Research

Filtration effectiveness of N95 medical mask exposed to repeated ultraviolet germicidal irradiation room

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ABSTRACT

Background: The global Coronavirus disease (COVID-19) pandemic has created shortages of personal protective equipment (PPE) including N95 respirator medical masks. Ultraviolet Germicidal Irradiation (UVGI) is an effective way for disinfection of N95 masks before reuse. The UVGI chamber is an effective method of disinfection against SARS-CoV-2, however its effect on the N95 medical masks filtration ability is still uncertain. **Purpose:** To evaluate filtration effectiveness of N95 mask after repeated UV-C irradiation in the UVGI chamber. **Method:** This was a parallel two-group experimental study to see the effect of repeated UVGI exposure on the filtration of 2 types of N95 medical masks (type 8210 and 1860), with 25 pieces each group, using an aerosol particle counter, after 10 cycles of repeated UVGI exposure in the UVGI chamber of the ORL-HNS Department Dr. Cipto Mangunkusumo Hospital. **Result:** There were no significant differences in the filtration effectiveness of N95 medical masks after repeated UVGI exposure up to 10 cycles for 2 types of N95 masks and there was no significant change in the filtration ability of the N95 medical masks after repeated UVGI exposure. **Conclusion:** The filtration of N95 medical masks type 8210 and 1860 filtration were maintained >95% after repeated UVGI exposure with cumulative dose of 10,126-16.200 mJ/cm2 in UVGI chamber of ORL-HNS Department, Dr. Cipto Mangunkusumo Hospital.

Keywords: UV-C radiation, UVGI chamber, disinfection, N95 respirator mask, filtration

ABSTRAK

Latar belakang: *Pandemi Coronavirus disease 2019 (COVID-19) menyebabkan keterbatasan tersedianya alat pelindung diri (APD) termasuk masker respirator N95. Ultraviolet Germicidal Irradiation (UVGI) merupakan salah satu cara desinfeksi yang menjanjikan dan efektif, sehingga masker N95 dapat digunakan kembali. Bilik UVGI merupakan metode yang efektif dalam disinfeksi terhadap SARS-CoV-2, namun efek paparan UVGI terhadap kemampuan filtrasi masker N95 belum diketahui. Tujuan: Untuk mengevaluasi efektivitas filtrasi masker N95 setelah paparan UV-C berulang di Bilik UVGI. Metode: Penelitian ini adalah studi ekperimental dua kelompok paralel untuk melihat efek paparan UVGI berulang terhadap filtrasi 2 tipe masker N95 (tipe 8210 dan 1860) sebanyak 25 masker di setiap grup, menggunakan aerosol particle counter setelah paparan UVGI berulang sebanyak 10 siklus di Bilik UVGI Departemen THT-KL RSCM. Hasil: Tidak didapatkan perbedaan bermakna pada masker N95 pasca-paparan UVGI berulang sebanyak 10 siklus dengan rerata filtrasi*

pada 2 tipe masker, serta tidak terdapat perubahan signifikan kemampuan filtrasi masker N95 pasca-paparan UVGI berulang. Kesimpulan: Filtrasi masker N95 pada penelitian ini dapat dipertahankan 95% pasca-paparan UVGI berulang hingga dosis kumulatif 10.126-16.200 mJ/cm2 di bilik UVGI Departemen THT-KL RSCM.

Kata kunci: *radiasi* UV-C*, bilik* UVGI*, desinfeksi, masker* N95*, filtrasi*

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INTRODUCTION

Coronavirus disease 2019 (COVID-19) pandemic is a real threat in the medical and economic sectors. To prevent further spread of the disease, preventive measures should be taken to control the disease, especially for health workers that have a higher risk of infection. During this pandemic, the use of personal protective equipment (PPE) of health workers is crucial to prevent exposure and reducing the risk of infection. PPE is especially used by these workers during aerosol generating procedures (AGP).

To deal with PPE shortage during Covid-19 pandemic, Dr. Cipto Mangunkusumo (RSCM) National Hospital had the innovation to build an Ultraviolet Germicidal Irradiation (UVGI) room. This room was meant to alleviate PPE shortage using *reuse* principle. The UVGI room used UV-C rays with 254 nm wavelength which was effective to disinfect air, water, and surface.[1] UVGI room has its advantages, which are short disinfection duration, huge capacity in one cycle, easy to use and relatively affordable to prepare and maintain. On the previous study, it was known that UVGI room of RSCM had the ability to disinfect SARS-CoV-2 viral using 1J/cm^2 dose.[2]

The safe standard of N95 respirator mask according to NIOSH is, if the N95 mask had the ability to filter >95%. The exposure of UVGI in the UVGI room could disinfect SARS-CoV-2 virus, but the effect of repeated UVGI exposure to N95 respirator filtration ability had not been known yet. The purpose of this study was to find out the effect of repeated exposure of UVGI to N95 medical masks, so that the safety of health workers, especially in RSCM could be maintained while providing health services.

STUDY METHOD

This was an experimental study implemented in the UVGI room, Dr. Cipto Mangunkusumo National Hospital. The study was carried out during August-December 2020. The researchers evaluated the filtration ability on N95 masks before UVGI exposure and after each exposure cycle of UVGI. Evaluation was done to assess the filtration ability of different types of N95 respirator and the N95 reduction of filtration ability.

The object of this study was two types of N95 mask, 3M 8210 and 3M 1860, 25 pieces of each type. This study was *in vitro* with strict workflow according to the operational standard to maintain the quality of study.

The dose of UV-C exposure was 1,080mJ/cm^2-1,643mJ/cm^2 for each cycle of exposure. Total cumulative dose that each object received until 10 cycles was 10,126-16,200mJ/cm^2. The objects were positioned so that each of them received the same angle and amount of UV-C exposure.

Figure 1. UVGI Exposure in the UVGI Room

RESULT

The characteristics of filtration were evaluated on six spots on the surface of N95 masks. The mean value of each spot was calculated using coefficient of variation. From each spot variation, homogenity for both N95 masks surfaces was found. The N95 masks 8210 type, the lowest value was 98.6% with the highest value 99.8%. Meanwhile the N95 mask 1860 type had the lowest filtration value of 99.3% and the highest filtration value of 99.8%.

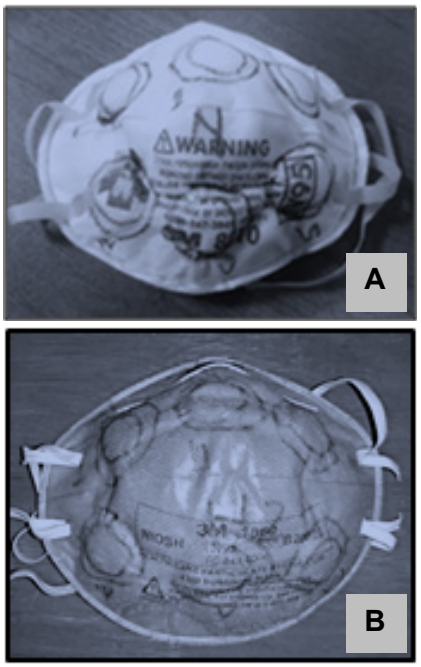

Figure 2. A) 6 spots on N95 type 8210, B) 6 spots on N95 type 1860

The evaluation of mean difference between each spot group in the N95 mask was assessed using ANOVA test and showed no statistical significance between spots, between groups, and intra-group spots. The p value for N95 mask type 8210 was p=0.071 (p>0.05). Mean pre-exposure filtration was 99.42%±0.26 with minimum value of 98.6% and maximum value of 99.8%. Meanwhile from N95 type 1860, the outcome was not significant statistically (p=0.119). Mean pre-exposure filtration was 99.73%±0.09 with minimum value of 99.3% and maximum value of 99.8%.

From the post-exposure of N95 masks filtration test, the variations between spots on the surface were homogenous on both types of N95 masks. The 8210 type, had shown minimum value of 98.6% and maximum filtration score of 99.8%. Meanwhile, N95 masks 1860 type had the lowest filtration value of 99.1% and the highest value of 99.8%.

Filtration effectiveness of N95 type 8210

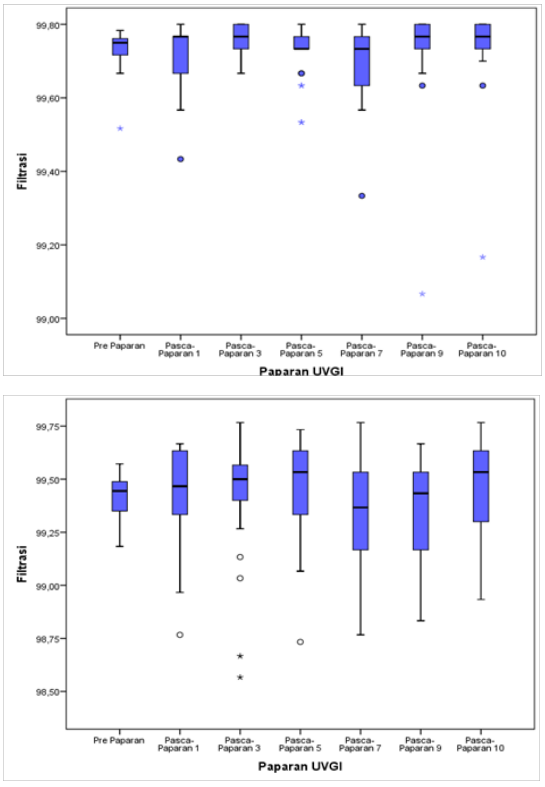

Figure 3. Boxplot of N95 type 8210 filtration post-exposure to repeated UVGI

The repeated exposure to UVGI on N95 mask was evaluated with a mean difference test on each spot between groups using ANOVA test. From the mean difference test, no statistical significance was found on spots between groups and spots intra-group with p value 0.376 (p>0.05) for 8210 types. **On figure 5**, filtration dynamics of N95 type 8210 was shown from before exposure until the 10th exposure. No significant reduction of filtration was seen until the last post-exposure and still met the safety standard criteria of filtration >95%.

Filtration effectiveness of N95 type 1860

The assessment of repeated UVGI exposure effect on N95 type 1860 was done using a mean difference test between groups on each spot. No statistical significance was found on spot between groups and spot intra-group with p value of 0.302 (p>0.05). Figure 6 showed the dynamics of N95 type1860 filtration from pre-exposure of UVGI until the 10th exposure. The graph showed no significant difference of filtration score from pre-exposure until the last UVGI exposure and still met the safety standard criteria of filtration >95%.

DISCUSSION

This was an experimental study between two parallel groups to find out the effect of repeated (10 cycles) UVGI exposure to evaluate N95 respirator mask filtration score. The study was performed *in vitro* inside the UVGI Room of ENT-HNS Department, Dr. Cipto Mangunkusumo (RSCM) National Hospital. The study used two types of N95 masks as study objects; 3M 8210 and 3M 1860 types. Study objects came from two groups of N95 masks, each group had 25 pieces of N95 mask.

Filtration ability was assessed quantitatively using an *aerosol particle counter*. For pre-exposure filtration, six spots on the surface of N95 masks were assessed as early filtration. Study objects were given code and placed inside the UVGI room on a 50-70 cm distance from the UV-C lamp according to the code which had been assessed in the previous study so each would get 1,080mJ/m2 – 1,643mJ/cm2 on each cycle. Both groups were evaluated cautiously during a 10 days course until the 10th exposure.

The filtration distribution variation on N95 mask was assessed on the surface of the mask, it showed variable filtration ability that was homogenous for both N95 mask types. On type 8210, the lowest filtration rate was 98.6% and highest was 99.8%, with mean early filtration of 99.42%±0.26. The N95 type 1860 had mean filtration rate of 99.73%±0.09, with the lowest rate of 99.3% and highest rate of 99.8%. The standard safety of N95 mask according to NIOSH was >95%. Lindsley, quoted from O'Hearn[3] stated that the mean particle penetration on N95 mask was 1.19% (0.70-2.48%), equal with 98.8% filtration. The study by Qian et al.[4], stated that effectiveness of N95 mask filtration could filter *M. tuberculosis* (size 0.8 μm) by 99.5%. That study also stated that a particle penetration of 1.8% from air particle 0.75 μm or less, were equal to 98.2% filtration.

Mean difference rate on spot between groups had no significant difference statistically on spots between group and spots intra-group with p value of 0.71 (p>0.05) for N95 type 8210 masks. On N95 type 1860 masks, no statistical significance was found (p=0.12), hence every spot evaluated on early filtration had homogenous value. This study result was in accordance with a study by Viscusi et al.[5] which stated no significant difference of early filtration on all the surface of N95 masks. Qian et al.[4], also stated in his study that N95 mask had equal filtration ability throughout the surface.

This study used UVGI radiation dose of 1.080mJ/cm^2-1.643mJ/cm^2 on each exposure. The dosage used in this study was the accurate

dose to disinfect SARS-CoV-2 virus that had been studied previously, which were >1J/cm^2 inside the UVGI Room, ENT-HNS Department, FKUI-RSCM.[2] In this study, the exposure was homogenous on each object until the 10th exposure. The cumulative dose of UVGI exposure was 10.126 -16.200mJ/cm^2. Heimbuch et al.[6] stated that UV-C disinfection effectiveness on 15 types of N95 mask model tested, an optimal dose of 1J/cm^2 was found to be able to inactive H1N1 influenza virus and SARS-CoV-2 virus on N95 mask surface. A study by Grist et al.[7], found that UVGI dose to disinfect a surface need to reach a minimum of 1.0J/cm^2 on all N95 mask surface and ideally went through validation for each exposure dose, or at least evaluated periodically.

Regarding post-exposure to repeated UVGI, filtration ability was assessed periodically until the 10th exposure. Variation between spots post-exposure to UVGI was homogenous for both N95 types surface. On the type 8210, the mean value was 99.42%±0.23 with highest rate of 99.8% and lowest filtration rate of 98.6%. On the 1860 type, the mean filtration value was 99.75%±0.13, with lowest filtration rate of 99.1% and highest rate of 99.8%. This study found that both types of N95 masks tested could maintain filtration standards according to NIOSH even after 10 cycles of UVGI exposure.

This study was in accordance with the previous study by Heimbuch et al.[6] which stated that particle penetration post-exposure 10 times of UVGI was 0.18-3.29%, equal to filtration ability of 96.7-99.8%. Unlike the study of Fisher et al.[8], which studied 6 different types of N95 mask with UVGI dose of 38-4.707J/cm^2, they found that the filtration effectiveness was about 87.2-99.5% post-exposure. Lindsley quoted from Grist et al.[7], stated that there was particle penetration about 1-2.5% post-exposure to high dose of UVGI. Those results were in accordance with the filtration ability of 97.5-99%.

A new report from the producer of N95 3M™ [9] about N95 mask decontamination and reuse, emphasized the importance of decontamination method that does not affect the filter efficiency. They also mentioned another internal study which found that N95 mask could maintain its filtration efficiency around 95% after repeated UVGI exposure (5-10 cycles of UV-C). However, the specific dose of cumulative UVGI used was not stated.

This study evaluated the effect of repeated UVGI exposure to N95 mask with mean difference test and found no statistical significance that compared spot between groups and spot intra-group with p value of p=0.376 (p>0.05) for N95 type 8210 and p value of 0.302 (p>0.05) on N95 type 1860. This study also showed that no significant filtration difference until the tenth cycle of UVGI exposure, and still met the standard safety criteria of >95%. According to the study of Lindsley et al.[10], a maximal dose of UVGI up to 10^2-10^3 (maximum of 950J/cm^2) could affect the filtration ability of N95 mask, hence repeated UVGI exposure to disinfect virus or bacterial pathogen could be done numerous times without affecting the ability of N95 mask to filtrate.

The study of Heimbuch et al.[6] compared particle penetration on 15 different types of N95 mask exposed to 10 cycles of UVGI. The mean particle penetration did not differ significantly, aside on one N95 type which was US Safety AD2N95A, having filtration ability less than 95% post-exposure. The study also found that UVGI until 20 cycles did not significantly affect the effectiveness of N95 mask filtration and did not significantly affect *fit test.*

On this study, the lowest decrease of filtration ability was 0.2% on both N95 type 8210 and type 1860 N95 mask after-exposure, but still met the safety criteria >95%. The filtration ability change did not decrease significantly but showed a change of filtration ability on cumulative exposure

dose of 10,126 mJ/cm^2 -16,200mJ/cm^2. According to Zhao et al.[11], radiation dose of UVGI up to 10 J/cm^2 did not affect N95 mask against mechanical strength and shape deformity. The study also mentioned that from first layer and third layer of N95 mask which was made from *polypropylene* played the part on protecting the mask from UV-C radiation. The test using optic microscope and scanning electron microscope (SEM) showed no significant morphological N95 mask change (fiber diameter, shape of fiber, particle distribution) post-exposure to UVGI. This study found that N95 mask did not have any significant degradation even until the 10th exposure of UVGI.

The effect of UVGI exposure was also discussed in a study of Viscusi et al.[5], which stated that UVGI did not affect aerosol filtration penetration, airflow resistant and even the physical appearance of N95 mask. On a study by O'Hearn et al.[3], no change in airflow resistance was found. On that study, a new post-disinfection smell sensation after UVGI was found, but didn't seem to affect any physical changes of N95 masks.

The consideration of N95 mask re-use was issued by CDC (Centers for Disease Control and Prevention), which includes ensuring the effectiviteness of disinfection procedure, the filtration ability of N95 masks, *fit test, sealed test* and damage to N95 masks due to disinfection process. The requirement of N95 masks that could be disinfected should also be in line with the recommendation by CDC.[12]

This study used the UVGI Room of ENT-HNS Department, FKUI-RSCM that had been studied previously and proven effective on disinfecting SARS-CoV-2 virus and pathogens.[2] In this study, one cycle of disinfection process might take up to 52 N95 masks. The work flow of disinfection in such a room was also applied in the University of Nebraska Medical Center (UNMC), a tool that could disinfect N95 masks in a huge amount at one time.[13] UVGI room also had some superiority, such as short disinfection duration, a huge amount of N95 masks at one time, easy to use, and relatively affordable to use and to maintain. In this study, the exposure was done until 10 cycles of disinfection dose, and the N95 masks had filtration effectiveness that still met the criteria of a safety standard N95 mask which was above 95%.

Study Limitation

This study could only evaluate 2 types of N95 masks which were 3M™ 8210 type and 1860 type. There are over 50 types of N95 masks that have passed the standard test from NIOSH, hence not a reliable standard and model for all N95 masks. Moreover, the filter materials on each brand and types are different and have different effects of UVGI exposure.

The study emphasized on the effect of repeated UVGI on N95 mask filtration ability, but there are still a number of factors that might affect the performance of N95 masks, such as *fit performance* and material resistance to exposure. *Fit performance* on N95 mask was affected by the shape of the mask, nose clip and headband of the mask which was evaluated qualitatively using *fit test.* Qualitative analysis should also be done post-exposure of UVGI to the mask. Both analyses are needed to evaluate the effectiveness of N95 mask.

This study showed that there was no reduction on N95 type 8210 and 1860 filtration even after numerous exposures to UVGI with cumulative dose of 10,126 mJ/cm^2 -16,200mJ/cm^2 in UVGI Room Faculty of Medicine Universitas Indonesia/Dr. Cipto Mangunkusumo National Hospital. In this study, no significant difference was found between the filtration ability of both types of N95 masks after 10 cycles of exposure to UVGI with mean filtration rate of 99.42%±0.23 for N95 8210 type

and 99.75%±0.13 N95 1860 type. Several follow-up studies should be conducted to have further understanding of N95 masks by evaluating the effectiveness on other types of N95 mask filtration post-exposure to UVGI before and after usage; assessing N95 mask filtration ability qualitatively in relation to the mechanical effect of repeated *donning and doffing* on the head mannequin; and evaluating UVGI radiation disinfection effectiveness on other types of N95 mask and post-exposure filtration.

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