate[b]	3.57	9.47	1.85	3.77	0.20
Foley days (utilization ratio)	878 (0.93)	555 (0.85)	558 (0.88)	523 (0.87)	
CAUTI rate[b]	4.56	7.21	1.79	1.91	0.23
Ventilator days (utilization ratio)	634 (0.67)	398 (0.61)	381 (0.60)	434 (0.72)	
VAP rate[b]	3.15	2.51	7.87	2.30	0.12
Overall device-associated infection rate	3.82	5.40	3.38	2.69	0.19

Utilization ratios: number of device-days/occupied bed days. CLABSI: central line associated bloodstream infection; CAUTI: catheter associated urinary tract infection; VAP: ventilator associated pneumonia.
[a] Intervention period compared to combined control periods.
[b] All rates expressed per 1000 device/days.

4. Discussion

In this study evaluating the impact of using PPX-UVD for a 3 month period in a burn ICU, we found that PPX-UVD significantly reduced environmental bioburden, which notably did not include MDROs after routine housekeeping. Numerous studies have demonstrated the contamination of hospital environmental surfaces by HAI pathogens, which can act directly as fomites for pathogen transmission or as a reservoir to contaminate hands of healthcare workers [22–24]. Epidemiologic studies have shown that patients hospitalized in rooms previously occupied by individuals infected or

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Table 4 – Healthcare associated multidrug resistant organisms (MDRO) reported during 3 month control periods and trial of portable pulsed-xenon ultraviolet light disinfection (PPX-UVD).

	Control: 1year prior (per 1000 OBD)	Control: pre-PPX-UVD (per 1000 OBD)	Intervention: PPX-UVD (per 1000 OBD)	Control: post PPX-UVD (per 1000 OBD)	p-Value[a]
Occupied bed days (OBD)	944	661	653	581	
–					
Clostridium difficile	2 (2.1)	2 (3.0)	0 (0)	0 (0)	0.35
ESBL[b] *Enterobacteriacae*	0 (0)	1 (1.5)	1 (1.5)	1 (1.7)	0.41
MDR[b] *Pseudomonas aeruginosa*	1 (1.1)	0 (0)	0 (0)	1 (1.7)	0.35
MRSA[b]	6 (6.4)	1 (1.5)	3 (4.6)	1 (1.7)	0.25
Stenotrophomonas maltophilia	1 (1.1)	1 (1.5)	3 (4.6)	2 (3.4)	0.15
Any MDRO[b]	10 (10.6)	5 (7.6)	7 (10.7)	5 (8.6)	0.72
Any MDR GNR[b]	2 (2.1)	2 (3.0)	4 (6.1)	4 (6.9)	0.17

[a] Intervention period compared to combined control periods.
[b] ESBL: extended spectrum beta lactamase; MDR: multidrug resistant; MRSA: methicillin-resistant *Staphylococcus aureus*; MDRO: multidrug resistant organism; GNR: gram negative rod.

Table 5 – Clinical bioburden (all positive clinical cultures) observed during 3 month control periods and trial of portable pulsed-xenon ultraviolet light disinfection (PPX-UVD).

	Control: 1year prior (per 1000 OBD)	Control: pre-PPX-UVD (per 1000 OBD)	Intervention: PPX-UVD (per 1000 OBD)	Control: post-PPX-UVD (per 1000 OBD)	p-Value[a]
Occupied bed days (OBD)	944	661	653	581	
All bacteria	117 (123.9)	94 (142.2)	86 (131.7)	93 (160.1)	0.18
All GNR[b]	85 (90.0)	74 (112.0)	69 (105.7)	69 (118.8)	1.0
Any MDRO[b]	30 (31.8)	15 (22.7)	14 (21.4)	42 (72.3)	0.03
% MDRO/all bacteria	25.6	16.0	16.3	45.2	0.07
Any MDR GNR[b]	16 (16.9)	8 (12.1)	8 (12.3)	29 (49.9)	0.07
%MDR GNR/all GNR	18.9	10.8	11.6	42.0	0.08
Any GP[b] MDRO	14 (14.8)	5 (7.6)	5 (7.7)	9 (15.1)	0.10
% MDR GP/any GP	53.8	31.3	41.7	45.0	0.22
Any *Clostridium difficile*	3 (3.2)	3 (4.5)	1 (1.5)	0 (0)	0.34

[a] Intervention period compared to combined control periods.
[b] GNR: gram negative rod; MDRO: multidrug resistant organism; MDR: multidrug resistant; GP: gram positive.

colonized with MRSA, VRE, *C. difficile*, *A. baumannii*, or *P. aeruginosa* are at risk of MDRO acquisition from the shared environment [9]. Cleaning the environment to reduce this risk is critical, but manual cleaning is complex and there are numerous limitations [8]. In this evaluation, PPX-UVD was shown to significantly decrease bioburden on the combined endpoint of high-touch surfaces and air in a burn ICU environment compared to manual cleaning alone. This reduction was driven through reduction of skin commensals, as typical HAI pathogens and MDRO were not identified in the environment either before or after PPX-UVD. These reductions in overall bioburden are concordant with other in vitro evaluations of this technology, either from inoculated surfaces or high-touch hospital surfaces after routine patient occupation [15,16,25]. While no HAI pathogens or MDRO were identified in the environment before PPX-UVD, this is not dissimilar to published outbreaks where only a minority of surfaces are contaminated and to a previous evaluation at this institution where only 5% of surfaces grew GNR from occupied rooms before routine cleaning [10].

This evaluation was not primarily designed to detect a statistically significant reduction in device-associated HAI or incident HA-MDRO acquisition, and differences were not seen. However, evaluation of these secondary endpoints demonstrated a prolonged period without a case of HA-CDI in the unit, despite multiple introductions of CDI as demonstrated by

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positive clinical specimens in the wash-in and intervention periods, and in the absence of a reintroduction during the post-intervention period. The microbiology methods used for bacterial culture from the environment would not support detection of *C. difficile*, so this apparent clinical reduction cannot be supported by microbiology data.

Despite recent evidence of reductions in a number of other HAIs, HA-CDI remains a serious problem and has become the most common etiologic agent of HAI in the United States [26]. A recent study estimated the number of HA-CDI cases in 2011 alone approached 300,000, resulted in over 61,000 recurrences, and caused over 27,000 deaths [27]. The scope and impact in burn patients, however, has not been well characterized. A 2011 evaluation from this institution revealed an incidence of 7.9/10,000 patient-days, which was lower than contemporaneous data from other units of the facility, and without apparent impact on morbidity or mortality [7]. The incidence in that study was also lower than that seen in the BICU during the control and pre-intervention periods of this evaluation, although detection methods changed in the interim from antigen detection tests to the more sensitive PCR. Another US-based single-center evaluation in 2002 reported a HA-CDI incidence of 7.2/1000 admissions, and a 2015 evaluation from Tehran noted an overall prevalence of 2.5/1000 admissions, with deaths attributed to comorbidities [28,29]. The population of this burn ICU notably differs from the population of most other ICUs, in that patients tend to be younger, with few comorbidities [7]. Nevertheless, each episode has the potential for serious morbidity and mortality, and drives an estimated excess cost of $4.8 billion in US acute-care facilities, so this should remain a problem deserving of attention in the burn ICU [30]. Even if *C. difficile* is not the highest infection prevention priority in the burn ICU, the opportunity to greatly reduce or eliminate this as a potential complication is clearly attractive.

The correlation seen here between use of PPX-UVD and the reduction of HA-CDI is supported by the existing literature and is biologically plausible. Nerandzic et al. have demonstrated a reduction in positive cultures for *C. difficile* from hospital surfaces (by 77% in rooms that had not been cleaned, and by 58% in rooms that had already undergone terminal cleaning including use of bleach) after PPX-UVD, and evaluations of other UVC disinfection units have also demonstrated reductions of *C. difficile* from the environment, depending on organic load, inoculum size, and dose of UVC [31,32]. A quasi-experimental clinical study reported a 53% reduction in the HA-CDI rate, with observed reductions in *C. difficile* associated deaths and colectomies [17]. It was noted that among the patients who did acquire HA-CDI after initiation of PPX-UVD, 73% had been placed in rooms that had not been treated with the device prior to their admission. A retrospective study in a community hospital demonstrated a 41% reduction in HA-CDI facility-wide, despite using the device outside the ICU only after discharges of patients known to the infected with *C. difficile* [19]. Another retrospective evaluation demonstrated a 17% reduction in HA-CDI after PPX-UVD initiation compared to prior, a significant difference despite missing approximately 25% of contact precautions discharges [33]. Recent data from the same group suggest a dose-response between percentage of room discharges treated with PPX-UVD and reductions in HA-CDI. Nagaraja et al. reported a 22% decrease in the rate of facility-wide HA-CDI despite an 18% increase in community-acquired cases during the first year of PPX-UVD use, driven predominantly by a 70% decrease in the adult ICU setting [18]. The use of the device was low throughout the facility, but significantly greater in the adult ICUs compared to other units. In our setting, where all rooms were single-bed, all patients on contact precautions, patient movement tightly controlled, and admission of patients with community-associated CDI infrequent, it is plausible that HA-CDI could be reduced at least to the extent seen in other non-burn ICUs. Data from our setting were not available on percentage of discharges where PPX-UVD was used, although the number of uses per week exceeded the average number of discharges (data not shown).

Limited published data are available relating UVC disinfection to reductions in GNR HAI pathogens. A study using inoculated surfaces with MDR *A. baumannii* demonstrated a 3–4 $\log_{10}$ reduction in inoculum [34]. An evaluation of inoculated surfaces with another PPX-UVD unit demonstrated >2 $\log_{10}$ reductions in *Escherichia coli* and *P. aeruginosa* [35]. One hospital-based study evaluated environmental cultures from rooms which had housed patients infected with HAI pathogens including *Acinetobacter* spp. This study included only 2 rooms (10 samples) from *Acinetobacter* spp. infected patients, and demonstrated a nonsignificant 1.16 $\log_{10}$ reduction in colony-forming units [25]. Clinical studies have focused on MRSA, VRE, and *C. difficile*, and data on UVC disinfection and GNR are extremely limited. Haas et al. noted a 19% decrease in HA MDR GNR rates during PPX-UVD use compared to prior; the proportion of this that represents colonization vs. infection is unknown [33]. Two recent evaluations of surgical site infections revealed reductions after use of PPX-UVD bundled with other interventions, but data on organisms were not provided [36,37]. Unfortunately, whether PPX-UVD may reduce environmental bioburden, HAI, or incident patient colonization by MDR GNR in the burn unit remains unresolved. Follow-up studies primarily powered to detect differences in HAI and HA-MDRO rates should be conducted in this environment.

Our study has a number of strengths and limitations. Its quasi-experimental design is clearly less robust than a randomized trial, although use of control periods before (including a wash-in period), after, and in the same season a year prior add validity to the design. A clinical bioburden category was included in order to account for the "organism pressure" in the unit which might drive environmental contamination and HAI rates in either direction. Interpretations of this as a stand-alone category must be very limited, but suggest no increase in clinical cultures positive for MDRO, a possible decrease, and most importantly add to the understanding of community-associated CDI pressure in this unit. Microbiological sampling could have missed some high-touch surfaces, and these were selected based on those commonly referenced by other investigators and based on prior information from sampling this unit [10]. Contact plates are also challenging to use on irregularly shaped surfaces such as door handles. However, the same sampling methodology was used for both before- and after-PPX-UVD sampling. There were no HAI pathogens or MDROs isolated from the environment even before PPX-UVD use, which excluded the possibility of demonstrating a reduction afterward. No demographic

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information on patients or severity of injuries was collected, although similar overall numbers of OBD particularly in the immediate pre- and post-intervention periods demonstrates a similar census, and utilization ratios of invasive devices were fairly consistent throughout, which speaks to similar acuity of illness. The most important limitation is the relatively short period of time for the intervention, which particularly limits the ability to exclude an effect on HAI and incident MDRO acquisition, or to demonstrate statistical significance for reductions in uncommon events like HAI.

5. Conclusions

This evaluation of PPX-UVD in a BICU setting revealed reductions in bacterial burden on the combined endpoint of high-touch environmental surfaces and air compared to terminal cleaning alone. This was driven by reductions in skin commensals, as no MDRO or GNR responsible for HAI were isolated from the environment, even before PPX-UVD. Statistically significant changes in clinical HAI and MDRO rates were not seen during this 3 month evaluation period compared to control periods, though the unit experienced a prolonged interval before the next HA-CDI case. Follow-up studies aimed primarily at detecting changes in HAI and MDRO rates in this setting, including GNR data, should be conducted.

Conflicts of interest

The authors endorse no conflicts of interest pertaining to the work described.

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