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Cone Shape Structure of Ultraviolet C Device: Effectiveness Against Surrogate Pathogen during COVID-19 Pandemic

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Introduction: COVID-19 has been declared as a pandemic. Unavoidable roles of anesthesiologist are anesthesia and endotracheal intubation in infected patients requiring surgical operation and suffering respiratory failure, respectively. Ultraviolet C (UVC) has been recommended for disinfecting the operating room in COVID-19 situation.

Objective: To study the effectiveness of our UVC device in disinfection of *Pseudomonas aeruginosa*, which was used as a surrogate of SARS-CoV-2.

Materials and Methods: The UVC device was comprised of 12 UVC lamps. The lamps were assembled in cone shaped. The power and timer of UVC lamps were controlled by mobile application. We studied disinfection effect of UVC device on *Pseudomonas aeruginosa* which generally tolerates to UVC more than coronavirus and is a common etiology of hospital acquired infection. The microbes were placed on glass and stainless-steel surfaces at 0.5-3 meters from the UVC device.

Results: The shorter distance and the longer exposure time were shown to increase killing effect of the device. Irradiation using this UVC device for 3 minutes eradicated *P. aeruginosa* on both glass and stainless-steel surfaces at least 99.9% (3 log10 reduction) at all tested distances. The effectiveness of killing was appeared to be higher on the bacteria placed on stainless-steel than on the glass surface.

Conclusion: This UVC disinfection device was effective in eradicating *P. aeruginosa*, which is more resistant to UVC than coronavirus. Using this UVC device to disinfect the operating room and other infected area may benefit in COVID-19 situation.

Keywords: COVID-19, Hospital disinfection, *Pseudomonas aeruginosa*, Ultraviolet C

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Introduction

Coronavirus disease 2019 (COVID-19) caused by severe acute respiratory distress syndrome coronavirus 2 (SARS-CoV-2) has been declared as pandemic by the World Health Organization (WHO) from March 2020.[1,2] An unavoidable role of anesthesiologist in this pandemic is endotracheal intubation in infected patients suffering respiratory failure patients. Additionally, anesthesiologist have to continue routine perioperative management for many patients, which some of them may be asymptomatic carriers of SARS-CoV-2. During endotracheal intubation, the viral-containing secretion can be aerosolized and spread more easily.[3] Generally, the virus can stay on fomites for several hours.[3] To prevent transmission of the virus to medical personnel, infectious control measures are very important.

Ultraviolet C (UVC) was included in recommendations for cleaning the operating room in COVID-19 situation by Anesthesia Patient Safety Foundation.[4] UVC was also suggested to reduce infectious risks in the Operating rooms by several reports.[5-9] It kills microorganisms, both viruses and bacteria, by destroying their genetic materials (e.g. RNA and DNA) leading to cell death.[10] Several factors involve in disinfection efficacy of UVC such as types of microorganism, cell characteristics, surface of fomites, distance from UVC generator and UVC dosage.[11,12] The dosage of UVC depends on radiation intensity and exposure time.[13] The higher radiation intensity, the lower exposure time. The efficacy of UV irradiation were decreased when the distance increase and not effective in area of the shadow from light source.[14] Warning about using UVC device were radiation exposure leading to health problems e.g. skin cancer, cataract.[15,16] The device should have system for shut off from remote area or automatically stop for prevent complications.

In the previous work, we evaluated the effectiveness of an innovative robotic UVC radiation in killing *Pseudomonas aeruginosa* on 3 surfaces including glass, plastic and stainless-steel.[17] We employed *P. aeruginosa*, a hospital acquired pathogen which has higher resistance to UVC irradiation compare to other bacteria and viruses, as a surrogate for SARS-CoV-2.[18] The SARS-CoV-2 itself is generally disinfected by lower UVC dosage comparing to other microorganisms as it is an enveloped, single-stranded RNA virus.[19-23]

Our innovative robotic UVC in the previous work had cylindrical stainless steel at the center of the UVC lamps that reflects the UVC radiation. However, the disinfection efficacy of the reflected radiation was inferior than that of direct radiation.[24,25] We thus designed a new version of UVC disinfection device. In this UVC disinfection device, there was no materials between the light sources that UVC can project to the opposite way and the design was increase the angle of the lamps for direct line of radiation to the floor and ceiling. We aimed to evaluate optimal timing and distance for this new device in eradicating *p. aeruginosa* as the surrogate of SARS-CoV-2.

Materials and methods

Bacterial preparation and inoculum of fomites

P. aeruginosa ATCC 27853 was cultured in tryptic soy agar at 37oC for 24 hours. The colonies were suspended in 0.85% sodium chloride and turbidity was adjusted to 0.5 McFarland standard. Bacterial samples (0.1 mL) were inoculated on glass and stainless-steel surfaces and were then exposed to UVC irradiation at different distances and exposure times. Samples not being exposed to radiation were used as the positive controls. After radiation test, the bacterial samples were diluted to 1:10, 1:100, 1:1000 and 1:10,000 solutions and then cultured in tryptic soy agar at 37oC for 24 hours. The growth colony were reported as CFU/ml and log10 reduction CFU/ml

Ultraviolet C disinfection device

The UVC device was comprised of 12 UVC lamps (TUV 36W SLV/6, Philips). The lamps were assembled in cone shaped and placed on 3 wheels as figure 1. The power supplies were Lithium-ion battery 24V/55Ah and charging input 220V AC. The power and timer of UVC lamps were controlled by mobile application.

UVC disinfection testing

We study the efficacy of UVC disinfection device in the test room. The bacterial samples were spread on glass and stainless-steel surfaces which placed at different locations. There were 2 study levels including floor and on the clear box 50 cm above the floor. There was some shadow from the base of the device then we choose 0.5 m for the nearest distance at floor level for test the efficacy at the floor. The samples were placed at 1,2 and 3 meters from the center of the device were test both levels. There was one positive control which not expose to the radiation. The exposure time were 3, 5, 10 and 15 minutes respectively.

UV intensity measurement

UV intensity was measure at each study site with DIGICON UV-370SD device and shown in mJ/cm2. The measurement at floor levels were assessed with 2 probe positions due to angle of the radiation. The probes were placed horizontally and vertically for evaluate the intensity.

Statistics

The reduction of microbes was shown as log10CFU reduction.

Log CFU reduction = log A – log B

A = CFU of microbes before treatment, B = CFU of microbes after UVC treatment

With 1, 2, 3 and 4 log10reduction means 90, 99, 99.9 and 99.99 % reduction of microbes after treatment respectively.

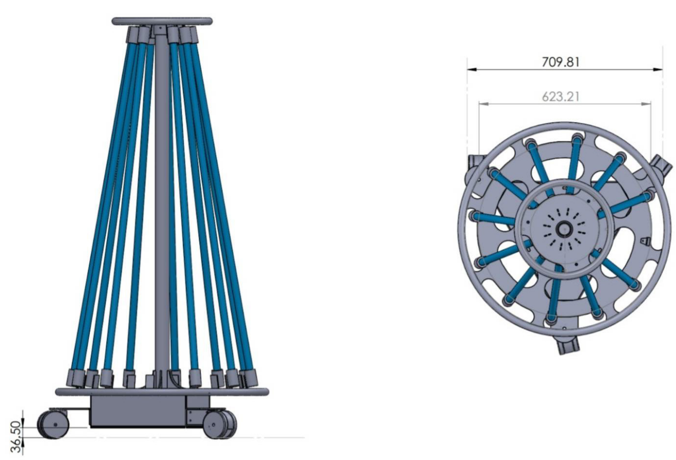

Figure 1 Ultraviolet C disinfection device

Results

Effectiveness of UVC disinfection device on killing *P. aeruginosa*

The results of UVC irradiation shown that the short distance and the longer exposure time increase killing effects. Irradiation using this UVC device for 3 minutes eradicated *P. aeruginosa* on both glass and stainless-steel surfaces at least 99.9% (3 log10 reduction) at all tested distances (Table 1 and Figure 2). The effectiveness was appeared to be higher on the stainless-steel than on the glass surface. For irradiation of 5 minutes or above, the microbes on stainless-steel surface were killed almost 100% at all distances, while on the glass surface, the killing effect was much lower at the longer tested distances (2 or 3 meters) (Table 2 and Figure 2). These findings indicated that the effectiveness for disinfection could be raised by increasing the exposure duration or by placing the device not too far away. Also, the bacteria on the stainless-steel surface

Table 1 Number of bacteria before and after UVC irradiation at each time and distance

		Number of bacteria (CFU/ml)			
		Glass		Stainless steel	
		Top	Bottom	Top	Bottom
3 min	Control	2.7×10^{10}		6.3×10^{10}	
	0.5m	-	0	6.3×10^{10}	0
	1m	2.8×10^{6}	2.1×10^{3}	9.0×10^{2}	0
	2m	1.13×10^{7}	7.5×10^{6}	1.0×10^{3}	4.0×10^{2}
	3m	1.23×10^{7}	9.1×10^{6}	1.5×10^{3}	9.0×10^{2}
5 min	Control	2.8×10^{10}		4.0×10^{10}	
	0.5m	-	0	-	0
	1m	0	0	0	0
	2m	4.4×10^{5}	2.5×10^{6}	0	0
	3m	7.9×10^{6}	9.0×10^{6}	0	0
10 min	Control	2.00×10^{10}		2.7×10^{10}	
	0.5m	-	0	-	0
	1m	0	0	0	0
	2m	2.2x103	2.9x104	0	0
	3m	3.4x106	2.7x106	0	0
15 min	Control	1.5×10^{10}		4.1×10^{10}	
	0.5m	-	0	-	0
	1m	0	0	0	0
	2m	0	1.7×10^{3}	0	0
	3m	2.6×10^{3}	1.4×10^{4}	0	0

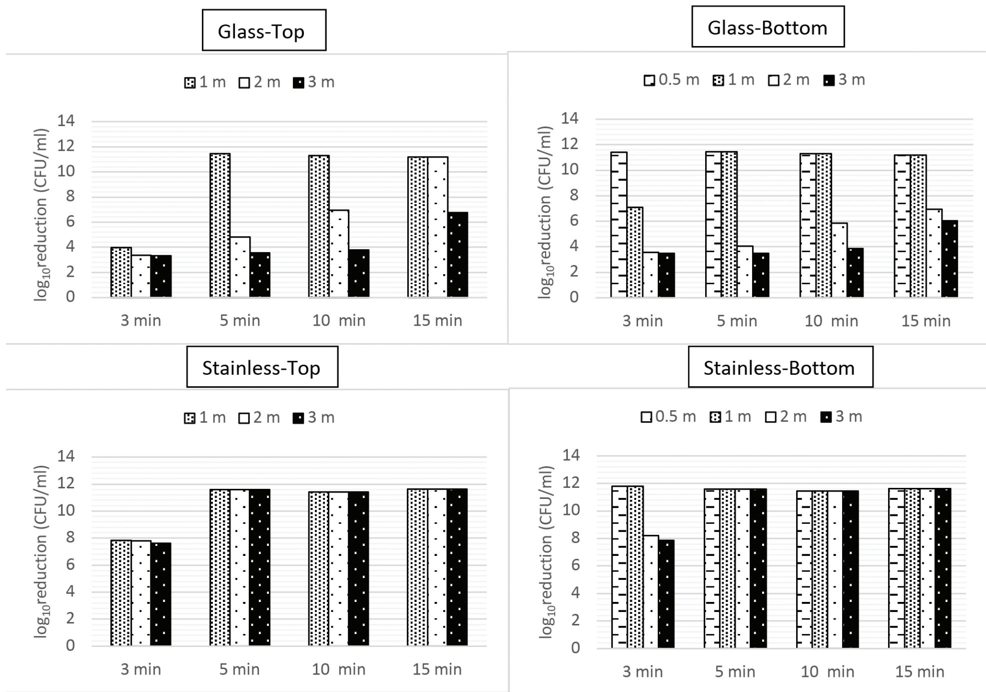

Figure 2 $\log_{10}$ reduction after UVC irradiation on each surface

were shown to be more vulnerable to UVC than those on the glass surface.

UVC intensity

Intensity of UVC on ground were 0.185-0.345, 0.126-0.415, 0.024-0.283 and 0.009-0.184 mW/cm^2 at 0.5, 1, 2 and 3 meters from center of the device. On height 50 cm from ground (Top), highest UVC intensity were 1.101 mW/cm^2 at 1 meter from the device. The intensity was decrease over distance. (Table 2)

Table 2 UVC intensity

Intensity (mW/cm^2)			
Distance (m)	Top	Bottom	
	Probe facing lamps	Probe facing up	Probe facing lamps
0.5	-	0.345	0.185
1	1.101	0.126	0.415
2	0.395	0.024	0.283
3	0.163	0.009	0.184

Discussion

This study aimed to evaluate the optimal timing and distance in killing *P. aeruginosa* using our new UVC disinfection device. Typical acceptable disinfection goal for fomites was 3 log10 reduction.[26] The results demonstrated that the device could eradicate at least 99.9% of the bacteria on both glass and stainless-steel surfaces under the 3-minute exposure to UVC radiation at all tested distances, which the shorter distance was more effective than the longer one. After being exposed to UVC for a longer duration, the effectiveness of eradication was shown to be higher. On the stainless-steel surface, the microbes were killed almost 100% at all distances equal to or more than 5 minutes. These basically reflect that the effectiveness of device depends on UVC dosage which is determined by radiation intensity and exposure time.[13] Microbes on glass surface were difficult to killed than stainless-steel. Previous study also demonstrates that eradication of pathogen on hard surfaces differ from suspensions. No clear explanation about relationship of each surface and microbial resistances.[11] In this study, *P. aeruginosa* was served as a surrogate for SARS-CoV-2 as disinfection of this bacteria generally requires higher dosage of UVC than many types of viruses.[18,22] Previous study demonstrated that coronaviruses were killed 99.9% at a UVC dosage of 0.6-40 mJ/cm.[20,27] UVC dosage (mJ/cm^2) is equal to UVC intensity (mW/cm^2) multiplies with exposure time (seconds). The intensities of this device were 29.34 - 33.12 mJ/cm^2 and 48.9 - 55.2 mJ/cm2 at 3 and 5 minutes of treatment which not less than the one indicated in the previous study.

We study at 0.5 meter from the center of the device due to the height of device base may create some shadow that decrease the effectiveness of the device on the floor. Interestingly, the highest killing effect was demonstrated at this location, which the UVC intensity on the ground was 0.185-0.345 mW/cm^2 depending on probe facing direction. In this study, the highest UVC intensity was measured at a distance of 1 meter form the device on the 50 cm-height clear box which the microbes were killed less than at a distance of 0.5 meters on the ground. This suggested that there might be factors contributing to the killing effect other than UVC dosage. Ozone is suspicious of such factor. UV has reaction with oxygen and produce ozone which was one method for hospital disinfection.[28,29]

This device showed a superior effectiveness in killing *P. aeruginosa* than our previous one, which could kill the microbes 99.9% (3 log reduction) at 10 minutes or over. Our previous device contained a cylindrical UVC reflector made of stainless-steel between the radiation sources.[17] The killing effectiveness of reflected light is typically inferior than direct light.[24,25] Thus, the new device was designed in purpose to remove the UVC reflector and placed UVC lamps in cone shape for project the light to ceiling and floor.

Previous studies shown that normal operating room disinfection process cannot eradicated all microbes. An environmental study using UV markers in operative room shown the cleaning process were removed only 47% of the markers and after feedback 82% of the markers were cleaned.[30] Another study showed that only 38.4% of microbials were disinfected by standard manual chemical cleaning process, but the reduction of microbes was increased to 96.5% when UV irradiation was combined in the cleaning process.[31] UVC disinfection is one of recommendations for optimization of infectious control and operating room management during COVID-19 pandemic from Anesthesia Patient Safety Foundation (APSF).[4] UVC is proven for disinfection of bacteria and virus and reduce human factors in cleaning process. However, the limitation of using UVC decontamination is shadowing then the cleaning protocol should comprise of manual chemical process and UVC irradiation.[32] In highly contagious virus situation such as SARS-CoV-2, it may appropriate for decontamination with UVC before human cleaning process for reduction of in hospital transmission. However, direct exposure to UVC potentially leads to several health problems, such as skin cancer and cataract.[15,16] We thus designed the device to be remotely operated by mobile application to avoid direct UVC exposure.

Our study has several limitations. Firstly, most parts of the study were conducted in the laboratory instead of operating room for safety reason. Secondly, the effectiveness of the device was tested by a single experiment due to resource limitation. However, all laboratory tests were performed by experience personnel and the results were theoretically justifiable and were not contradicted to the previous study.[17] Lastly, *P. aeruginosa* were used in laboratory tests instead of SARS-CoV-2, owing to the complexity of virus preparation and to safety reason during pandemic.

What is the new knowledge of this study?

We modified the UVC disinfection device by adjusting the angle of radiation lamps and by removing of reflecting material. Our result proves the usefulness of this device on microbial eradication. In addition, this modification may lead to a better capability on microbial eradication comparing to the traditional device design.

How to apply this knowledge?

Our device can be used for disinfecting the operating room and other infected area. Further modification of structure or control system should be encouraged and tested to maximize the efficiency of the UVC disinfection device.

Conclusion

This UVC disinfection device is effective in eradicating P. aeruginosa, which is more resistant to UVC than coronavirus. Using this UVC device to disinfect the operating room and other infected area may benefit in COVID-19 situation.

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