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Concise Communication

Efficacy of UV-C disinfection in hyperbaric chambers

Bobby Glenn Warren MPS[1,2], Jason Masker RN, BSN, OCN, CNIII[3], Gregory Brown MBA, BS, CHT[3], Isabella Gamez[4], Becky Smith MD[1,2], Deverick J. Anderson MD, MPH[1,2] and Nicholas Turner MD[1,2]

[1]Duke Center for Antimicrobial Stewardship and Infection Prevention, Durham, North Carolina, [2]Division of Infectious Diseases, Duke University Medical Center, Durham, North Carolina, [3]Duke Center for Hyperbaric Medicine and Environmental Physiology, Duke University Medical Center, Durham, North Carolina and [4]North Carolina School of Science and Mathematics, Durham, North Carolina

Abstract

Ultraviolet C (UV-C) light reduces contamination on high-touch clinical surfaces. We assessed the efficacy of 2 UV-C devices at eradicating important clinical pathogens in hyperbaric chambers. Both devices were similarly efficacious against MRSA but differed significantly against *C. difficile*. Additionally, direct UV-C exposure was more efficacious against both species than indirect exposure.

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Contaminated healthcare environmental surfaces contribute to pathogen transmission. Among the UV-C disinfection studies conducted in clinical settings, results have been mixed, perhaps in part due to heterogeneity in device design, protocols for use, and application within real-world clinical settings.[1,2] Testing individual products in clinical environments before deploying them in healthcare facilities is critical.[3,4] Additionally, few studies have tested UV-C devices in specialized healthcare settings such as hyperbaric chambers. In this study, we evaluated the efficacy of 2 UV-C devices for disinfection of surfaces contaminated with epidemiologically important pathogens (EIPs) in hyperbaric chambers of varying shapes.

Methods

We assessed the efficacy of the Tru-D (SmartUVC) and Moonbeam-3 (Diversey) UV-C devices at eradicating EIPs in 2 hyperbaric chambers at Duke University Health System in Durham, North Carolina.

For MRSA, bacterial suspensions were prepared by incubating in tryptic soy broth (TSB) at 37°C until reaching an optical density at 600 nm (OD_{600}) of 0.8 and serially diluting them. For *Clostridioides difficile*, bacterial suspensions were prepared by resuspending 48-hour growth from anaerobically incubated trypticase soy agar (TSA) blood agar in phosphate-buffered saline and diluting it to a prestandardized OD_{600}. We inoculated 10×10-cm Formica sheets with 10^6–10^7 colony-forming units (CFU) of methicillin-resistant *Staphylococcus aureus* (MRSA, USA300) or 10^4–10^5 *C. difficile* (NAP1; BEI Resources, NIH isolate no. 20120236). Inocula were spread on the center 25 cm^2 of the Formica sheets and were allowed to dry for 5 minutes. Inoculated sheets were placed in 6 predetermined locations throughout each of 2 hyperbaric chambers (chambers A and C). Inoculated control plates remained outside the chambers during disinfection and sampled alongside inoculated sheets.

Chamber A was a 2-hatched cylinder with a diameter of 6 m (19'6") and a length of 4.4 m (14'6"). Chamber C was a 3-hatched spherical chamber 6 m (20') in diameter. In chamber A, inoculated Formica sheets were placed on the regulator connection area, which received direct UV-C for Tru-D experiments (direct exposure) and indirect UV-C for Moonbeam-3 experiments (indirect exposure), patient chair armrest (direct exposure), medlock (indirect exposure), chamber door handle (direct exposure), medical supply cart (direct exposure), and the underside of the patient chair side table (indirect exposure). In chamber C, the locations and exposure pathways were the same, except the medlock was replaced with the sink (direct exposure). Samples were placed between 0.6 m (2') and 1.5 m (5') away from the UV-C device in chamber A and between 1.2 m (4') and 3 m (10') from the UV-C device in chamber C. Each sample site was defined as receiving direct UV-C exposure if a straight line could be extended from a UV-C bulb to the sample site uninterrupted, otherwise it was defined as receiving indirect exposure.

For this experiment, 2 Moonbeam-3 UV-C devices were positioned in the center of each chamber back to back, with each bulb at a 45° angle from the center of the device, and was run for a 3-minute cycle (according to the manufacturer's instructions) and a 5-minute cycle. One Tru-D was positioned in the center of the chamber center and was then run on the vegetative cycle for MRSA and the spore cycle for *C. difficile*. UV-C irradiance was measured for both machines at each sample location using 2 different quantitative radiometers (Grainger, Raleigh NC), and dosages were calculated. Quantitative cultures were collected using RODAC plates with DE neutralizing agar. The *C. difficile* was replica plated onto prereduced TSA sheep's blood agar. Both were incubated at 37°C for 48 hours. Each combination of chamber, microbe, UV-C device, and device cycle was run in triplicate for a total of 108 samples per species.

Author for correspondence: Bobby Glenn Warren, E-mail: Bobby.warren@duke.edu.

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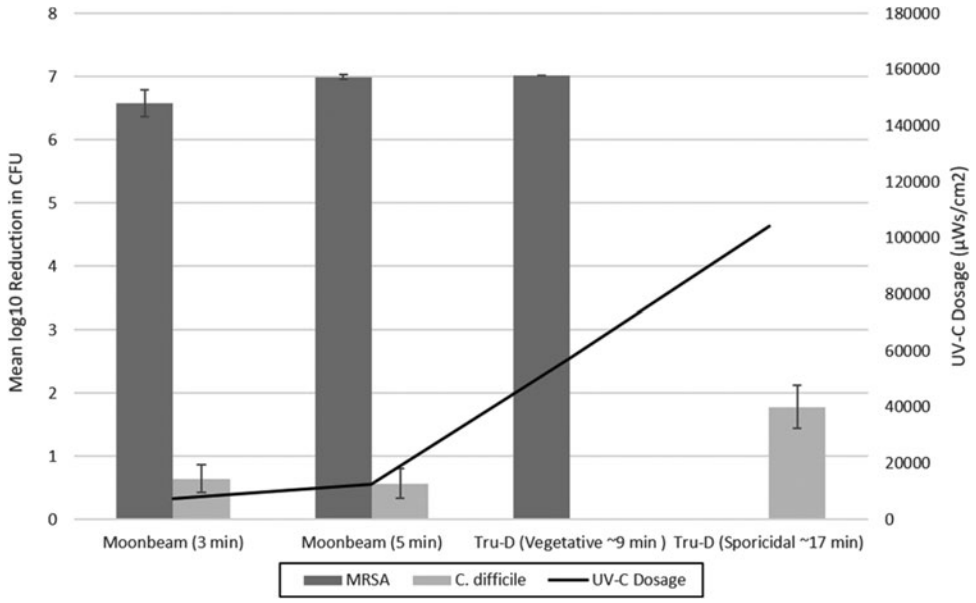

Fig. 1. Colony-forming units (CFU) $\log_{10}$ reduction and ultraviolet C (UV-C) dosage.

The independent *t* test was used to compare CFU $\log_{10}$ reductions among cycles, machines, and exposure pathways. A *P* value of .05 was considered significant. All statistical tests were 2-tailed and were conducted using R software (R Foundation for Statistical Computing, Vienna, Austria).

Results

UV-C dosages

The mean UV-C dosages of the 3- and 5-minute Moonbeam-3 cycles were 7,403 and 12,338 µWs/cm^2, respectively (Fig. 1). The direct and indirect UV-C dosages achieved with the 3-minute cycle were 10,813 and 3,510 µWs/cm^2, respectively, and with the 5-minute cycle, 16,971 and 5,850 µWs/cm^2, respectively (Fig. 2).

The mean UV-C dosage of the Tru-D spore cycle (mean time, 17 minutes) was 104,041 µWs/cm^2, and the mean UV-C dosage of Tru-D vegetative cycle (mean time, 9 minutes) was 57,705 µWs/cm^2 (Fig. 1). With the Tru-D spore cycle, the direct UV-C dosage achieved was 152,557 µWs/cm^2 and the indirect UV-C dosage achieved was 55,525 µWs/cm^2. With the Tru-D vegetative cycle, the direct UV-C dosage achieved was 83,882 and the indirect UV-C dosage achieved 31,812 µWs/cm^2, respectively (Fig. 2).

MRSA

The Tru-D vegetative cycle resulted in an average CFU $\log_{10}$ reduction of 7.02 (95% CI, 7.02–7.02), the 3-minute Moonbeam-3 cycle resulted in an average CFU $\log_{10}$ reduction of 6.58 (95% CI, 6.37–6.79), and the 5-minute Moonbeam-3 cycle resulted in an average CFU $\log_{10}$ reduction of 6.99 (95% CI, 6.95–7.02) (Fig. 1). The Tru-D vegetative cycle and the 5-minute Moonbeam-3 cycle were similarly efficacious ($P > .99$), and both were more efficacious than the 3-minute Moonbeam-3 cycle ($P < .001$, $P < .001$, respectively). The MRSA samples subjected to direct UV-C exposure showed significantly greater $\log_{10}$ reductions (6.95; 95% CI, 6.89–7.01) than those subjected to indirect exposure (6.67; 95% CI, 6.46–6.87; $P < .05$) (Fig. 2).

Clostridioides difficile

The Tru-D sporicidal cycle resulted in an average CFU $\log_{10}$ reduction of 1.78 (95% CI, 1.43–2.12), the 3-minute Moonbeam-3 cycle resulted in an average CFU $\log_{10}$ reduction of 0.57 (95% CI, 0.33–0.81), and the 5-minute Moonbeam-3 cycle resulted in an average CFU $\log_{10}$ reduction of 0.64 (95% CI, 0.42–0.86) (Fig. 1). The Tru-D sporicidal cycle was significantly more effective than either the 3-minute Moonbeam-3 cycle or the 5-minute Moonbeam-3 cycle ($P < .01$). The *C. difficile* samples receiving direct UV-C exposure had significantly greater $\log_{10}$ reductions (1.34; 95% CI, 1.10–1.58) than those receiving indirect exposure (0.58, 95% CI, 0.31–0.86; $P < .01$) (Fig. 2).

Discussion

UV-C light reduces contamination of high-touch clinical surfaces, yet more studies are needed to test the comparative efficacy of UV-C devices in real-world clinical environments.[5-7] We tested the efficacy of 2 UV-C devices in clinical hyperbaric chambers. The use of the Tru-D vegetative cycle and the 5-minute Moonbeam cycle resulted in similar reductions in MRSA; both resulted in significantly larger reductions than the manufacturer's recommended 3-minute Moonbeam-3 cycle. For *C. difficile*, the Tru-D sporicidal cycle was significantly more efficacious than either of the Moonbeam-3 cycles; however, neither device approached the >3 $\log_{10}$ threshold. Therefore, healthcare facilities should re-evaluate manufacturer-recommended run times in their specific clinical setting. If possible, hospitals should test different machines in their own facilities and varying room configurations. Direct UV-C exposure resulted in greater average reductions than indirect exposure, which is likely due to the large differences in UV-C dosage. In addition to manufacturer's instructions, run time, path of UV-C exposure, resultant UV-C dosage, and pathogen type are key components to consider when designing facility-specific recommendations.

Previous studies have shown the potential of UV-C as a disinfectant in controlled environments, but it is imperative to test UV-C in the real-world clinical environment.[1] In a previous

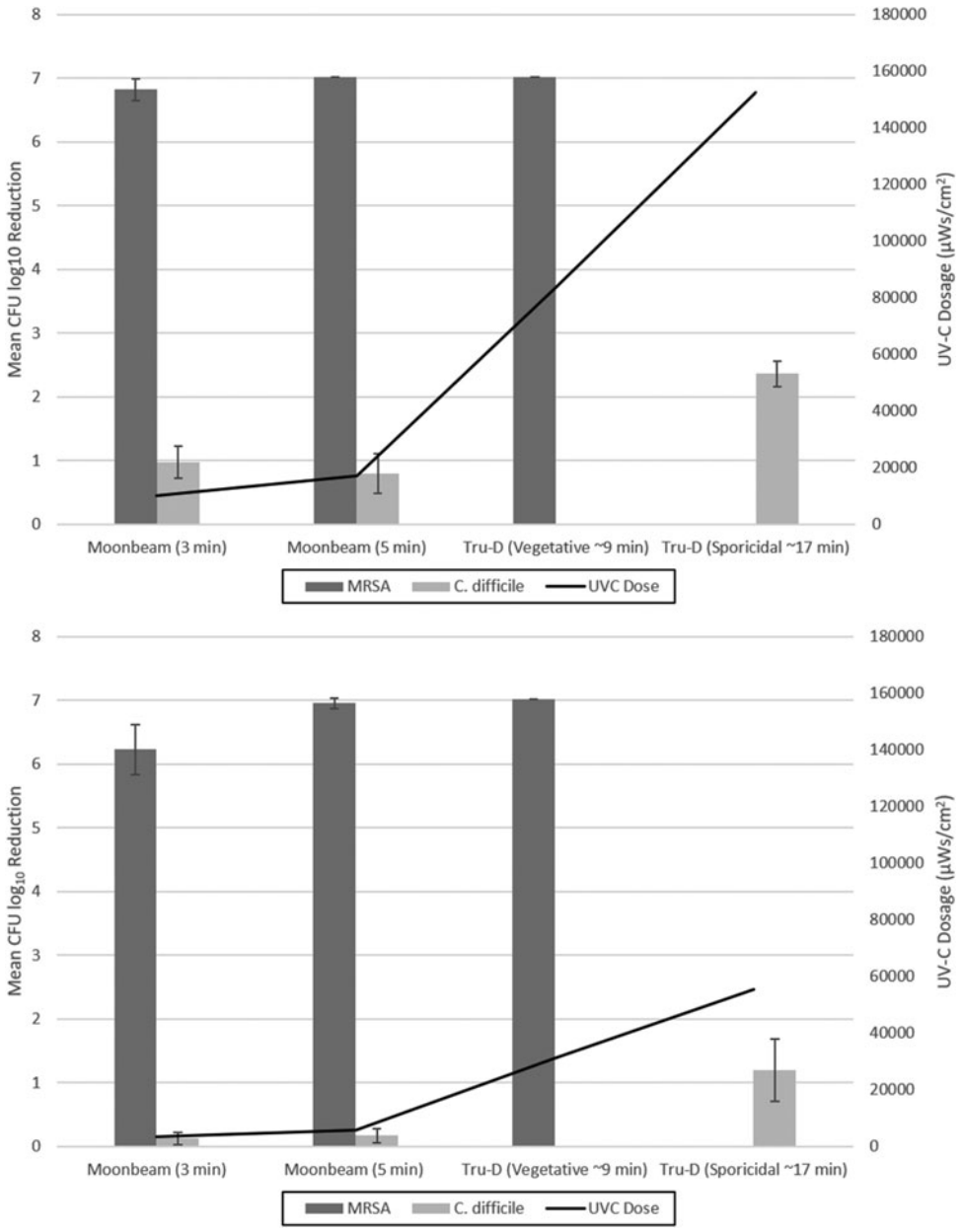

Fig. 2. (a) Direct ultraviolet C (UV-C) exposure colony-forming units (CFU) $\log_{10}$ reduction and UV-C dosage. (b) Indirect UV-C exposure CFU $\log_{10}$ reduction and UV-C dosage.

clinical trial, we demonstrated the benefit of Tru-D UV-C disinfection in addition to routine cleaning, but no clinical trials including patient outcomes have evaluated the Moonbeam-3 or other UV devices.[8] Our $\log_{10}$ reductions of 6 or higher for MRSA are larger than those of prior studies, most likely due to differences in inoculum size.[9,10]

Our study has several limitations. We sampled Formica sheets instead of sampling directly from clinical surfaces. We evaluated only 2 pathogens, and our experimented lacked contamination simulation (eg, concomitant organic load or co-contaminants). Because our experiments were conducted in hyperbaric chambers, the results may not be generalizable to other contexts. Subsequent trials should further evaluate UV-C for disinfection by replicating the real-world clinical environment as accurately as possible.

In conclusion, UV-C disinfection can be efficacious in hyperbaric chambers by reducing the levels of clinically relevant bacteria by at least 3 $\log_{10}$, but individual UV-C devices should be tested and optimized internally while also recognizing that similar efficacy may not be achieved with certain pathogens such as *C. difficile*.[2]

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Conflicts of interest. No authors report any conflicts of interest.

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