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Ultraviolet Germicidal Irradiation of Influenza-Contaminated N95 Filtering Facepiece Respirators

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ABSTRACT

An influenza pandemic could lead to a shortage of Filtering Facepiece Respirators (FFRs), leaving health care workers unprotected. Past research on FFR decontamination and reuse (FFR-DR) strategies indicate ultraviolet germicidal irradiation (UVGI) is effective at killing influenza on FFRs. This study expands this research by 1) optimizing UVGI dose for influenza kill in the presence of soiling agents, 2) optimizing the dose to reduce exposure time, and 3) evaluating 15 FFR models to understand universal application of the technology.

For UVGI dose optimization, triplicate 3M 1870 coupons were contaminated with influenza and either sebum or mucin. Test coupons were exposed to 254-nm UV-C dose ranging from $1 \times 10^3 - 2 \times 10^6$ µJ/cm^2. Influenza virus was extracted and quantified using a median tissue culture infectious dose ($TCID_{50}$) assay. A UVGI device was built to apply the optimized UV dose to an intact FFR in ~1 min. Triplicate samples of 15 FFR models were contaminated as described above on three facemask locations and one strap location per FFR. After UV treatment, coupons were cut from the FFRs, and remaining viable virus extracted and quantified.

The optimized dose was determined to be ~1×10^6 µJ/cm^2. Whole FFR exposure demonstrated high variability in UVGI decontamination between FFR models and surface type, with log reductions ranging from 0.00 – 4.85 $\log_{10}$ $TCID_{50}$. The mean log reduction on the facemask portion of all 15 FFR models was 3.42 ± 1.08 $\log_{10}$ $TCID_{50}$ and 2.48 ± 1.29 $\log_{10}$ $TCID_{50}$ for straps. Only two of the FFR models demonstrated ≥ 3-mean log reduction for all contaminated surfaces. FFRs with hydrophilic surfaces correlated with the lowest log reduction values, and vice versa for hydrophobic surfaces.

These data suggest that FFR-DR using UVGI is possible, but not universal. Some FFRs are not compatible, presumably due to material incompatibilities. These data are critically important for regulators and hospitals to understand in the event FFR-DR technologies are deployed during a pandemic. Studies are currently underway to evaluate FFR durability and performance following multiple UVGI cycles and to evaluate logistical parameters for implementing UVGI-based FFR-DR technology into health care settings.

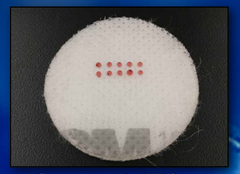
METHODS

UVGI DOSE OPTIMIZATION

- Multiple UV doses were evaluated to determine the optimal UVGI dose to achieve ≥ 3-log reduction in viable H1N1 influenza virus while in the presence of soiling agents (artificial skin oil, artificial saliva).
- For each test, triplicate 3M 1870 FFR coupons (3.8-cm dia.) were used for both control and test samples..
- Coupons were inoculated with ten 1-µL droplets of ~8-9 $\log_{10}TCID_{50}$ H1N1 influenza.
- Inoculated areas were then overlaid with soiling agent, depending on the condition being tested:
  - No soiling agent
  - Artificial saliva (mucin): 50 or 100 µL
  - Artificial skin oil (sebum): 2.5 or 5.0 mg
- Treated coupons were then exposed to 7 mW/cm^2 254-nm UV-C radiation at various times to achieve the following doses:

1×10^3 µJ/cm^2	5×10^5 µJ/cm^2
1×10^6 µJ/cm^2	2×10^6 µJ/cm^2

- Coupons were extracted, and extracts were plated in MDCK cells using a $TCID_{50}$ assay according to WHO protocol.

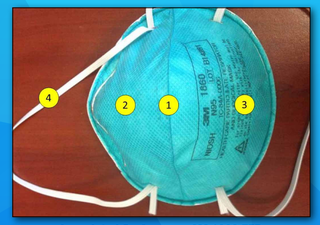


Influenza-Inoculated FFR Coupon

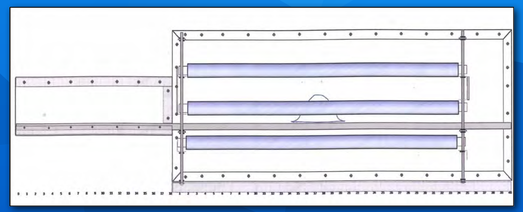
UVGI Device for Dose Optimization

WHOLE FFR DECONTAMINATION

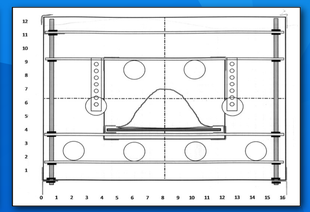
- Fifteen commercially available N95 FFR models were evaluated.
- Six masks per FFR model (three UV-treated and three non-UV-untreated) were used for each test.
- Each replicate was inoculated with ten 1-µL droplets of ~8-9 $\log_{10}$ T-CID_{50} H1N1 influenza on four unique locations.
- Inoculated areas were then soiled with 50 µL mucin or 2.5 mg sebum.
- Using a custom UV device, UV-treated FFRs were exposed to 1.0 – 1.2×10^6 µJ/cm^2 of 254-nm UV-C.
- 3.8-cm diameter coupons were aseptically cut from inoculated surfaces of both UV-exposed and control FFRs; strap coupons were cut at the point of attachment.
- Coupons were extracted, and extracts were plated in MDCK cells using a $TCID_{50}$ assay according to WHO protocol.



Inoculated Surfaces on 3M 1860 FFR



Custom UVGI Device (Sagittal View)

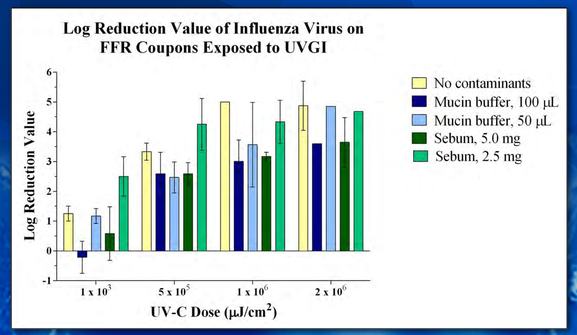


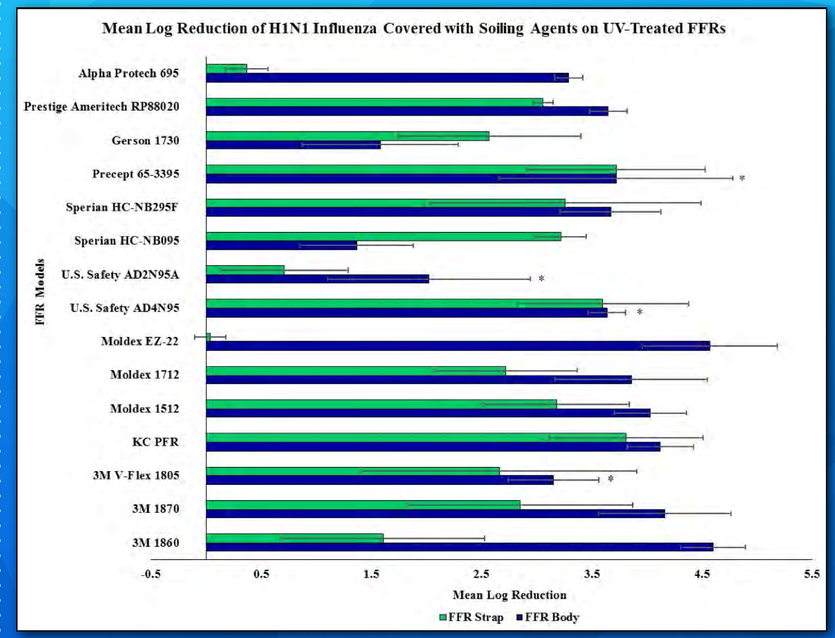
Custom UVGI Device (Coronal View of Chamber Only)

Fifteen N95 Models Evaluated for Whole FFR Decontamination

RESULTS

For UVGI optimization, the minimum UVGI dose demonstrating ≥ 3-log reduction in viable H1N1 influenza in the presence of protective factors was 1×10^6 µJ/cm^2.





* denotes >1-log reduction difference in viable H1N1 influenza between mucin-soiled and sebum-soiled UV-treated FFRs

CONCLUSIONS

- An increase in UV approaches diminishing returns at 1×10^6 µJ/cm^2 for H1N1 decontamination on N95 FFRs.
- UVGI can be effective against H1N1 influenza in the presence of soiling agents, but respirator shape, respirator material, and UV light arrangement may significantly affect decontamination efficacy.
- Two main factors limit the ability to demonstrate a higher log reduction value with a corresponding higher UV dose: 1) the level of viable influenza recovery obtained from the control coupons, and 2) the detection limit of the $TCID_{50}$ assay.
- Future studies using UVGI on select agent viruses will be conducted to determine the decontamination efficacy.
- Durability and performance testing will be performed using 15 N95 FFR models exposed to multiple UV cycles to determine any functional loss that could occur as a result of UVGI exposure.

ACKNOWLEDGEMENTS

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The published material represents the position of the authors and not necessarily that of the FDA.