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Major Article

Effect of a shielded continuous ultraviolet-C air disinfection device on reduction of air and surface microbial contamination in a pediatric oncology outpatient care unit

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Key Words:
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ultraviolet C
pediatric oncology

Background: For a clean hospital environment, we evaluated whether ultraviolet-C (UV-C) air disinfection reduces airborne and surface microbial contamination in an outpatient pediatric oncology center.

Methods: A pre- and post-intervention study compared 6 test locations, where continuous shielded UV-C air disinfection devices were installed, with 10 control locations without UV-C. Pre- and post-intervention air and surface samples were collected for bacterial and fungal cultures. Percent changes in colony forming unit (CFU) counts in the test and control locations were compared.

Results: Mean bacterial CFU count per cubic meter air and per surface contact plates decreased by 27% ($P = .219$) and 37% ($P = .01$), respectively, in test locations compared to 40% ($P = .054$) and 30% ($P = .006$) reductions in control locations. Mean fungal CFU count per cubic meter air and per surface contact plates increased by 14% ($P = .156$) and 19% ($P = .048$), respectively, in test locations compared to 24% ($P = .409$) and 2% ($P = .34$) increases in control locations.

Conclusions: There were no consistent statistically significant differences in the air and surface culture results between test locations where UV-C devices were installed and control locations. The effectiveness of UV-C air disinfection in reducing air and surface microbial contamination in outpatient clinical areas where immunocompromised children are encountered was not proven.

BACKGROUND

The hospital environment plays an important role in the transmission of health care–associated infections (HAIs) caused by airborne pathogens or surface contamination.[1-6] For this reason, the Centers for Disease Control and Prevention provided recommendations for environmental disinfection and control to prevent HAIs.[7] Maintaining a clean protective environment is especially important in immunocompromised patient care areas. Pediatric oncology patients are at an increased risk for acquisition of infections, not only in the inpatient care settings but also in outpatient settings, where most health care delivery including chemotherapy infusions occurs. To protect immunocompromised patients, our pediatric oncology center has actively sought ways to reduce the burden of pathogens, including airborne transmission of infections.[8]

The effectiveness of germicidal ultraviolet-C (UV-C) light irradiation has been demonstrated for the disinfection of water and air-handling systems, in the food industry, and for laboratory disinfection, among other uses.[9-11] Over the past decades, UV-C light technology has been increasingly used in health care settings as a tool to prevent infection by disinfecting the hospital environment, including surfaces, water, and air. Recent studies demonstrated the effectiveness of UV-C light in environmental disinfection and a reduction in the acquisition

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Conflicts of interest: L.D.L. was formerly employed by American Green Technology (South Bend, IN), the manufacturer of the VidaShield technology. The other authors have no conflicts of interest to disclose.

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Table 1
Change in mean air bacterial and fungal colony counts in locations where continuous UV-C air disinfection devices were installed and where UV-C devices were not installed

Location	Bacterial CFU count/m^3 of air				Fungal CFU count/m^3 of air			
	Mean count		Percent change	*P* value	Mean count		Percent change	*P* value
	Pre-installation	Post-installation			Pre-installation	Post-installation		
Continuous UV-C air disinfection device installed								
1. North clinic reception	95.0	66.2	−30%	.449	23.8	17.6	−26%	.240
2. Infusion room	30.0	31.4	5%	.879	8.3	4.7	−43%	.278
3. Women's Center A restroom	125.1	70.3	−44%	.151	27.1	63.2	133%	**.014**
4. Women's Center B restroom	124.5	78.4	−37%	.280	14.1	8.7	−38%	**.04**
5. Pharmacy supply area	32.3	33.4	3%	.570	11.9	3.2	−73%	**.01**
6. Transplant waiting area	56.7	58.9	4%	.880	4.6	4.6	0%	.592
Overall	77.3	56.4	−27%	.219	15.0	17.0	14%	.156
No continuous UV-C air disinfection device installed								
7. South clinic reception	90.5	83.8	−7%	.571	10.4	12.6	21%	.939
8. Clinic hallway	102.7	57.1	−44%	**.012**	29.3	52.0	77%	.472
9. Infusion waiting area	55.8	21.7	−61%	**.025**	13.8	3.8	−72%	**.010**
10. Infusion center hallway	25.8	30.9	20%	.448	17.3	3.3	−81%	**.004**
11. Men's Center A restroom	87.4	81.9	−6%	.762	28.0	57.0	104%	.085
12. Center A restroom hallway	103.9	65.2	−37%	.058	45.2	83.9	86%	.344
13. Men's Center B restroom	52.1	60.8	17%	.705	13.2	13.2	0%	.677
14. Center B restroom hallway	381.0	100.9	−74%	**.005**	45.9	34.9	−24%	.211
15. Pharmacy hallway	85.5	74.0	−13%	.791	34.4	30.4	−12%	.426
16. Transplant elevator lobby	54.0	44.7	−17%	.496	6.3	10.7	70%	.446
Overall	103.9	62.1	−40%	.054	24.4	30.2	24%	.409

NOTE. Bold values are statistically significant $P < .05$.
CFU, colony-forming unit; *UV-C*, ultraviolet C.

of multidrug-resistant organisms.[12-15] However, the UV-C light delivery method has been challenging because it can only be used in nonoccupied hospital rooms. In addition, it provides a one-time disinfection of the environment, which will become contaminated again when the room is occupied. Finding a delivery method that allows UV-C light to continuously disinfect the environment would address these limitations. Existing knowledge is limited with regard to the effectiveness of continuous shielded UV-C air disinfection technology in cleaning an occupied environment by reducing the microbial contamination of the air and surfaces.[16-19] This technology was evaluated in the following inpatient settings but not in outpatient units: a hospital pharmacy,[17] a special care unit in a long-term acute care hospital,[16] a long-term care ventilator unit in a skilled nursing facility,[18] and inpatient wards in acute care hospitals.[19]

The objective of this study was to evaluate whether using a continuous UV-C light air disinfection device reduces airborne and surface bacterial and fungal contamination and community-acquired infections in an outpatient health care setting of a pediatric oncology center.

METHODS

Study setting and design

The study was conducted in the outpatient care units of a pediatric oncology center, where air quality is maintained using high-efficiency particulate air filters throughout the hospital. The outpatient care units are located on the ground floor of the hospital. The study was designed as a pre- and post-intervention test-control study in which test locations were defined as locations where a continuous shielded UV-C devices were installed, and control locations were those that did not have UV-C devices. Some control locations were selected to match test locations based on their location in the same unit and being supplied by the same air ventilation system. Air and surface samples were collected for bacterial and fungal cultures from a total of 16 locations before and after installation of the UV-C devices in 6 test locations (Tables 1 and 2). Results from test locations were compared to 2 types of controls, one being the same location before installation of the UV-C device and the other a different location in the same unit where UV-C devices were not installed.

Description of the continuous shielded UV-C light air disinfection device

The continuous shielded UV-C light device aims at disinfecting the circulating air by killing airborne microorganisms using UV-C germicidal irradiation, which denatures their DNA (VidaShield, American Green Technology, South Bend, IN). The device consists of a chamber installed above a 2 by 4 ceiling light fixture. The room air is drawn into this chamber to pass through fans and MERV 6 filters to a shielded UV-C lamp (253.7 nm), where it is disinfected. Then, the treated air exits the chamber from the opposite end to return to circulation. The shielded device operates continuously and safely in occupied rooms, allowing for continuous disinfection of the circulating air. The number of UV-C devices that were installed in each test location was determined based on the manufacturer's recommendations for 1 device per 100 square feet of surface area in order to achieve maximal effectiveness. A total of 40 devices were installed in 6 locations.

Room cleaning and disinfection protocols

The cleaning of the study locations was conducted by environmental services staff per institutional protocols with no change in practice or products during the study period. The environmental services personnel were blinded to the study.

Environmental testing procedure

A total of 1280 samples were collected during this study. At preinstallation, 320 air samples and 320 surface samples were collected from October 2 to 3, 2017. Ten air samples for bacterial cultures and 10 for fungal cultures were collected from each of the 16 locations. Similarly, 10 surface samples for bacterial cultures and 10 for fungal cultures were collected from each location. After baseline samples

Table 2
Change in mean surface bacterial and fungal colony counts in locations where continuous UV-C air disinfection devices were installed and where UV-C devices were not installed

Location	Bacterial CFU count/contact plate surface area of 25 cm^2				Fungal CFU count/contact plate surface area of 25 cm^2			
	Mean count		Percent change	*P* value	Mean Count		Percent change	*P* value
	Pre-installation	Post-installation			Pre-installation	Post-installation		
Continuous UV-C air disinfection device installed								
1. North clinic reception	14.3	15.7	10%	.650	3.7	3.7	0%	.562
2. Infusion room	15.1	2.3	−85%	**.004**	3.5	0.8	−77%	.052
3. Women's Center A restroom	43.4	31.4	−28%	.256	5.5	13.9	153%	.160
4. Women's Center B restroom	29.4	24.4	−17%	.970	3.0	2.3	−23%	.349
5. Pharmacy supply area	17.8	10.7	−40%	.596	8.2	9.8	20%	.596
6. Transplant waiting area	22.3	5.8	−74%	**.002**	4.4	3.1	−30%	.146
Overall	23.7	15.1	−37%	.012	4.7	5.6	19%	.048
No continuous UV-C air disinfection device installed								
7. South clinic reception	–	21.9	−6%	.570	5.5	3.4	−38%	.127
8. Clinic hallway	35.1	20.5	−42%	.075	18.4	7.5	−59%	.053
9. Infusion waiting area	11.11	6.4	−42%	.085	3.0	8.4	180%	.166
10. Infusion center hallway	18.0	7.9	−56%	**.031**	10.9	5.3	−51%	.403
11. Men's Center A restroom	30.5	14.1	−54%	.173	4.3	17.1	298%	**.01**
12. Center A restroom hallway	20.7	21.5	4%	.623	9.5	10.4	9%	.703
13. Men's Center B restroom	28.1	21.2	−25%	.306	3.4	2.3	−32%	.268
14. Center B restroom hallway	28.5	18.9	−34%	.353	5.0	9.0	80%	.97
15. Pharmacy hallway	19.3	14.5	−25%	.383	10.2	4.8	−53%	**.031**
16. Transplant elevator lobby	24.4	20.8	−15%	.910	9.8	10.4	6%	.676
Overall	24.0	16.8	−30%	.006	8.0	7.9	−2%	.342

NOTE. Bold values are statistically significant $P < .05$.
CFU, colony-forming unit; *UV-C*, ultraviolet C.

were collected, a total of 40 UV-C devices were installed in 6 locations (Tables 1 and 2) in October and November 2017. The test locations were selected before collection of the pre-installation samples based on heavy traffic in the areas and patient population risk levels. After UV-C device installation, the same air and surface sampling methods for bacterial and fungal cultures from the same 16 locations were repeated from January 9 to 11, 2018. The last installed device had been in operation for 5 weeks before the post-installation samples were collected.

For air testing, approximately 1000 liters of air were pulled through a 219-hole perforated cover and impacted on 15 × 100-mm tryptic soy agar with 5% sheep blood plates (Hardy Diagnostics; Santa Maria, CA) for bacterial cultures, using a SAS 180 air sampler (Bioscience International; Rockville, MD) run over approximately 5.5 minutes. The same procedure was followed to collect air fungal cultures, but the agar plate was 15 × 100-mm malt extract agar with 0.01% chloramphenicol (Hardy Diagnostics). Samples from high-touch surfaces were collected for bacterial cultures using 15 × 60-mm tryptic soy agar contact plates (Hardy Diagnostics) applied on surfaces for 30 seconds. Surface fungal cultures were collected using 15 × 60-mm malt extract agar contact plates (Hardy Diagnostics). All contact plates contained lecithin and TWEEN 80 to control for antimicrobial surface cleaners.

All plates were shipped refrigerated to an independent certified environmental microbiology laboratory (Aerobiology Laboratory Associates, Inc.; Sterling, VA). Samples were incubated at 30 ± 2°C for 5 days, after which they were evaluated by colony forming unit (CFU) counts. The CFU counts on air cultures are adjusted, using a correction hole factor, for the probability that >1 viable particle was pulled through a single sampling hole producing a single colony.[20]

Statistical methods

Culture results were reported as CFU count/m^3 air or CFU count/contact plate surface area. The CFU counts in 2 groups were compared using the Wilcoxon rank-sum test. Two-sample *t*-tests were used to compare 2 groups of percentage changes using R 3.4.3. All *P* values are 2 sided, and a *P* value of 0.05 or less is considered significant.

RESULTS

Overall change in air and surface contamination pre- and post-installation of UV-C air disinfection devices

The mean bacterial CFU count/m^3 of air samples decreased in both test and control locations. This reduction was not statistically significant (Table 1 and Fig 1A); however, the mean fungal CFU count/m^3 of air non-significantly increased in both locations, with and without UV-C devices (Table 1 and Fig 1B). For surface samples, the mean bacterial CFU count/plate decreased significantly in both locations (Table 2 and Fig 1C). There was no consistent trend in the change of mean fungal CFU count/plate for both types of locations (Table 2 and Fig 1D).

Individual location change in air and surface contamination pre- and post-installation of UV-C air disinfection devices

Table 1 shows changes in mean CFU counts/m^3 in bacterial and fungal cultures of air samples collected from each location. In test locations, we observed no statistically significant change in bacterial air counts, but significant reductions in fungal air CFU counts were detected in the women's Center B restroom (38% reduction) and pharmacy supply area (73%). Surprisingly, the air fungal CFU counts in the women's Center A restroom significantly increased by 133% after installation of the UV-C devices. In locations where UV-C devices were not installed, statistically significant reductions in bacterial CFU counts were detected on air cultures collected from the clinic hallway (44%), infusion center waiting room (61%), and Center B restroom hallway (74%). Significant reductions in the air fungal CFU counts were detected in the infusion center waiting area (72%) and its hallway (81%), despite UV-C devices not being installed in these locations.

The changes in mean CFU counts/contact plate for surface bacterial and fungal cultures are shown in Table 2. In test locations, there were statistically significant reductions in surface bacterial CFU counts in the infusion room (85%) and transplant unit waiting area (74%), but we found no statistically significant changes in fungal CFU counts. In control locations, statistically significant reductions in bacterial CFU counts on surface cultures were shown in the infusion

center hallway (56%). Surface fungal CFU counts in the men's Center A restroom significantly increased (298%), and those in the pharmacy hallway significantly decreased (53%).

Change in air and surface contamination in test locations with UV-C air disinfection devices compared to matched control locations without UV-C devices

The 6 test locations were compared to matched control locations that are located in the same outpatient care unit, are supplied by the same ventilation system, and witness similar traffic levels but did not have UV-C devices installed. In general, percent and direction of change in mean CFU counts in air and surface bacterial and fungal cultures collected from test locations did not differ significantly from those in matched control locations (Tables 3 and 4). The transplant waiting area with a UV-C device had a significantly higher percent reduction (74%) in surface bacterial CFU counts compared to the matched control location of the transplant elevator lobby (15%; Table 4). Interestingly, the air bacterial CFU counts detected in the infusion room where UV-C devices were installed increased by 5%,

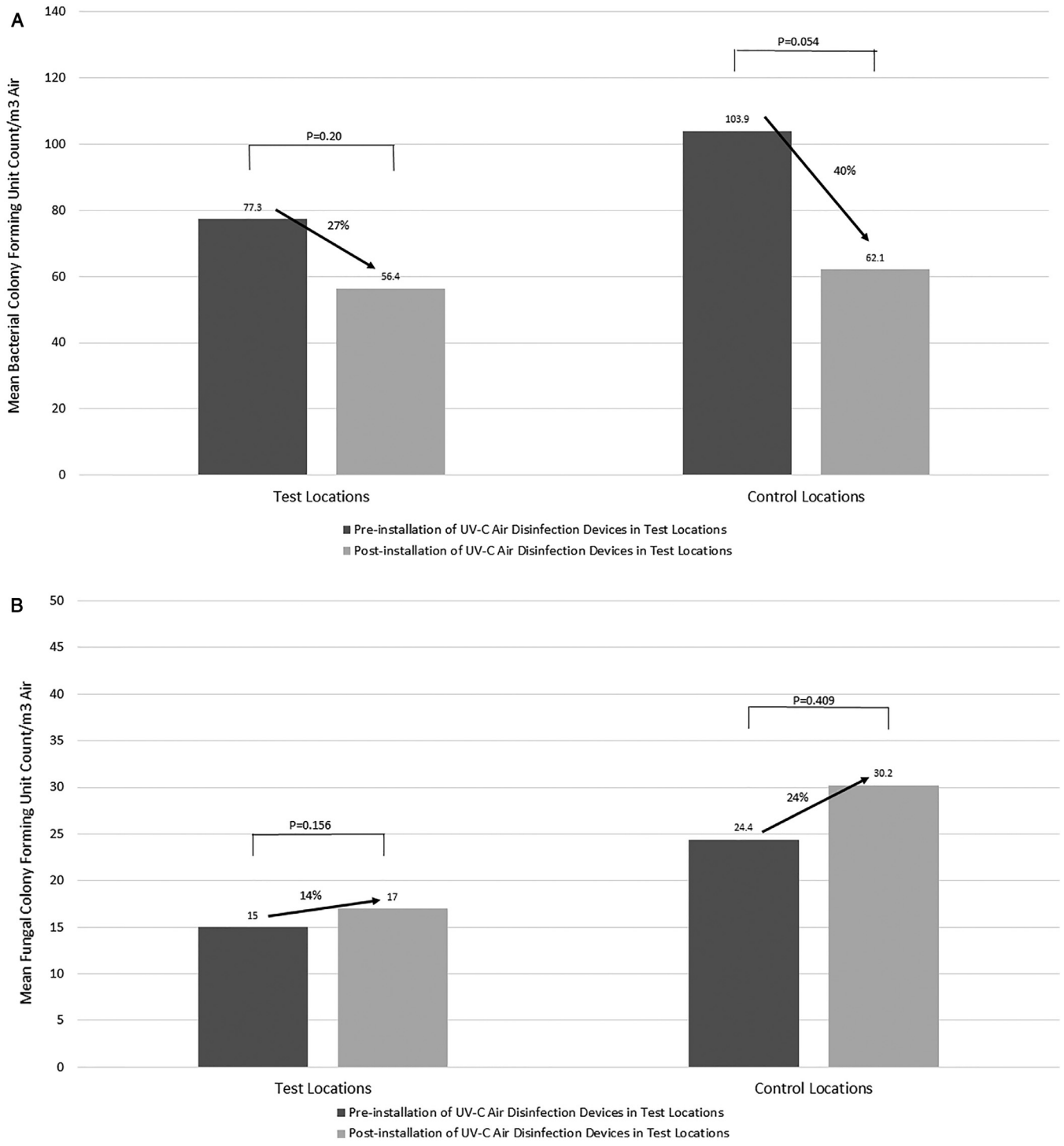
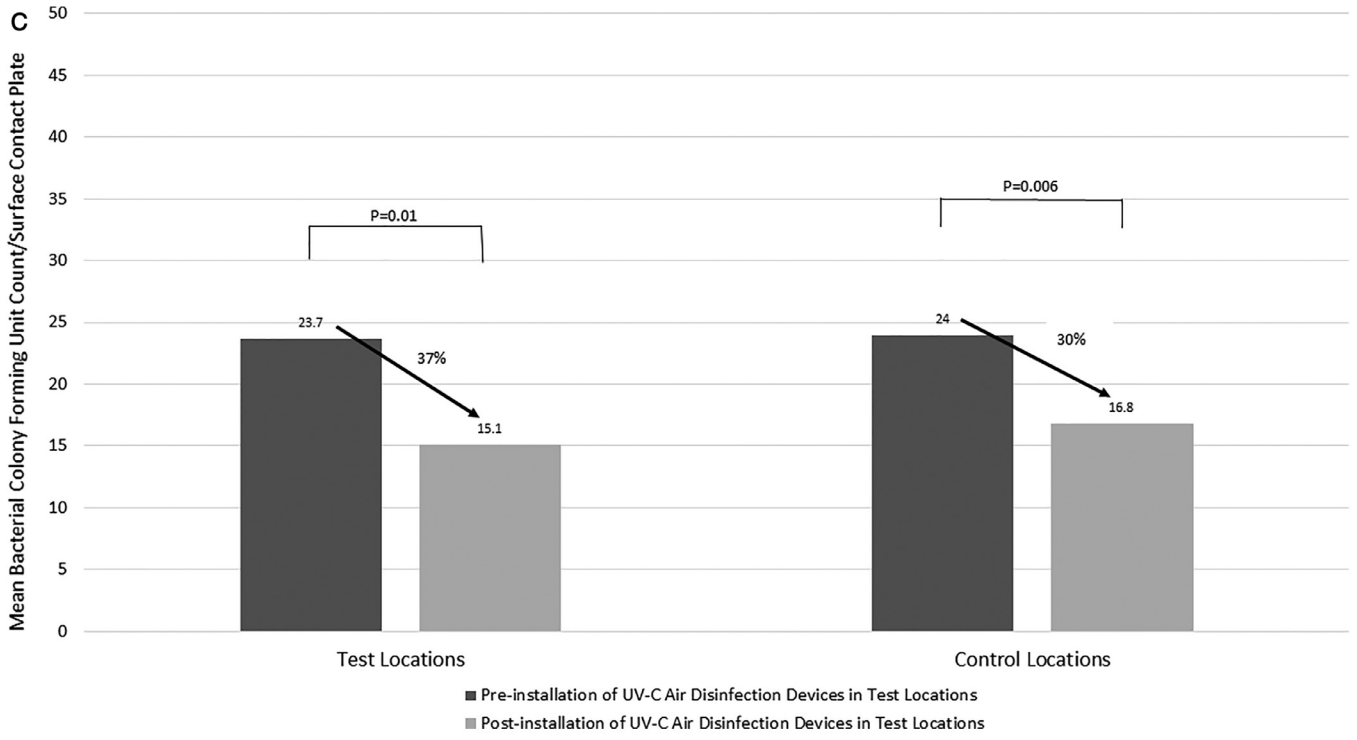


Fig 1. Overall changes in mean colony-forming unit counts in (A) bacterial air cultures, (B) fungal air cultures, (C) bacterial surface cultures, and (D) fungal surface cultures collected from locations where continuous ultraviolet-C (UV-C) air disinfection devices were installed and those where UV-C devices were not installed.



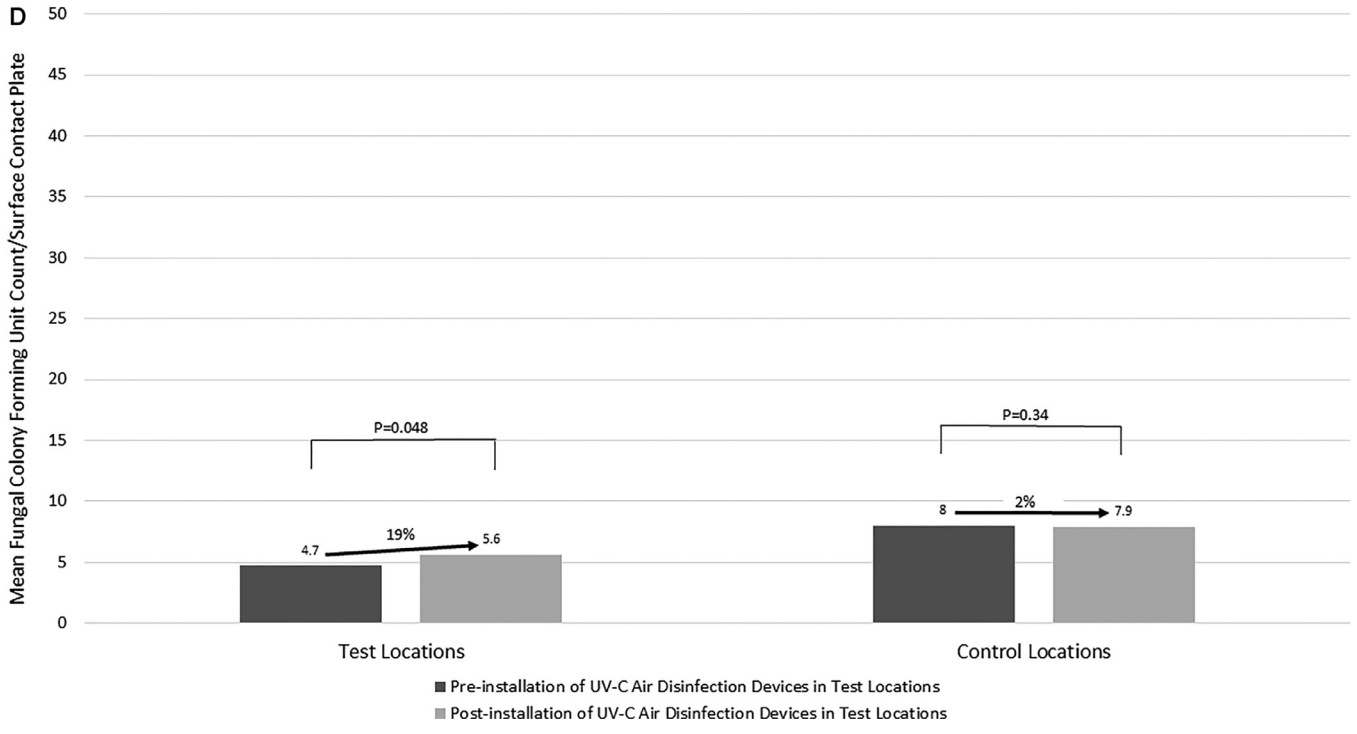


Fig 1. *Continued.*

whereas the control location of the infusion waiting area had a 61% reduction ($P = .018$; Table 3).

DISCUSSION

We present the findings of the first study to evaluate the effectiveness of continuous UV-C air disinfection in reducing the microbial contamination of an occupied environment in a pediatric oncology outpatient care unit. Although not all reductions were statistically significant, we detected reductions in bacterial and fungal contamination in clinically significant areas where severely immunocompromised patients are located—patients who are at increased risk for prolonged shedding of pathogens and for the acquisition of opportunistic infections. This reduction was detected in both test locations where shielded continuous UV-C air disinfection devices were installed and control locations with no UV-C devices; for example, the airborne reductions in bacteria and fungi in the north clinic waiting area where patients with leukemia are present were 30% and 26%,

Table 3
Change in air bacterial and fungal CFU counts in test locations with UV-C air disinfection devices matched to control locations without UV-C devices

Comparison group		Mean bacterial CFU count/m^3 of air			Mean fungal CFU count/m^3 of air		
Test location	Control location	Percent change in post- vs pre-installation counts in test location	Percent change in post- vs pre-installation counts in control location	*P* value	Percent change in post- vs pre-installation counts in test location	Percent change in post- vs pre-installation counts in control location	*P* value
1. North clinic reception	7. South clinic reception	−30%	−7%	.402	−26%	21%	.321
2. Infusion room	9. Infusion waiting area	5%	−61%	**.018**	−43%	−72%	.410
3. Women's Center A restroom	11. Men's Center A restroom	−44%	−6%	.134	133%	104%	.777
4. Women's Center B restroom	13. Men's Center B restroom	−37%	17%	.121	−38%	0%	.329
5. Pharmacy supply area	15. Pharmacy hallway	3%	−13%	.645	−73%	−12%	.321
6. Transplant waiting area	16. Transplant elevator lobby	4%	−17%	.523	0%	70%	.303

NOTE. Bold values are statistically significant $P < .05$.
CFU, colony-forming unit; *UV-C*, ultraviolet C.

respectively. Similarly, the infusion room benefited from a 43% reduction in airborne fungal counts, 85% reduction in surface bacterial counts, and 77% reduction in surface fungal counts after installation of UV-C air disinfection devices.

However, the effectiveness of these UV-C devices in reducing the microbial environmental contamination was neither consistently nor statistically significantly demonstrated in all test locations compared to non-treated locations. We found that it is challenging to further improve the indoor air quality in a hospital environment controlled with high-efficiency particulate air filters, which is reflected in pre-intervention counts being not so high. In addition, other than the restrooms, several of the tested locations of the outpatient care units are open to the hallway or other areas with heavy traffic and not treated with UV-C devices. This allows for air flow across open adjacent locations and cross-contamination from people and air currents. Despite this, we saw reductions in many clinically significant locations where outpatient care is provided to immunocompromised children.

Our findings are in contrast to other reports evaluating this device.[16-19] Guimera and colleagues[17] showed significant reductions in airborne bacterial and fungal organisms in some areas of an inpatient hospital-based pharmacy; the areas that benefited from continuous UV-C air disinfection devices included work areas and anterooms. Similarly, in another study involving inpatient units in acute care hospitals, the airborne and surface bacterial CFU counts significantly decreased after installation of these devices.[19] Ethington et al[16] reported that, after the installation of UV-C devices, levels of airborne bacteria detected inside patient rooms of a special care unit in a long-term acute care hospital were reduced by 42%, and this air disinfection was significantly associated with a reduction in HAIs. In another study conducted in a long-term care ventilator unit in a skilled nursing facility, Kane et al[18] demonstrated significant reductions in HAIs in a wing where UV-C devices were installed compared to an adjacent wing of the same unit with no UV-C devices (12.5 vs 17.5 per 1000 patient-days; $P = .022$).

Several factors affect hospital air quality, including seasonality; human activities and traffic; heating, ventilation, and air conditioning (HVAC) circulation rates; outside air quality; humidity; temperature; and winds. To try to control for such independent variables, we collected before and after measurements at the same locations and times of the day and in similar weather conditions (fall and winter seasons). One potential explanation for our different findings from prior reports is the containment and traffic level of the tested units. The previous reports evaluated hospital areas that are enclosed and have controlled traffic, thus controlling for several dynamic and constantly changing factors that affect environmental microbial contamination. On the other hand, we aimed at evaluating the impact of continuous UV-C air disinfection in our busy outpatient care units, which encounter a daily average of 300 patients. Seasonal variation of the outside air quality and its impact on the air quality inside the outpatient care units located on the ground floor close to the main entrance might have played an important role. For example, on the January dates of post-installation sampling, the outside temperature ranged between 50°F and 66°F, but in October it was 78°F to 87°F during the day. In January, therefore, we observed people walking in with coats and scarves, which might carry significant particle counts. Also, the HVAC system was switched from a cooling function in October to heating in January. It is not clear whether this change in HVAC function had any impact. That said, the results shown in Tables 3 and 4, where concurrent culture results for test and control locations are compared, suggest that differences in weather patterns between October and January or other potential time-related variables had minimal or no impact on our findings.

After demonstrating UV-C germicidal effectiveness in a controlled lab setting,[10,21] it is an important advancement to implement this technology in an operational hospital setting and further relate its

Table 4
Change in surface bacterial and fungal CFU counts in test locations with UV-C air disinfection devices matched to control locations without UV-C devices

Comparison group		Mean bacterial CFU count/contact plate surface area of 25 cm^2			Mean fungal CFU count/contact plate surface area of 25 cm^2		
Test location	Control location	Percent change in post- vs pre-installation counts in test location	Percent change in post- vs pre-installation counts in control location	*P* value	Percent change in post- vs pre-installation counts in test location	Percent change in post- vs pre-installation counts in control location	*P* value
1. North clinic reception	7. South clinic reception	10%	−6%	.729	0%	−38%	.614
2. Infusion room	9. Infusion waiting area	−85%	−42%	.062	−77%	180%	.134
3. Women's Center A restroom	11. Men's Center A restroom	−28%	−54%	.320	153%	298%	.615
4. Women's Center B restroom	13. Men's Center B restroom	−17%	−25%	.864	−23%	−32%	.782
5. Pharmacy supply area	15. Pharmacy hallway	−40%	−25%	.606	20%	−53%	.188
6. Transplant waiting area	16. Transplant elevator lobby	−74%	−15%	**.007**	−30%	6%	.516

NOTE. Bold values are statistically significant $P < .05$.
CFU, colony-forming unit; *UV-C*, ultraviolet C.

effectiveness to reduction in HAIs. In a cluster-randomized, crossover, multicenter trial, Anderson and colleagues[12] reported that using UV-C room disinfection in addition to terminal room cleaning after patient discharge resulted in a significantly lower incidence of multidrug-resistant organisms (33.9 vs 51.3 cases per 10,000 exposure-days; relative risk, 0.70; 95% confidence interval, 0.50-0.98; $P = .036$). Although this study was done in an operational hospital setting, the UV-C delivery method was limited by its use in a non-occupied environment only for safety reasons. Recently, 2 studies have demonstrated that continuous shielded UV-C technology was associated with reducing HAIs in patients in a special care unit of a long-term acute care hospital[16] and in a long-term care ventilator unit in a skilled nursing facility.[18] Although attendance at outpatient clinics is a risk for acquiring infection, the risk is expected to be less than that in an inpatient setting. In addition, it is more challenging to associate changes in community-acquired infections with any reductions in airborne contaminants inside an outpatient care unit. Community infections can be acquired in any location, not only in the outpatient care unit. To investigate similar questions, robust outpatient surveillance programs are required to track infections that might be diagnosed in other health care settings, including emergency departments, after the patient leaves the clinic. Even if this surveillance network is available, it would be resource intensive to prove that the infection was acquired during health care delivery at the outpatient care unit rather than due to outside community exposures. Well-designed surveillance programs are needed to directly measure the impact of improvements in air quality in the outpatient care units on patient infection outcomes while controlling for seasonality and other factors that facilitate or mitigate transmission.

Our study was also characterized by evaluating surface microbial contamination in relation to air disinfection. The effectiveness of UV-C germicidal technology in the reduction of surface contamination has been demonstrated in previous studies, where the environmental surface was directly irradiated by UV-C light.[13-15] We have shown that the surface bacterial and fungal counts decreased, although not significantly, in some test locations. Although several factors affect surface contamination in an occupied environment, including direct contact with people in the environment, UV-C irradiation of air might possibly kill airborne organisms suspended as respiratory droplets before they settle down on surfaces; however, testing this mechanism is outside the scope of this study. Our study also has weaknesses, one of which is collecting samples on only 2 consecutive days during the pre-installation and 3 consecutive days in the post-installation periods, thus reflecting snapshots of airborne and surface contamination patterns; however, more frequent sampling is hindered by cost and feasibility.

In conclusion, although statistically significant differences were not consistently found, reductions in microbial air and surface contamination were seen in test locations after the installation of a continuous shielded UV-C air disinfection devices, as well as in control locations without UV-C devices, in outpatient care settings. This reduction in microbial contamination is clinically important to reduce exposure of immunocompromised patients to infectious pathogens, despite not being directly attributable to UV-C devices. There is a known risk reduction by limiting exposure of these patients to bacteria and fungi; however, more studies are needed to measure the impact of this technology on patient outcomes in an outpatient setting.

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