The Effectiveness of Cipto Mangunkusumo Hospital Ultraviolet Germicidal Irradiation (UVGI) Chamber for N95 Respirators Disinfection in COVID-19 pandemics: A Preliminary Study

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Abstract

Background*: During the COVID-19 pandemic, where the disease might spread in a medical facility setting, the common problems found in every country is the shortage of personal protective equipment (PPE) for medical personnel – especially the disposable N95 respirators. Thus, a higher amplitude to disinfect and reuse N95 is urgently needed. In this study, we designed an effective and safe disinfection methods through an Ultraviolet Germicidal Irradiation (UVGI) chamber in Dr. Cipto Mangunkusumo Hospital to control the shortage of PPE by disinfecting and reusing disposable N95 respirators. Purpose: To evaluate the dosage and effectiveness of UV-C radiation for disposable N95 respirators disinfection in our designated UVGI chamber.*
Methods*: This study used a cross-sectional design to determine the dose and the effectiveness of UV-C radiation in eradicating SARS-CoV 2 on disposable N95 respirators.*
Results*: Using two different distances from the light source, we confirmed the inverse square law of UV-C radiation power. Irradiation for 2 hours with a radiation dose of 1080 mJ/cm^2 resulted in undetected SARS-CoV-2 gene based on PCR examination in 10 out of 10 samples.*
Conclusion*: This UVGI chamber is a potential solution for hospitals or medical facilities to overcome the limitations that occurred in the pandemic by disinfecting PPE.*

Keywords: *UV-C, Dr. Cipto Mangunkusumo Hospital UVGI chamber, SARS-CoV-2, N95 respirators, COVID-19*

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Efektivitas Kamar Ultraviolet Germicidal Irradiation (UVGI) Rumah Sakit Cipto Mangunkusumo untuk Disinfeksi Respirator N95 di Pandemi COVID-19: Studi Pendahuluan

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Abstrak

Pendahuluan: *Selama pandemi COVID-19, masalah umum yang ditemukan di setiap negara adalah kekurangan alat pelindung diri (APD) untuk tenaga medis – terutama respirator N95 sekali pakai. Dengan demikian, diperlukan strategi untuk mendisinfeksi dan menggunakan kembali respirator N95. Dalam penelitian ini, dilakukan penelitian untuk mengetahui metode desinfeksi yang efektif dan aman menggunakan ruang Ultraviolet Germicidal Irradiation (UVGI) di Rumah Sakit Dr. Cipto Mangunkusumo untuk mengatasi kekurangan APD dengan mendisinfeksi dan menggunakan kembali respirator N95 sekali pakai. Tujuan: Untuk mengevaluasi dosis dan efektivitas radiasi UV-C untuk desinfeksi respirator N95 sekali pakai di ruang UVGI yang dirancang.*
Metode: *Penelitian ini menggunakan desain potong lintang untuk mengetahui dosis dan efektivitas radiasi UV-C terhadap SARS-CoV 2 pada respirator N95 sekali pakai.*
Hasil: *Penelitian ini menemukan bahwa penyinaran selama 2 jam dengan dosis radiasi 1080 mJ/cm^2 di dalam ruang UVGI menghasilkan tidak terdeteksinya gen SARS-CoV-2 berdasarkan pemeriksaan PCR pada 10 dari 10 sampel.*
Kesimpulan: *Ruang UVGI ini merupakan solusi potensial bagi rumah sakit atau fasilitas medis untuk mengatasi keterbatasan yang terjadi di masa pandemi dengan melakukan disinfektan APD.*

Kata kunci: *UV-C, ruang UVGI RS Dr. Cipto Mangunkusumo, SARS-CoV-2, respirator N95, COVID-19*

Introduction

Infectious disease with pandemic causes high mortality and morbidity. Medical personnel could be imposed on a very high-risk situation due to the lack of personal protective equipment (PPE). Healthcare workers rely on the PPE to afford protection from being infected and infecting others. The gap between the needs and shortage of disposable N95 respirators becomes a challenge as the number of cases in the pandemic is rising.[1] Lowe JJ et al previously made an innovation for disinfecting disposable N95 respirators or equivalent standards using Ultraviolet Germicidal Irradiation (UVGI).[2] This method could be a promising method for PPE disinfection, especially for disposable N95 respirators, to control the supply shortage.

UVGI uses ultraviolet wavelengths (200-320 nm) for air, water, and surface disinfection in the germicidal range.[3,4] Research shows that UVGI has been shown to kill or deactivate common pathogens effectively, including coronavirus.[3,5] Based on the modelling results from various studies,[6–10] the UVGI dose required for the inactivation of a coronavirus is lower than the radiation dose that affects the filtration and characteristics of N95 masks.[2,11] Furthermore, the UVGI microorganism susceptibility factor was the highest for the viruses, about 13-20 times higher than for endospore bacteria or fungal spores.[12]

Before conducting this study, we evaluated our UVGI disinfection chamber's effectiveness by measuring the power and dose of Ultraviolet-C (UV-C) in the target positions measured by a UV-C meter and pre-post bac-

terial culture from disposable N95 respirators. We evaluate reduction of bacterial load such as *Staphylococcus epidermidis*, *Staphylococcus saprophityccus*, Non-lactose fermenting *Enterobacteriaceae*, and *Escherichia coli* using UVGI with a total dose of UV-C radiation as high as 108 mJ/cm^2 for 30 minutes. However, direct testing of our UVGI chamber on the SARS-CoV-2 virus had not been tested before. Therefore, this study determined to test the effectiveness of the UVGI chamber to disinfect SARS-CoV-2 virus on the surface of N95 respirator.

Methods

This study used a cross-sectional design to determine the dose and the effectiveness of UV-C radiation in eradicating SARS-CoV-2 on disposable N95 respirators. The Department of Ear Nose - Head & Neck Throat initiated this study, which involved the Prevention and Control of Infection Committee of the Dr. Cipto Mangunkusumo General Hospital, Central Sterilization Installation – Dr. Cipto Mangunkusumo General Hospital, Department of Microbiology, and Department of Medical Physics/Medical Technology Cluster IMERI– Faculty of Medicine Universitas Indonesia in April 2020. The faculty of Medicine University of Indonesia Ethics Committee has approved this study protocol with number KET-418/UN2.F1/ETIK/PPM.00.02/2020

UVGI Method

A UVGI chamber was designed using 4 x 3 x 2.5 m plywood with an outer coating material of High-Pressure Laminate (HPL) and an inner coating in aluminum foil. The chamber had one inlet ventilation and one outlet ventilation with a vacuum fan (Figure 1). Our setting used four units of 254 nm peak 36-Watt UV-C mercury lamps (Philips UV Germicidal, 36-Watt T8, made-in Poland), each placed at the corner of 1-meter sides square (Figure 2) and set on a self-made stand 40 cm above the floor. This setting was made to ensure that UV-C radiation can be distributed equally to the front- and back-side of respirator surfaces. The power and dose were measured by placing the UV-C meter probe (Lutron UVC-254SD UVC light meter type K/J temp, made-in Taiwan) at several points within the chamber (Figure 1). The operator controlled the lamp switch outside the chamber for safety reasons. The radiation dosage measurement was calculated using UV-C power and radiation duration as written below.

$$\boldsymbol{dosage(D)}\left[\frac{mili\ joule}{cm^2}\right] = \boldsymbol{power\ (P)}\left[\frac{mili\ watt}{cm^2}\right] . \boldsymbol{duration\ (t)}[second]$$

COVID-19 Specimen Collection

To evaluate UVGI's effectiveness in eradicating SARS-CoV-2, we collected bronchial aspirate from COVID-19 patients in Covid-19 ICU Dr. Cipto Mangunkusumo General Hospital. The bronchial aspirate was collected using 5 mL of sterile 0,9% saline washed into the ETT tube, and the aspirate was collected using an aspirate collector. The specimen was then inserted into a sterile container. Later, it was smeared onto the outer and inner surfaces of 20 pieces N95 respirators (the 3M™ Particulate Respirator type 9210) just before the UVGI irradiation. The smearing site was marked to locate the region of interest.

The respirators were then assigned into two groups: the first ten respirators were given 324 mJ/cm^2 irradiation for 60 minutes, and the second group of ten respirators was irradiated with 1080 mJ/cm^2 UV-C for 120 minutes. Before and after the irradiation, we swabbed the marked site on both groups of respirators and performed polymerase chain reaction (PCR) as the gold standard in determining the SARS-CoV-2 genes. The PCR methods used in this study is GeneAmp PCR System 9700 Applied Biosystem/PTC 200 Thermal cycler. The principle of the PCR method is mix enzyme in Qiagen OneStep RT-PCR contains Reverse Transcription and PCT amplification enzyme to change RNA to DNA. The PCR is highly sensitive in detecting SARS-CoV2.[13]

Measurement of UVC power

For measurements, we used the Lutron UVC-254SD UVC light meter type K/J temp. have a high precision for measuring UVC irradiation and real time data recorder.

We performed eight points measurement inside the UVGI chamber. The points A, B, C, D, E, and F were at a horizontal line (Figure 1B), positioned 1 meter above the ground. Points D and E had a 50 cm distance to the two closest UV-C lamps, while points A, B, and C were positioned 70 cm from the closest UV-C lamp. Additionally, we measured at a lower point 5 cm above ground for points D and E (Figure 1C). The measurement of point F was special because the probe was put facing the wall instead of facing the light source (Figure 1C).

Results

We checked the UV-C radiation using a

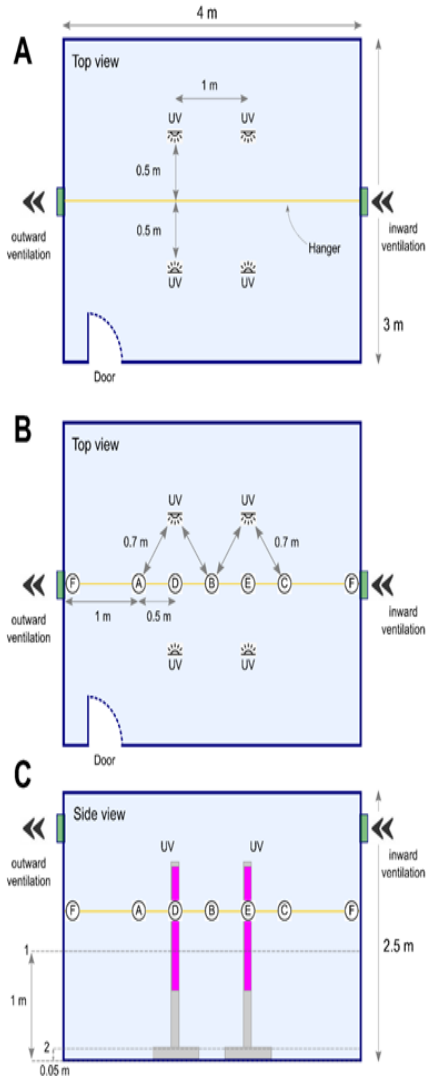

Figure 1 Schematic UVGI Chamber Design
A. Top-view and layout of the 4 x 3 x 2.5 m plywood UVGI chamber.
B. Point D and E was indicating the sensor of UV-C meter was placed 50 cm from light source, point A, B, C was placed 70 cm diagonally from the light source, point F was indicating the sensor within 1 m from point C and the sensor was placed facing the wall.
C. Layout from the side-view; Point 1 was indicating the placement of the sensor within 1 m above the floor while point 2 was indicating the placement of the sensor within 5 cm from the floor.

UV-C meter probe at several points in the chamber and confirmed the inverse square law of radiation. Four UV-C lamps in the chamber reliably emitted radiation energy needed for germicidal irradiation purposes.

The measurement results at several points using a UV-C meter were summarized in Table 1. The radiation power measurements at D and E were 0.09 mW/cm^2. These points had 0.04 points higher than A, B, and C, which were 0.05 mW/cm^2. Measurements at the lower points of D and E were 0.03 mW/cm^2, 0.06 points lower than the upper points. No radiation was measured in point F as the probe was placed against the light source

Figure 2. Disposable N95 respirator during disinfection process inside UVGI chamber

and facing the wall.

UV-C meter was then positioned just beside a disposable N95 respirator during the radiation process, and the power measured was 0,06

Table 1. Measurement Results Obtained Using a UV-C Meter at Several Points

Measurement point	UV-C Power (mW/cm^2)
A	0.05
B	0.05
C	0.05
D	0.09
E	0.09
F	0
D (lower point)	0.03
E (lower point)	0.03

watts/cm^2. The total UV-C radiation dosage received for 30 minutes was 108 mJ/cm^2.

The results of PCR examination for the first group (60 minutes of irradiation, the radiation dose of 324 mJ/cm^2) were undetectable SARS-CoV-2 gene in 6 out of 10 samples (Table 2). For the second group (2 hours of irradiation, radiation dose of 1080 mJ/cm^2), we found undetectable SARS-CoV-2 gene in 10 out of 10 samples from the PCR results. (Table 3)

Discussion

Ultraviolet Germicidal Irradiation

Table 2. Pre and post 324 mJ/cm² UVGI for N95 disinfection (PCR SARS-CoV-2)

Sample number	Before UVGI	After 60 minutes UVGI (total dosage: 324 mJ/cm²)
1	SARS-CoV-2 positive	SARS-CoV-2 Negative
2	SARS-CoV-2 positive	SARS-CoV-2 Negative
3	SARS-CoV-2 positive	SARS-CoV-2 Negative
4	SARS-CoV-2 positive	SARS-CoV-2 Negative
5	SARS-CoV-2 positive	SARS-CoV-2 Negative
6	SARS-CoV-2 positive	SARS-CoV-2 Negative
7	SARS-CoV-2 positive	SARS-CoV-2 positive
8	SARS-CoV-2 positive	SARS-CoV-2 positive
9	SARS-CoV-2 positive	SARS-CoV-2 positive
10	SARS-CoV-2 positive	SARS-CoV-2 positive

(UVGI) uses ultraviolet wavelengths in the germicidal range (200-320 nm) to disinfect the air, water, and surfaces.[3,4] These wavelengths have actinic properties that cause photochemical reactions in microorganisms (bacteria, fungi, and viruses).[3] The wavelength of 265 nm has the highest peak of germicidal effectiveness, where the wavelength is most lethal to microorganisms. However, the wavelength of 254 nm is generally used with low-pressure mercury lamps in UVGI applications that emit Ultraviolet-C shortwave radiation (UV-C, 100-280 nm). At a wavelength of 254 nm, UV-C effectively deactivates biological contaminants and controls bacteria in the air.[14,15] Ultraviolet disinfection generally uses irradiation units (intensity) in the form of Watts/m² and ultraviolet doses in the Joule/m² or their derivatives.[3]

According to the literature, the dose of UVC radiation needed to kill the SARS-CoV-2 virus varies. A study in Germany stated that a UVC dose of 1,048 mJ/cm² is needed to eradicate the SARS-CoV-2 virus with a viral load of 5 x 106, applied for 9 minutes.[16] Another study in 2020 stated that the radiation dose needed to kill the Human Coronavirus alpha and beta strains was 1.2 – 1.7 mJ/cm².[17] Surface concentrations or viral loads can influence these large differences. The higher the viral load, the greater the radiation dose needed to kill 100% of the virus. In this study, the 60% result obtained at 1 hour of irradiation (radiation dose 325 mJ / cm²) is possible due to high viral loads in the respirator samples. This causes viral DNA to be detected on the post-radiation PCR examination. However, this study has several limitations: the PCR examination, which did not directly calculate the viral load. Viral viability also cannot be described on PCR examination. The sampling method by swabbing the respirator also might carry the risk of reducing the virus concentration in the specimen, which can bias the reading of the results. There are several advantages of using UV-C disinfection. Disinfection time is short; therefore, it could effectively disinfect large numbers of PPE within a brief period. Disinfection is relatively easy because we only need to set the dose, time and, ensure that the disinfection surface is not

Table 3. Pre and post 1080 mJ/cm² UVGI for N95 disinfection (PCR SARS-CoV-2)

Sample number	Before UVGI	After 120 minutes UVGI (Total dosage: 1080 mJ/cm²)
11	SARS-CoV-2 positive	SARS-CoV-2 Negative
12	SARS-CoV-2 positive	SARS-CoV-2 Negative
13	SARS-CoV-2 positive	SARS-CoV-2 Negative
14	SARS-CoV-2 positive	SARS-CoV-2 Negative
15	SARS-CoV-2 positive	SARS-CoV-2 Negative
16	SARS-CoV-2 positive	SARS-CoV-2 Negative
17	SARS-CoV-2 positive	SARS-CoV-2 Negative
18	SARS-CoV-2 positive	SARS-CoV-2 Negative
19	SARS-CoV-2 positive	SARS-CoV-2 Negative
20	SARS-CoV-2 positive	SARS-CoV-2 Negative

blocked. In the UV-C system, there is no necessity in establishing special airflow patterns and room insulation. It also does not require a chemical mixture. UV-C systems require low costs because of their simple care and maintenance. UV lamps also last for thousands of hours at the output peak.[5]

This study is a preliminary study and the study subject is limited to ten samples, but the results give promising use of UVGI in sterilizing N95 respirators. The advantage of this UVGI study used is also cost effective compared to purchasing mass N95 respirators in terms of pandemic. This study also used a highly sensitive Real Time (RT) PCR to detect the SARS-CoV-2, thus the results is reliable, even though more sample is needed for further research

The decontamination process using UV-C radiation is environmentally friendly since no dangerous residues or byproducts are produced. Therefore, no special cleaning procedure nor special handling of hazardous chemicals is needed. The UV lamps also do not require special handling or disposal. Hence, this disinfection procedure is a strong alternative to common disinfecting chemicals.[5]

UV-C radiation works only on the irradiating surface in a straight line despite its various advantages. The side that is not exposed does not receive adequate disinfection. Rotating the object or placing a source of the UV-C radiation on the other side could be a solution for exposing all surfaces for disinfection. The penetration of UV light is ineffective on organic matter. A standard cleaning must be done to remove organic matter from the surface before the disinfection process using UV-C radiation. Also, the strength of the UV-C radiation is inversely square proportional to the distance of the light source, so the placement of the distance greatly affects the effectiveness of radiation.[5] In our study, the object for disinfection was placed between four UV-C light sources against each of them. The object would receive the light from the front and back, increasing the disinfection effectiveness on all surfaces.

Another disadvantage that needs careful consideration, UV-C radiation is carcinogenic to humans; thus, direct exposure and indoor uses are not recommended by the WHO. This radiation poses a danger to the skin and eyes, so direct UV-C exposure must be avoided. The UV-C radiation can be blocked by the glass (not quartz glass) and most clear plastics allowing the user to observe the irradiation through the window.[5] In the UVGI disinfection chamber that we designed, the switch button was located outside the chamber, making it safe for humans. Moreover, UV-C lamps can be turned on and turned off automatically by a timer, protecting the operator from harmful UV-C radiation exposure.

A study in 2015 found that UVGI had a small effect on the filtration performance of disposable N95 respirators.[18] The study also found no essential effect on flow resistance at doses up to 950 J/cm^2, while the integrity of the respirators showed a noticeable decrease at lower doses. The strength of the respirator straps was less affected by UVGI than the strength of the body material.[18] Our UVGI chamber dose of 108.1 mJ/cm^2 was much lower than the dosage threshold for affecting the flow resistance and filtration performance of disposable N95 respirators.

In terms of the costs and the advantages, this UVGI chamber is affordable with simple material and cost-effective with considerable capacity numbers for personal protective equipment in a short disinfection time. This chamber could be a promising method for disinfecting numbers of PPE to overcome the shortage in the pandemic era.

Conclusions

The making of the UVGI chamber in terms of costs and benefits of this research is certainly very beneficial and cost-effective because it can disinfect in a short time with a large amount of N95 respirators capacity. The pandemic is yet to end, even though the vaccination program has started. Therefore, a balance between demand and supply of N95 must be anticipated to maintain safety from the transmission of the SARS-CoV-2 virus. The UVGI booth can be a hospital or health facility solution for disinfection in overcoming the limitations of N95 respirators. Further research needs to be carried out by conducting viral cultures to determine the effectiveness of UVC radiation through the UVGI chamber method to eradicate the SARS-CoV-2 virus.

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Conflict of interest

The authors declare no competing financial interests.

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Contributors

RDR designed the project, the experiment, and obtain the funding. HP designed the UVGI chamber. HP, RRS, AAS, TJA, AP, GS, FA, SDP performed the experiment. RRS and AAS analyze data and drafted the first version of the manuscript with the supervision of RDR and HP. RDR, HP, AAS, PAY, and AP edited it. PAY designed the figure schematics. All authors approved the manuscript.

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