Photochemical and photobiological sciences author guidelines

UVC Germicidal Units: Determining the dose received and the parameters to be considered for N95 respiratory decontamination and reuseIndermeet Kohli, Alexis B. Lyons, Bob Golding, Shanti Narla, Angeli E. Torres, Angela Parks-Miller, David Ozog, Henry W. Lim, Iltefat H. HamzaviAbstract I Full Text (HTML) Learn about our remote access options Volume 96, Issue 5 First published: 07 August 2020 Pandemic COVID-19 led to an international shortage of funds individual protection including N95 facepiece respirator filtration (FFRs), resulting in many agencies using ultraviolet hermicide (UVGI) technology for N95 FFR decontamination. In order to ensure proper decontamination, it is essential to determine the dose received by the various parts of the FIU in the process. Recently, our team set up a UVGI device to decontaminate the N95. With an experimental and theoretical approach, this manuscript discusses the minimum dose received by various parts of the N95 respirator after one full cycle of decontamination with this UVGI unit. Results show that all parts of the FFR N95 received at least 1 J cm-2 after one full decontamination cycle with this device. Because there are different UVGI devices and different types of FFRs, this study provides a model by which the UVC dose obtained by different areas of FFRs can be accurately evaluated to ensure proper decontamination for the safety of health care providers. The COVID-19 pandemic has led to a lack of personal protective equipment (SIS), including N95 face filterers (FFRs). Thus, decontamination methods, such as ultraviolet hermicide (UFFI), are used for their reuse. The effectiveness of OFGI decontamination has been well documented in the literature with a reduction in the logs achieved after the treatment of UFFI in different doses (1-4). Possible explanations for the variations in OFGI dosing may include (1) differences in pathogens, as each of them will require a dose based on a specific biological formation, (2) the difference between the substrates used, which may be porous or non-porous, flat or curved, and (3) distance from the UVGI radiation source (5-7). With several agencies reusing their UFFI technology for N95 decontamination, hospital systems throughout the United States have begun to use UVGI for decontamination and reuse of PFI. Dosing is a critical parameter, and insufficient doses will result in incomplete decontamination, which can be dangerous for the health care professional. For decontamination N95 (8-11) a dose of at least 1 J cm2 is recommended. Given that UVC photons are only effective if they have direct contact with and that N95 respirators have curvature, it is important to take into account the actual dose dose different parts of the respirator in the repurposed block. Recently, our team set up a UVGI device for decontamination and reuse of the N95, called the Daavlin unit in this manuscript (4). With an experimental and theoretical approach, this manuscript discusses the minimum dose received by various parts of the N95 respirator after one full cycle of decontamination with this UVGI unit. This method, to determine the dose received by different parts of the N95 respirator, can be used as a model for other UVC units repurposed for decontamination of the N95. In addition, parameters were proposed that health facilities across the country could consider when investing and using the N95 unit for decontamination purposes. Davlin desktop UVC germicidal lamp (Daavlin, Byron, OHIO), called Daavlin unit in the manuscript, was used to irradiate UVGI (4). The 3M 1860 N95 FFR was used as a FFR model. Two different factors were considered to measure the dose change received by the different parts of the N95 FFR: the impact of the N95 curvature and the distance of the irradiated site from the lamp. To account for the RPF curvature effect, radiation was measured at different angles between the normal surface and the UVC incident. Fig. 1a is a diagram of the normal surface orientation on the representative respirator N95. The measurements were made by targeting the UVC sensor at angles of 0 to 90 degrees between the surface of the normal sensor and the UVC incident (Figure 1b). The UV512C calibrated UVC meter (General Tools and Instrument, Secaucus, NJ) was used. The sensor was placed on a stainless steel tray of mayo stand, readily available in clinical settings when taking measurements. It should be noted the tray/table was approximately 14 cm from the lamp, and the sensor was about 11.5 cm (sensor height 2.5 cm) (Figure 1b). (a) Surface diagram, normal from different parts of the representative respirator N95, and (b) a sensor orientation scheme (0-90 degrees), in which radiation measurements are taken (with) radiation factor depending on the distance from the lamp To assess the impact of distance on radiation, the simplified approach is to take into account that the source of radiation, including the UVC lamp, is an even-cut source of the uvC. In this case, exposure at a distance of r from the source follows the reverse square law and proportionally 1/r2, where the distance from the lamp (12). However, this approximation is only valid when the irradiation is measured at distances more than five times greater than the longest measurement of the source. The longest measurement of the lamp used in the Daavlin block was approximately 38.5 cm, and the tray containing N95 FFRs was placed at a distance of about 14 cm. Because this distance is much less than five times longer (5x38,5 and 192.5 cm), this rendered the approximation of the point source invalid in this situation. To make a conservative approximation of the change in intensity at a distance from the lamp, with the detector directly in front of the lamp, instead the line source model (13) described by Eq was used. 1. E (h, d) - S R L - h d 2 (L - h) 2 x d 2 and h 2 (1) Here, E is irradiation, S R and φ 2 litre is intensity per unit length, ϕ is a useful UVC intensity (at 254 nm), L is the length of the lamp, h the distance from the end of the lamp (for the point located in the middle of the lamp h and L /2), and d the distance between the lamp and the irradiated site. ϕ was close to 12 W, which is about one-third of the power of the UVC lamp (36 W), the L was 38.5 cm (the length of the UVC lamp), h was used as an L/2, and d was varied to account for changes in radiation exposure at a distance from the lamp. Equation 1 was used to calculate the radiation ratio. This factor, combined with measured radiation values with the Irradiible UVC, allows for radiation changes depending on the distance from the lamp. Equation 1 applies to all systems with a setting similar to those discussed in this manuscript, namely the daavlin block with tubular lamps. As mentioned above, the approach to assessing radiation (approximately 1/r vs. 1/r2) depends on the geometry of the device, the type of lamp, the distance between the lamp and the N95, etc., and should be chosen accordingly. Additional experiments were also conducted with THE UV bands. The Tesa 54140 (©tesa SE - Beiersdorf Company, UK) uv bands were used, which consisted of a sensitive UVC polymer film that changes color after UVC exposure. The UV dosage was measured using a compatible Hoenle UV Scan (Hoenle UV America, Inc., Marlboro, MA), which determines the UVC dose obtained based on color change. The bands had a linear detection range of up to 200 mJ cm2. The Hoenle scan measurements were calibrated in relation to measurements taken by the UV sensor integrated into the Daavlin unit. This was done by placing the UV strip at a fixed distance from the lamp and comparing the doses measured by UV scanning for those sensor integrated into the Daavlin unit located at the top of the block above the lamp. After that, the strips were used to (1) test the accuracy and consistency of the aforementioned experiments by placing the UV band at the top of the N95 respirator and on the curved surface (Figure 2a) and (2) to study the UVC penetration percentage through all layers of the N95 FFR by placing the UV strip on the side directly and indirectly irradiated (Fig. 2b). (a) The N95 respirator with ultraviolet stripes located on the surface closest to the lamp and edge (yellow arrows). Left: before and right: after UVC treatment. Note, the band changed color after (b) Stripes on a surface directly or indirectly irradiated. Upper panel: before exposure to the lower panel: after exposure. (c) Measurements of Hoenle's UV scan as a dose function, measured by a UV sensor integrated into the Daavlin unit to measure dose changes received by different parts of N95 FFRs, were considered two different factors - the first being the impact of the N95 curvature, and the second - the distance of the irradiated area from the lamp. For the Davalin unit, the FFR curvature effect was taken into account by measuring radiation at different angles between the normal surface (Figure 1a) and the UVC incident. With the sensor colliding with the UVC radiation incident (orientation in Figure 1b), radiation approximately 10 mW cm-2 with less than 10% variation was measured at various locations in the radiation zone. However, as expected, with changes in sensor orientation, less than 2 times the decrease in radiation exposure was observed between two extreme orientations from 10.2 mWh/2 (targeting in Figure 1b) to 6.2 mWh2 (targeting g in Figure 1b). Given that the N95 respirator has a small curvature, it is possible to approach the fact that the lowest irradiation received on the curved surface corresponds to the orientation of the f sensor in rice. 1b. To the edge of the device, the measured radiation for this orientation was 4.0 mW cm2. In order to minimize the effect of changing irradiation near the edges of the device, for the daavlin unit, it is suggested that the placement of the respirators be such that there is at least 10 cm distance between the edge of the N95 respirator and the edge block on the side of the controller and approximately 5 cm on the other side. This recommendation is based on the location of the lamp inside the device. This ensures that the least radiation exposure is at least 6 mW cm.2. Thus, the curved parts of the N95 respirator closer to the tray will observe 60% of the dose administered, called the curvature factor in Table 1. Table 1. Representative calculations for the observed dose taking into account the radiation of the surface of the outer surface with 1.5 cm-2 Distance from the lamp (see) The curvature factor Irradiance factor received dose (Eq. 2) (J cm-2) 8 1.000 1.998 2.997 9 0.918 1.742 2.401 10 0.903 1 .401 1 .536 2.080 11 0.867 1.366 1.778 12 0.750 1.224 1.37 8 13 0.602 1.104 0.997 14 0.602 1.000 0.903 After curvature effect, the effect of the remoteness of the irradiated site from the lamp has been investigated. For the daavlin unit, when a dose of 1.5 J cm-2 has been introduced into the control panel, the time is automatically taken into account by the UV sensor integrated into the unit. The sensor, located at the top of the device above the lamp, was calibrated to use radiation 14 cm away from the UVC lamp, which corresponded to the distance between the lamp and the table/lot (Figure 1b). Areas closer to the lamp should observe higher exposure resulting in a higher dose. The radiation factor shown in the rice. 1c, was calculated with Eq. 1 by normalizing against radiation at a distance of 14 cm from the lamp. The radiation values at different distances from the lamp were determined by the radiation factor and measured radiation values of approximately 8 mW cm at a distance of 14 cm from the lamp and approximately 10 mW cm at a distance of 11.5 cm from the lamp. The height of the FFR N95 varies depending on the model, and the conservative approximation is about 6 cm. Given this, the nearest part of the respirator, when treating any surface, will be about 8 cm from the lamp and will be observed at 1.99 times the distance of 14 cm from the lamp (Figure 1c, table 1). Taking into account the effect of curvature and distance from the lamp, it was found that the dose received by different parts of N95 during THE PROCESSING of UVC of one surface with 1.5 J cm2, ranged from approximately 900-2900 mJ cm2 (Figure 3, Table 1). The resulting dose was calculated using Eq. 2. Received dose (J cm. 2) - Administerable dose (J cm - 2) ∗ Curvature Factor ∗ Irradiance Factor (2) Received dose as a function of the angle between the surface of normal and incident UVC and distance from the lamp. The top of the FFR model, approximately 8 centimeters from the lamp with 0 between the surface of normal and case UVC, received approximately 3 J cm'2, whereas the side part of the lamp, at a vertical distance of 14 centimeters from the lamp with approximately 75 between the surface of normal and case UVC, received approximately 900 mJ cm'2 here, for the Daavlin unit , the introduced dose at one surface amounted to 1.5 cm. Experiments with the UV band were conducted to test the accuracy and consistency of the above-mentioned experiments, as well as to study the percentage of UVC penetration across all layers of FFR N95. These stripes changed color when exposed to UVC, and the accumulated dose was measured using Hoenle UV scanning. Figure 2c shows measurements taken using Hoenle UV scanning as a function made by a sensor integrated into the Daavlin block. Differences in measurements are partly explained by fluctuations in the spectral sensitivity curves of the UV tape and THE UV-meter from the respective manuals. The UV tape was applied on the outer surface of the respirator on the surface closest to the lamp, and on the edge, which was further from the lamp and had a curvature (Figure 2a). Measured values showed that the edge received a 29% dose compared to the top, 610 mJ cm at the top and 175 mJ cm-2 on the edge. Figure 2b shows the placement of ultraviolet bands on the top of the respirator both outside and surfaces before and after UVC treatment. The surface on the outside was irradiated (719 mJ cm.2), and measurements showed that approximately 10.5% of the controlled UVC was detected on the wear surface (75 mJ cm.2). One complete cycle of decontamination with the daavlin unit consisted of treating the outer surface of the N95 respirator and then flipping the respirator to treat the wearer's face surface. This device can decontaminate about 18 N95 respirators at the same time. A dose of UVC 1.5 J cm'2 was injected for each surface; Total dose of 3 J cm-2. This dose, delivered in about 6 minutes (3 minutes on each side), corresponded to the surface of the table/lot with areas closer to the lamp, receiving a relatively higher dose. The results of UV-measurable experiments showed that after exposure to the outer surface of the N95 respirator with 1.5 J cm-2, all parts of the respirator on this surface received a dose of at least 900 mJ cm2, while the upper part of the FIU, closest to the light source, received approximately 3 J cm.2. Experiments with UV bands also supported this output with the side of the FFR, receiving approximately 29% of the dose received at the top. In addition, experiments with UV band show that approximately 10% of the dose of UVC can penetrate all layers of the N95 respirator. This suggests that after one full cycle of decontamination, the observed dose for all parts of the N95 respirator should be at least ≈1 J cm-2, as recommended by the consensus groups (10) for reprofiling N95 respirators. It should be noted that the presence of UVC lamps on both sides will increase the observed dose. In addition, the use of highly reflective surfaces, such as polished aluminum, as a base/lot (both on the inside and back) with a daavlin unit will further increase homogeneity, as well as general UVC exposure in the unit resulting in a higher dose. Due to the shortage of SIS across the United States, various agencies are repurposing their UVGI technologies to decontaminate the N95. Because the N95 respirators have curved surfaces and all UVGI devices have a unique geometry, the methodology described in this manuscript should be used to collect radiation data for change from the angle and distance from the UVC lamp. This data will help determine the dose received (Eq. 2) by different parts of the N95 decontaminated using the corresponding UVC unit. In addition, measuring radiation as a angle function near the edge of the device will provide important instructions on how to place N95 respirators during the decontamination cycle to ensure proper dosing. The limitation of UVC decontamination systems is that UVC photons can only be effective if they have direct contact with the surface. Given this and the fact N95 respirators have curvature, it is important to take into account the actual dose observed by different parts of the respirator in the repurposed block. The relatively low level of strap decontamination is another limitation of the decontamination of N95 respirators mediated by UVC. To address this problem, the N95Decon team offered to wipe the straps with a compatible napkin along with UVC treatment to achieve the desired level of decontamination (14). Important factors to consider in determining and comparing the effectiveness of potential UVGI devices specifically for N95 decontamination are the maximum exposure to the UVC unit if the radiation was measured or calculated, the availability of test data after UVC treatment, the number of decontamination cycles after which the FFR will be tested, the maximum number of respirators that can be processed during the 1st cycle, and whether the device requires. To facilitate these considerations, these parameters are included in Table 2 with proposed scoring, which can be used to gather agencies information on specific devices to compare UVGI devices. This scoring system was developed as a screening tool when several providers with repurposed UVC technologies for N95 decontamination contacted our hospital system. Although it has not been tested, it has proved to be practical and useful. Other agencies can benefit from this. Table 2. Options that can be used to compare different UVGI 1 devices. Maximum exposure: The higher the maximum exposure, the faster the dose will be delivered, making the unit time effective. Time Efficiency/Maximum Exposure Example: Time for delivery of 1.5 J cm-2 with irradiation data Score of 10 mWh2 cm2 s 30 s q 5-10 mw cm q 2 mins q 30 s-5 mins cm-2 q 5 min-25 mins 0.5-1 mw cm-2 25 min-50 mins Radiation irradiation data data Score measured 5 Calculated 1 3. Fit-testing post-UVC treatment Fit-testing data score is available for some models of N95 5 No data available 0 4. Maximum number of respirators treated in one cycle Number of respirators per cycle Is 45 5 30-45 4 15-30 3 5-15 2 qlt;5 1 q 5. cost per respirator: this comparison can be done by the dividing q cost of the unit. Respirators' that can be but sterilized' in one of the cycle.' since the units will be used multiple times, the actual cost of the respirator will be lower. $100.00 5 q $100.00-$200.00 q 4 q $200.00-300.00 q 3 q $300.00-$400.00 q 2'gt;$400 for a respirator 1 6. Ventilation: Some blocks emit ozone and may need ventilation Score No required 2 Required 1 Maximum possible score: 5 x 5 x 5 x 5 x 2 x 27. In conclusion, this study is a model for a thorough and methodical assessment of the zlt;$100.00/zlt;0.5 mW cm.2 effectiveness of UVC in decontamination of N95 respirators. While a specific UVC device and one type of N95 respirator have been used, the evaluation process can be summarized by other UVGI devices and other types of respirators. It is essential that such an assessment be carried out in order to ensure that the decontamination is properly decontaminated. Failure to do so could have disastrous consequences for frontline health workers. 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