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Original Article

A far ultraviolet-C light technology is effective for decontamination of items in proximity to sinks and is enhanced by a far UV-C reflective surface

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Abstract

Background: Dispersal of gram-negative bacilli from sink drains has been implicated as a source of transmission in multiple outbreaks.

Methods: In an acute care hospital, we assessed how often patient care supplies and other frequently touched items were within 1 meter of sink drains. We tested the efficacy of a ceiling-mounted far ultraviolet-C (UV-C) light technology for decontamination of sink bowls and surfaces near sinks with and without a wall-mounted film that reflects far UV-C light.

Results: Of 190 sinks assessed, 55 (29%) had patient care supplies or other frequently touched items within 1 meter of the drain. The far UV-C technology reduced *Pseudomonas aeruginosa*, *Enterobacter cloacae* and *Candida auris* on steel disk carriers by ≥1.5 $\log_{10}$ colony-forming units (CFU) in 45 minutes. On inoculated real-world items, ≥1.9 $\log_{10}$ CFU reductions in *P. aeruginosa* were achieved on sites in line with the light source versus 0.4–1.8 $\log_{10}$ CFU reductions on shaded surfaces. The addition of the reflective surface significantly enhanced efficacy in shaded sites ($P < 0.01$).

Conclusions: In a hospital setting, patient care supplies and other frequently touched items were often in proximity to sinks. The far UV-C light technology could potentially be useful for sink decontamination in high-risk areas.

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Introduction

Numerous outbreaks of infections due to gram-negative bacilli have been linked to sinks and other wastewater drainage sites.[1–12] To reduce the risk, current hand hygiene guidelines recommend that steps be taken to reduce environmental contamination associated with sinks and sink drains.[13] These steps include ensuring that medications and patient care supplies are not placed on surfaces within 1 meter of sinks, and disinfection of sink bowls and faucets daily.[13] However, limited information is available on how often patient care items and other frequently touched surfaces are in proximity to sinks in clinical settings. Moreover, daily disinfection of sink bowls and countertops or other items near sinks might have limited efficacy if organisms accumulate rapidly between episodes of cleaning.

In response to outbreaks, a variety of interventions have been used to address colonized sinks. These include repeated application of liquid or foam disinfectants, replacement of drainage pipes and traps, installation of heater-vibrator devices for trap disinfection, installation of self-disinfecting sinks and complete removal of sinks from patient rooms.[2,4,6–10] However, such measures can be costly, labor-intensive, and potentially damaging to drainage systems. Thus, there is a need for additional approaches to reduce the risk for transmission of gram-negative bacilli colonizing sink drains. Here, we evaluated the efficacy of a far ultraviolet-C (UV-C) light technology that could be used for continuous or intermittent decontamination of sink bowls and surfaces near sinks. Far UV-C was evaluated rather than 254-nm UV-C due to safety considerations. Far UV-C doses within threshold limit values proposed by the American Conference of Governmental Industrial Hygienists (ACGIH) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) may be safe.[14] In addition, we conducted observations to determine the frequency and type of patient care supplies and other frequently touched items located in proximity to sinks in a hospital setting.

Methods

Survey of patient care supplies and other frequently touched items placed near sinks

An observational survey was completed at the Cleveland VA Medical Center. The observations were approved by the Cleveland

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VA Medical Center's Research and Development Committee as a quality improvement project exempt from institutional review board review. During a 1-month period, 2 individuals recorded whether patient care supplies or other high-touch items were within 1 meter of sink drains in a convenience sample of rooms in patient care areas. There was no interaction with patients or staff during the survey. Sinks were classified as being in outpatient clinics, medical-surgical rooms, intensive care unit (ICU) rooms, or staff work areas. Items within 1 meter of sink drains were classified as patient care supplies, portable equipment, personal items, or other items.

Description of the far UV-C light technology and sink used for testing

The protocol for use of the far UV-C technology was approved by the Research and Development and Biosafety Committees at the Louis Stokes Cleveland VA Medical Center. The far UV-C technology (Mynatek, Inc., Oakland, CA) uses 3 krypton-chloride excimer lamps that emit a primary wavelength of 222 nm with filters to block emitted wavelengths greater than 230 nm.[15] Each of the lamps has a field of illumination of 60°. The device includes proprietary sensors that detect the presence of people within the area of far UV-C light delivery. For the purposes of this study, the device was programmed to automatically shut off all 3 far UV-C lamps whenever people were detected within the area of far UV-C delivery and to automatically resume operation 30 seconds after they moved outside the area of far UV-C exposure.

A sink in a research laboratory was used for testing. The bowl is 56.3 cm^2 diameter with a depth of 46.8 cm; the countertop is 0.8 meters from the floor. For sink decontamination, the device is intended to be mounted on the ceiling above and anterior to the front of the sink and directed toward the sink bowl. For these experiments, the device was mounted on a pole in front of the sink. The device was positioned just below the ceiling 2 meters from the floor above the front of the sink and angled toward the sink bowl.

Measurement of irradiance and far UV-C dosage with and without a far UV-C reflective surface on the wall behind the sink

Prior to the experiments, a radiometer (UIT2400 Handheld Light Meter for 222 nm (Ushio America, Cypress, CA) was used to measure irradiance in $\mu W/cm^2$ at the locations of steel disk placement for testing and in locations where a person would stand in front of the sink. The sensor was pointed toward the light source. The far UV-C dose in mJ/cm^2 was calculated at each site for a 45-minute exposure time. Measurements were taken with and without a wall-mounted visibly transparent Far-UVC film technology designed to reflect 200–250-nm UV-C light at normal angles (obtained from 3M Company, St Paul, MN) adhered on poster-board to the wall behind the sink.

Reduction in organisms on steel disk carriers placed in proximity to a sink

We tested the efficacy of the technology against *Pseudomonas aeruginosa* and *Enterobacter cloacae* isolates recovered from sink drains at the Cleveland VA Medical Center and *Candida auris* Antibiotic Resistance Bank (AR) #0385. The *C. auris* strain was included based on evidence that *Candida* species often colonize sink drains.[16] A modification of the American Society for Testing and Materials (ASTM) standard quantitative disk carrier test method (ASTM E 2197-02) was used with 5% fetal calf serum as soil load.[17] A 10 μL inoculum containing 5–6 $\log_{10}$ colony-forming units (CFU) of the test organisms was spread to cover 20 mm steel disks. The disks were adhered to petri dishes and placed in a sink bowl adjacent to the drain, 0.30 meters from the drain on the countertop, and 0.91 meter from the drain at the height of the countertop. The disks were exposed to far-UV for 45 minutes and processed as previously described.[15,16] A 45-minute continuous exposure was chosen based on previous data demonstrating that vegetative organisms on steel disk carriers 2 or 3 meters from the devices were reduced by >3 $\log_{10}$ after 45 minutes.[15] Experiments were completed in triplicate. Log_{10} CFU reductions were calculated in comparison to untreated controls.

Reduction in gram-negative bacilli in biofilm recovered from sink drains

Because bacterial in sink drains may be present within a biofilm matrix, we assessed the efficacy of the technology against organisms associated with sink drain biofilm. Cotton-tipped swabs were used to recover biofilm material from the proximal 2.5 cm of pipes below the strainer of 2 hospital sinks with known *P. aeruginosa* or *E. cloacae* colonization. The swabs were used to inoculate 1-cm^2 areas of the sink bowl and the sink countertop. The sink was then exposed to far UV-C light for 45 minutes. Pre-moistened cotton-tipped swabs were used to sample the inoculated sites and organisms were quantified as previously described. Experiments were completed in triplicate. Log_{10} CFU reductions were calculated in comparison to untreated controls.

Reduction in gram-negative bacilli on real-world items with and without a far UV-C reflective surface

To assess the efficacy of the technology in reducing organisms on real-world items, 10 μL containing 6 $\log_{10}$ CFU of the *P. aeruginosa* strain in 5% fetal calf serum was inoculated onto a 1 cm^2 area on items identified in the survey as often being found near sinks in outpatient clinics. These included a canister of disinfectant wipes, a package of Kerlix gauze, and a box of gloves. Each item was inoculated on the horizontal top surface, a vertical side surface at a 90° angle from the light source, and a vertical shaded surface opposite the light source. After the inoculum air dried, the items were positioned on the sink countertop and exposed to far UV-C for 45 minutes.

Testing with real-world items was completed with and without the wall-mounted visibly transparent Far-UVC film technology designed to reflect 200–250-nm UV-C light adhered on poster-board to the wall behind the sink. The tests with the reflective material were included to assess whether the technology might increase efficacy in shadowed areas not in direct line of site of the far UV-C light. Pre-moistened cotton-tipped swabs were used to sample the inoculated surfaces and organisms were quantified by plating on selective media.[5] Experiments were completed in triplicate. Log_{10} CFU reductions were calculated in comparison to untreated controls. Far UV-C delivery to sites with and without the reflective wall-mounted coating was assessed using the radiometer.

Evaluation of the feature that discontinues far UV-C output during use of the sink

To assess the feature that discontinues output when the sensors detect people within the area of far UV-C light delivery, research personnel performed hand washing 20 times and visually

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Table 1. Frequency and types of patient care supplies and other frequently touched items within 1 meter of the drain for sinks in an acute care hospital

Location	Patient care supplies	Portable equipment	Personal items	**Other[a]**	Any items
ICU patient rooms (N=50)	4 (8)	6 (12)	2 (4)	10 (20)	17 (34)
Medical-surgical rooms (N = 100)	8 (8)	6 (6)	6 (6)	14 (14)	27 (27)
Outpatient clinic rooms (N = 20)	6 (30)	0 (0)	0 (0)	5 (25)	6 (30)
Staff work area (N = 20)	4 (20)	0 (0)	0 (0)	4 (20)	5 (25)
Total (N = 190)	22 (12)	12 (6)	8 (4)	33 (17)	55 (29)

Note. Data are shown as number (%). ICU: intensive care unit.
[a]other items included trash cans, towels and bedding, chairs, cannisters of disinfectant wipes, glove boxes, and tissues

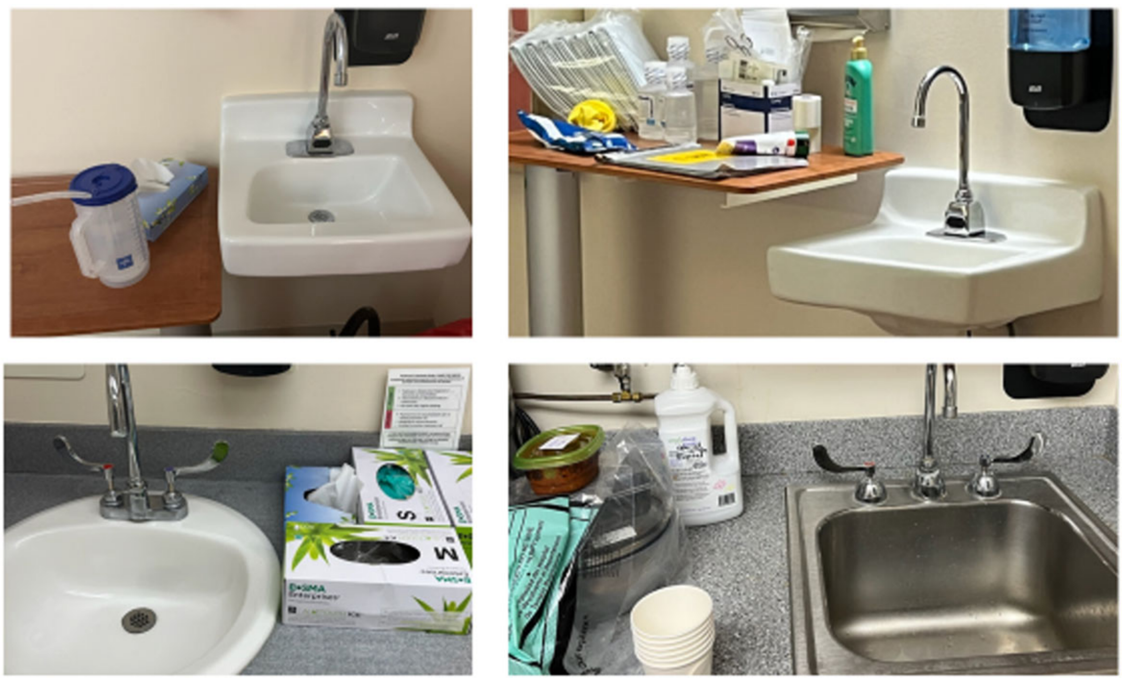

Figure 1. Pictures of sinks with items present within 1 meter of the drain.

monitored far UV-C output (ie, the lamps emit visible light when operating). We assessed when the lamps turned off, if they remained off during hand washing, and when they turned back on after exiting the area in front of the sink. To determine the potential for individuals standing near the sink to be exposed to far UV-C when the device was on, the radiometer was used to measure irradiance at multiple locations in the room outside the area where the lamps would detect a person and automatically turn off.

Data analysis

Welch's unequal variances *t*-test was used to compare reductions in *P. aeruginosa* in shaded locations on real-world items with versus without the reflective surfaces.

Results

Table 1 shows the results of the observational survey. Of 190 total sinks assessed, 55 (29%) had patient care supplies or other frequently touched items within 1 meter of the drain. The overall percentage of sinks with items within 1 meter of the drain was similar for sinks in outpatient clinics, medical-surgical rooms, ICU rooms, and staff work areas (25% to 34%). Figure 1 provides pictures of sinks with items present within 1 meter of the drain.

Figure 2 shows the irradiance readings and far UV-C dosages for 45 minutes of exposure at sites of steel disk placement and in locations where a person would stand in front of the sink during hand washing. The addition of the reflective wall surface increased the far UV-C irradiance measured in all the test sites on the counter and at 0.91 m from the drain. No far UV-C light was detected in locations lateral to and behind the device in locations where hand washing would occur without the reflective surface, whereas low levels of far UV-C were detected in these locations when the reflective surface was present.

The far UV-C technology reduced *P. aeruginosa*, *E. cloacae*, and *C. auris* on the steel disk carriers in each of the test locations by $\geq$1.5 $\log_{10}$ CFU with a 45-minute exposure (Figure 3). For biofilm-associated *P. aeruginosa* or *E. cloacae* transferred from colonized sink drains, a 45-minute exposure to far UV-C light reduced recovery by $\geq$1.8 $\log_{10}$ CFU. On real-world test items, $\geq$1.9 $\log_{10}$ CFU reductions in *P. aeruginosa* were achieved in the sites on top

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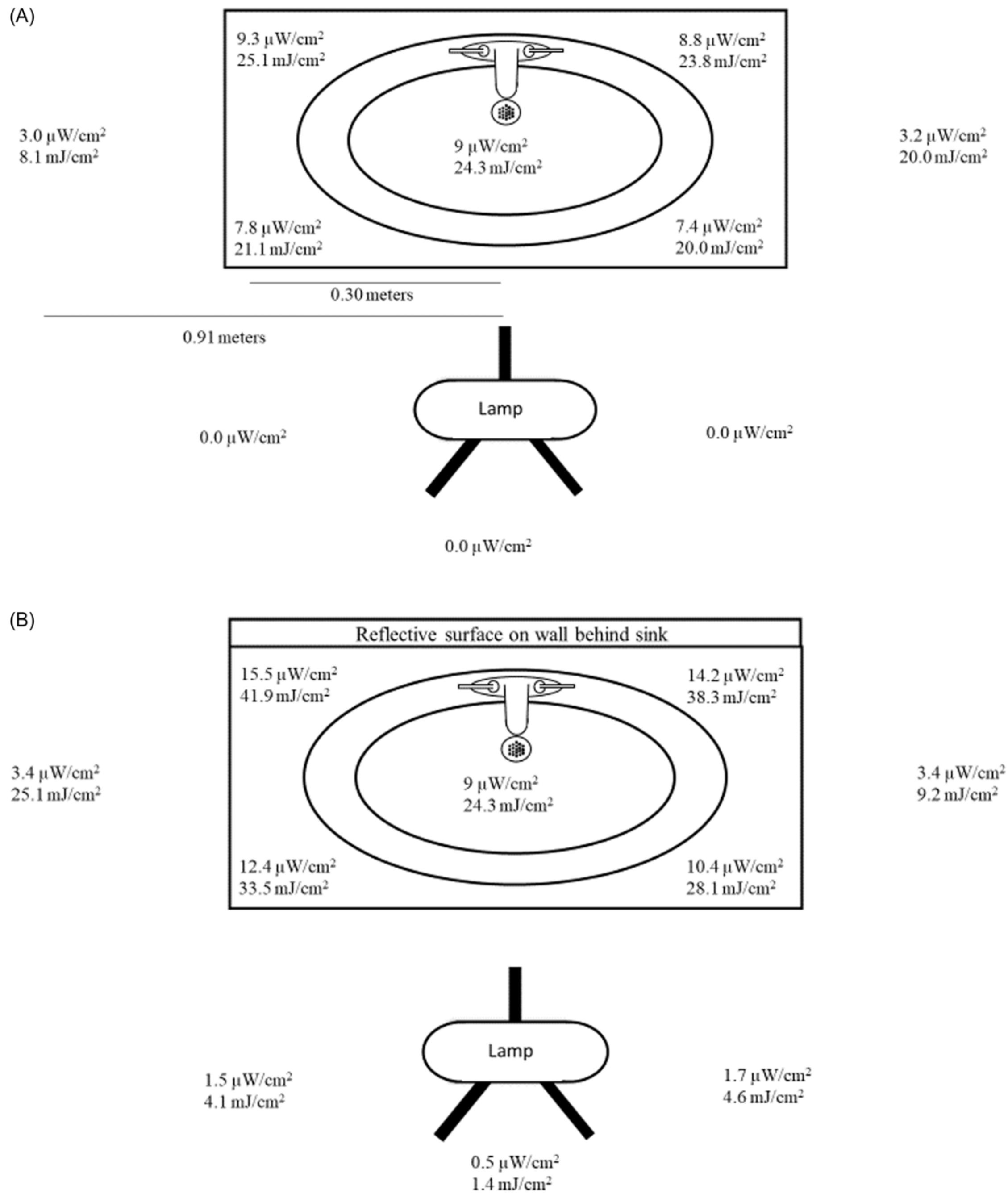

Figure 2. Irradiance measurements and dosages of far ultraviolet-C light with a 45-minute exposure without (A) and with (B) a wall-mounted transparent film technology designed to reflect 200–250-nm UV-C light.

of the test items that were in direct line of site of the far UV-C light source, but by 0.4 to 1.8 $\log_{10}$ CFU in the shaded sites (Figure 4); with the addition of the reflective surface, there was a significant increase in the reduction in *P. aeruginosa* in the shaded sites ($P < 0.01$).

During 20 episodes of hand washing, the device consistently turned off immediately when personnel entered the area in front of the sink where far UV-C was detectable. The device remained off during hand washing and turned back on 30 seconds after individuals moved away from the front of the sink. With the device on, no measurable levels of far UV-C light were detected in locations in the room outside of the area where the device detects people and automatically turns off.

Discussion

In response to outbreaks linked to sinks, a variety of interventions have been used to reduce the burden of colonization and removal of sinks from patient rooms has been considered in some situations.[2,4,6–10] There is a need to evaluate new approaches as such interventions can be costly, labor-intensive, and difficult to sustain. In the current study, we demonstrated that a far UV-C

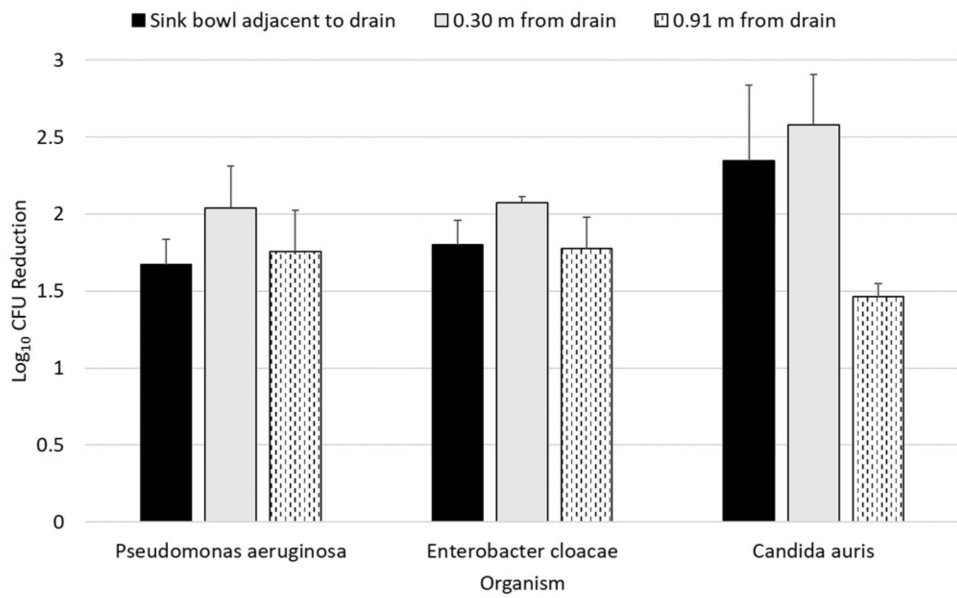

Figure 3. Efficacy of a far ultraviolet-C (UV-C) light technology against *Pseudomonas aeruginosa*, *Enterobacter cloacae,* and *Candida auris* on steel disk carriers in 3 test locations with a 45-minute exposure. Error bars show standard error.

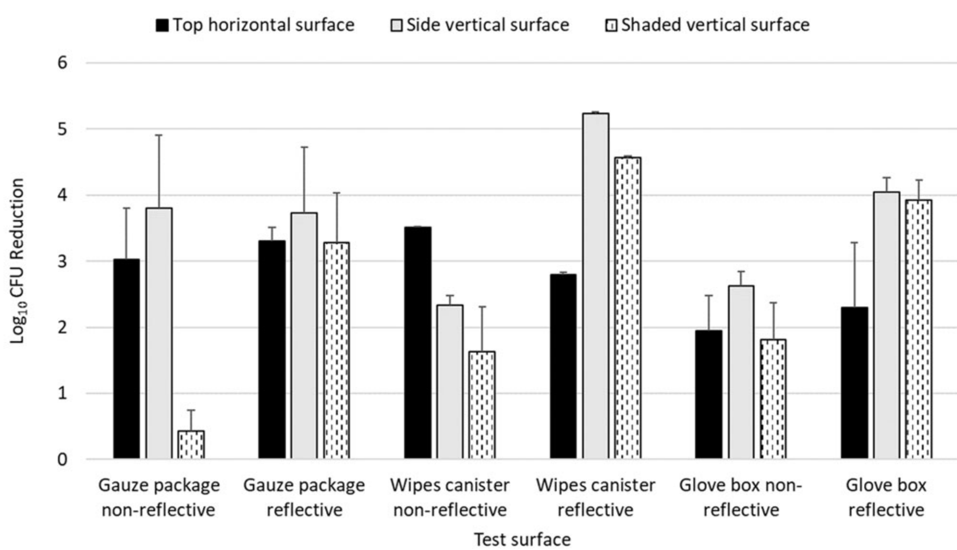

Figure 4. Efficacy of a far ultraviolet-C (UV-C) light technology with a 45-minute exposure against *Pseudomonas aeruginosa* inoculated onto real-world test items placed on a sink countertop with and without a wall-mounted transparent film technology designed to reflect 200–250-nm UV-C light. The items were inoculated on the horizontal top surface, a vertical side surface at a 90° angle from the light source, and a vertical shaded surface opposite the light source. Error bars show standard error.

light technology was effective in reducing gram-negative bacteria and *C. auris* on steel disk carriers placed in a sink bowl or on surfaces within 1 meter of the drain. On real-world items, the technology was effective in reducing *P. aeruginosa* in sites directly exposed to far UV-C light, but less effective on shaded surfaces. The addition of a reflective surface on the wall behind the sink substantially enhanced far UV-C delivery to the shaded surfaces with significant improvement in reductions in *P. aeruginosa*. These results suggest that the far UV-C light technology could be considered as an adjunct to manual cleaning and disinfection to reduce the risk for transmission of pathogens from sinks in high-risk areas.[13]

One implication of our findings is that there is a need for healthcare facilities to assess the frequency and type of patient care supplies and other high-touch items located in proximity to sinks. Such assessments are particularly needed in ICUs and areas providing care for immunocompromised patients.[1,13] Although most outbreaks related to colonized sinks have involved ICUs and other inpatient settings, there is a risk for transmission from contaminated sinks in outpatient settings providing care for immunocompromised patients. For example, an outbreak of *Pantoea agglomerans* bloodstream infections in an oncology clinic was linked to a colonized pharmacy sink.[18]

There is a growing body of evidence that far UV-C doses within proposed threshold limit values may be safe.[14,19–24] However, additional real-world studies are needed in occupied areas. Our findings demonstrate that the application tested here would result in minimal far UV-C exposure. The device consistently turned off and stayed off while people used the sink for hand washing. With the device directed toward the sink, no far UV-C irradiance was detected outside of the area immediately in front of the sink when the reflective material was not present. With the reflective material present, a low level of far UV-C light was detected outside the area where the device detects people and turns off. However, it is anticipated that this level of exposure would be well below the 8-hour threshold limit values proposed for far UV-C exposure (161 mJ/cm^2 for eyes and 479 mJ/cm^2 for skin).[14]

Our study has some limitations. The observational evaluation of items in proximity to sinks was conducted in one facility and a

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convenience sample of sinks was assessed. The efficacy testing was conducted in a laboratory setting and with a high organism inoculum and only a 45-minute exposure. Additional studies are needed in real-world settings that are likely to include a lower organism burden and longer far UV-C exposure times; Hajar et al.[5] recovered a median of 2 bacterial colonies (range, 1 to 80) from countertops after hand washing. We did not perform air sampling to assess for aerosolized pathogens or examine the impact of far UV-C on aerosolized organisms. Finally, we did not assess ozone production by the far UV-C technology. It is recommended that those using far UV-C technologies ask the manufacturers to provide information on the potential for their devices to generate ozone, and requirements for adequate ventilation to prevent ozone accumulation.[14]

Conclusion

Patient care items and other frequently touched items were often in proximity to sinks in our healthcare facility. There is a need for assessments in other facilities and for development of strategies to reduce the presence of such items near sinks. In the setting of outbreaks linked to sinks, a ceiling-mounted far UV-C light technology could be useful in reducing the risk for transmission of organisms colonizing sink drains. Given that far UV-C delivery is substantially reduced in shaded areas, the addition of a far UV-C light reflective material should be considered if the technology is used.

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Competing of interest. C.J.D has received research grants from Clorox and Pfizer. T.J.H is an employee of 3M and has pending patents for the visibly transparent far UV-C reflective film. All other authors report no conflicts of interest relevant to this article.

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