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Brief Report

Focused multivector ultraviolet (FMUV) technology rapidly eradicates SARS-CoV-2 *in-vitro*: Implications for hospital disinfection of COVID-19 environments

Steven Park BA [a], David S. Perlin PhD [a], Sean Fitzgerald MPH [a], Vidmantas Petraitis MD [b,*], Thomas J. Walsh MD, PhD [b]

[a] *Hackensack Meridian Health Center for Discovery and Innovation, Nutley, NJ*
[b] *Department of Medicine, Division of Infectious Diseases, Weill Cornell Medicine of Cornell University, New York, NY*

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UV disinfection
Shadowless delivery

A B S T R A C T

Focused Multivector Ultraviolet technology rapidly killed the SARS-CoV-2 coronavirus *in-vitro*. Plates were inoculated with a mean of greater than 10^6 plaque forming units of USA-WA1 Washington index patient strain of SARS-CoV-2 and exposed to ultraviolet, resulting in mean reductions of 99.99% within 30 seconds, 99.999% within 60 seconds, and 99.9999% within 90 seconds. These results support the effectiveness of Focused Multivector Ultraviolet technology for SARS-CoV-2 disinfection.

Hospitals worldwide have suffered the effects of the COVID-19 pandemic. Surface contamination by SARS-CoV-2 is a prevalent problem in hospitals caring for COVID-19 patients,[1] and has been noted as a potential source of transmission.[2] Chia et al. studied airborne infection isolation rooms where patients with COVID-19 were hospitalized and found high touch surface contamination in 66.7% of patient rooms in the first week of illness.[1] Additionally, an overview study showed SARS-CoV-2 viral particles extensively contaminated both the air and surfaces in rooms of COVID-19 patients. For all instances where air samples were positive for SARS-CoV-2 RNA, environmental surface samples were also positive.[2]

Several studies have demonstrated the activity of ultraviolet-C (UV-C) against SARS-CoV-2.[3-5] However, the test conditions utilized do not easily translate to the hospital environment. UV instruments using a single lamp or centralized source of lamps lose microbicidal activity as an inverse function of the radial distance from the source ($1/r^2$), while also being limited by shadowing effects for 3-dimensional surfaces. However, Focused Multivector Ultraviolet (FMUV) systems sustain high UV-C energy levels in the exposure field and overcome shadowing by virtue of the technology's method of light delivery from multiple sources. FMUV has been previously shown as an automated approach for overcoming inconsistencies inherent to manual cleaning.[6]

It was hypothesized that the technology being tested would rapidly eradicate SARS-CoV-2 *in-vitro* to document its efficacy for continued use in healthcare applications for environmental disinfection. Therefore, this study investigated the efficacy of FMUV for various exposure durations on a patient strain of SARS-CoV-2 *in-vitro*.

METHODS

All stages of this study were conducted in a biosafety level 3 (BSL-3) facility at the Center for Discovery and Innovation according to strict biosafety guidelines.

Inoculum preparation

A solution of the USA-WA1 Washington index patient strain of SARS-CoV-2 stock was prepared in accordance with ASTM E1053 standards[7] in Dulbecco's Modified Eagle Medium +2% Fetal Bovine Serum with a titer of mean 1.125×10^6 PFU/mL for controls.

Test configuration

An FMUV system (PurpleSun Inc.) was deployed in a configuration to surround a 76×183 cm test table centered in the rectangular-

* Address correspondence to: Vidmantas Petraitis MD, Weill Cornell Medicine of Cornell University, 1300 York Ave, Box 125, New York, NY 10065.
E-mail address: Vip2007@med.cornell.edu (V. Petraitis).

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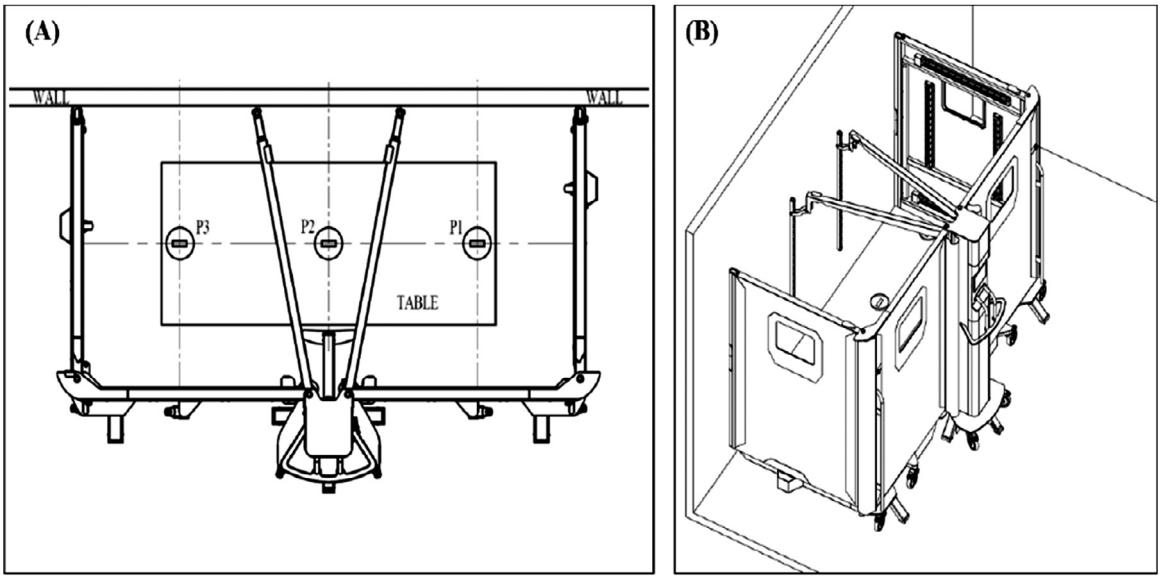

Fig 1. (A) Top view and (B) isometric view of the test equipment in rectangular configuration surrounding a table with triplicate test samples equally spaced in the center of the 195 × 140 × 274 cm FMUV target zone.

shaped target zone at a 74 cm height (Fig 1). This zone is typically designated for disinfection of critical patient care equipment as large as patient beds and operating tables.[6]

Carrier preparation and FMUV exposure

Glass slide carriers (25 × 75 × 1 mm) were cleaned, sterilized, placed within sterile Petri dishes, and inoculated with a 0.1 mL viral droplet. Due to BSL-3 safety and containment requirements, Petri dishes were covered with UV-transmissible material throughout the test, which were known to partially reduce UV exposure to the samples. Samples were exposed to FMUV light for durations of 0, 30, 45, and 90 seconds.

Quantification

After exposure, viral droplets were extracted from their carrier using a P200 pipette with a sterile aerosol barrier tip, diluted by a factor of 10, and assayed for infectivity in VeroE6 cells in Dulbecco's Modified Eagle Medium + Fetal Bovine Serum, supplemented with Penicillin, Streptomycin, and Amphotericin B. Cells were stained with 0.5% crystal violet, washed, and the detected number of viable organisms for each carrier was listed as plaque forming units (PFUs). Standard methods for data analysis and calculations were utilized to determine Log Reduction (LR) and Percent Reduction (PR).[8]

RESULTS

Data from the plaque assay on virus infectivity at the given dilution is shown in Table 1.

Current standards such as ASTM E2197 do not address methods for analyzing zero detected PFUs, such as observed here.[9] However, this is addressed in the Data Analysis section of Environmental Protection Agency MB-31-03, which was therefore used to compute the results. At a 10-fold dilution when a portion of carriers at a given time point showed zero, a value of 5 PFU/mL was used. The mean LR and PR was then calculated for the 30 seconds and 45 seconds time points. The standard further describes, for time points where zero PFUs are observed for all treated carriers, the LR and PR are recorded as ≥ the mean $\log_{10}$ density of the control carriers, which was followed for the 90 seconds time point.

The germicidal activity of FMUV resulted in a mean 4-log reduction (99.9954%) of PFUs/carrier within 30 seconds, 5-log reduction (99.9994%) in 45 seconds, and ≥6-log reduction (≥99.9999%) in 90 seconds. Using the Aspin-Welch Test for Unequal Variance, *P*-values at all time points were .011, which is considered statistically significant.

DISCUSSION

This study demonstrated rapid *in-vitro* eradication of viable SARS-CoV-2 within 90 seconds. To our knowledge, this is the first study to demonstrate a ≥6-log reduction of viable SARS-CoV-2 in a large-scale test setup within 90 seconds. One study reported a >6-log reduction after 540 seconds of UV exposure using one lamp at a 3 cm distance,[4] while another described a >3-log reduction after 84.4 seconds also using one lamp at 25 cm.[5]

The system employed in this study has been utilized in a wide range of hospital settings for equipment disinfection, especially between patient cases. Although this system is designed to treat equipment, the deployment wall and any other surfaces that are within the target zone will also disinfected. As United States hospitals

Table 1
Results for individual and mean detected plaque forming units for all carriers when exposed to Focused Multivector Ultraviolet light for 0, 30, 45, and 90 seconds

Condition	Exposure time (s)	Plaque forming units (PFU)				Mean PFU	Percent reduction
Control Carriers	**0**	700,000	1,300,000	900,000	1,60,0000	1,125,000	N/A
Test Carriers	**30**	80	30	50		53.33	99.9954%
	45	0	10	0		3.33	99.9994%
	90	0	0	0		0	99.9999%

become increasingly overwhelmed with variant COVID-19 cases, the need for rapid and effective disinfection is highlighted to properly facilitate safe patient room turnover. Though there is little *in-vitro* data on air disinfection of SARS-CoV-2 to date, pathogens are known to be more susceptible to UV-C in air than on surfaces or in liquid.[10] Furthermore, as this study demonstrated significant activity against the virus *in-vitro* suspended in a droplet on surfaces, the data suggests that this method of delivery would produce similar effects on aerosolized SARS-CoV-2 droplets.

This study demonstrates FMUV rapidly reduced the SARS-CoV-2 coronavirus by ≥99.9999% within 90 seconds. Coupled with this technology's ability to treat equipment without requiring users to evacuate the room,[6] this data identifies FMUV as a potentially important approach to controlling COVID-19 in healthcare environments.

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