What are the effective methods of decontaminating N95 mask for reuse?

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KEY FINDINGS

Based on laboratory-based studies, ultraviolet germicidal irradiation (UVGI), microwave generated steam, warm moist heat, and hydrogen peroxide vapor (HPV) were able to reduce the load of influenza viruses (A/H5N1, H1N1) or G. stearothermophilus and at the same time maintain the integrity of N95 respirators.

- Considering the current pandemic, there is a potential for shortage of N95 facepiece filtering respirator (FFR) for healthcare workers.
- No studies in humans were found comparing effectiveness of N95 post-decontamination.
- Laboratory based studies done on influenza virus (A/H5N1, H1N1) have shown that ultraviolet germicidal irradiation, microwave generated steam, or warm moist heat was able to reduce the viral load by as much as 4 log and at the same time maintain respirator performance by keeping the percent penetration below 5% and the pressure drop within standards.
- While UVGI was able to maintain integrity of FFRs up to 3 cycles, microwave generated steam may melt the metallic components of certain N95 masks.
- Hydrogen peroxide vapor (HPV) had minimal effect on respirator performance and structural integrity up to 20 cycles and was also effective in eradicating G. stearothermophilus and aerosolized bacteriophages.
- Bleach, ethanol and isopropanol all affected the mean penetration of the mask beyond the 5% limit.
- The Centers for Disease Control (CDC) does not recommend decontamination then reuse of FFRs as standard care but decontamination with UVGI, HPV or moist heat may be considered as an option in FFR shortages.

\RESULTS

No studies in humans were found comparing effectiveness of N95 after decontamination.

Laboratory studies on decontamination of 3 to 6 models of N95 respirators using UVGI demonstrated a reduction of >4 log in both H1NI and H5N1 influenza virus when virus was aerosolized or in droplets. However, its performance may go down to a reduction of log 1.25 if mask is soiled with mucus or sebum. Respirator performance and structural integrity after decontamination was still within acceptable standards. Mean penetration percent was below 5% even up to three cycles of decontamination and initial resistance was below 25mmH_20. Structural integrity and fit of N95 masks were not significantly altered. No studies established the effect of decontamination beyond three cycles. The efficiency of UVGI, however, may be affected by shadowing and material of respirator facepiece and straps.

Like UVGI, microwave generated steam and warm moist heat had good decontamination performance. Both reduced viral load of influenza by >4 log with mean penetration and resistance still within acceptable standards. Although respirator filtration and fit were preserved for most of the N95 models tested, partial separation of the inner foam nose cushion from the respirator was noted on one model of N95 respirator tested. Also, N95 metal parts may melt when subjected to microwave generated steam.

Hydrogen peroxide vapor (HPV) decontamination of one model of N95 respirators showed successful decontamination of *G. stearothermophilus* and aerosolized bacteriophages with measured hydrogen peroxide concentration below the permissible exposure limit. Respirator performance was not compromised with aerosol collection efficiency at 99% and airflow resistance at 8 to 11 mm H_2O after decontamination. There were no observed physical changes in the masks after 20 cycles, but strap degradation was noted after 30 cycles. Respirator fit was assessed using a manikin head form and results suggested fit was unaffected up to 20 HPV cycles.

Bleach, ethanol and isopropanol all increased the mean penetration of the mask above the 5% limit. All do not leave a residue however bleach creates an odor that may be uncomfortable to the wearer. No studies demonstrated the bactericidal or viricidal effect of these chemicals on N95 respirators.

The Centers for Disease Control (CDC) does not recommend decontamination then reuse of FFRs as standard care but decontamination with UVGI, HPV or moist heat may be considered as an option in FFR shortages. However, proper precautionary measures need to be taken such as cleaning hands with soap and water before and after touching the FFR, using a pair of non-sterile gloves when donning the respirator and performing a seal check, inspecting the respirator for any defects or degradation of parts, and performing a user seal check.

CONCLUSION

Based on laboratory test done on N95, the following decontamination methods were shown to be effective in reducing either viral/bacterial load and still maintain the integrity of the mask: 1. Ultraviolet germicidal irradiation 2. Microwave generated steam 3. Warm moist heat 4. Hydrogen Peroxide Vapor. However, the effectiveness of these methods against SARS-CoV-2 is not known. None of the studies on N95 decontamination have extensively evaluated and met all the important criteria for decontamination methods which are as follows: the method must be effective against the target organism, not damage the respirator's filtration, not affect the respirator's fit and be safe for the person wearing the respirator. If any of the above measures are done, it should be tailored to the capacity of the hospital and its viability while taking the necessary precautions. Testing the mask for SARS-COV-2 after decontamination can validate it further.

Declaration of Conflict of Interest

No relevant conflict of interest

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Appendix 1. Characteristics of included studies

Study	Infectious Agent	Method of Decontamination	Outcomes	Number of N95 models tested
Lore 2012[5]	Influenza Virus (A/H5N1)	1. Ulltraviolet Germicidal Irradiation (UVGI) 2. Microwave-generated steam (MGS) 3. Warm Moist Heat (WMH)	Decontamination measured by viral culture Decontamination measured by qRT-PCR Post-decontamination Filter Performance	2
Heimbuch 2012[7]	Influenza Virus (H1N1)	1. Ulltraviolet Germicidal Irradiation 2. Microwave-generated steam 3. Moist Heat	Decontamination measured by viral culture	6
Heimbuch 2014 [18]	Staphylococcus aureus	1. Hypochlorite 2. Benzalkonium chloride 3. Nonantimicrobial wipes	Decontamination measured by culture	3
Batelle 2016 [13]	G. *stearothermophilus*	1. Hydrogen Peroxide Vapor	Decontamination Filter performance Respirator fit (manikin head form)	1
Kenney 2020 [14]	bacteriophages: T1, T7, and Pseudomonas phage phi-6	1. Hydrogen Peroxide Vapor	Decontamination	3
Mills 2018[4]	Influenza Virus (H1N1)	1. Ulltraviolet Germicidal Irradiation (UVGI)	Decontamination measured by viral culture	15
Lin 2018[16]	B. subtilis spores	1. Ethanol 2. Bleach 3. UVGI 4. Autoclave 5. Traditional electric rice cooker	Relative survival	4
Viscusi 2009[11]	None	1. UVGI 2. Ethylene Oxide 3. Hydrogen Peroxide Vapor	Observational physical changes	6

		4. Microwave oven irradiation 5. Bleach	Filter aerosol penetration	
Bergman 2010 [10]	None	1. UVGI 2. Ethylene Oxide 3. Hydrogen peroxide glass plasma (HPGP) 4. Hydrogen peroxide vapor (HPV) 5. Microwave oven generated steam 6. Bleach 7. Liquid hydrogen peroxide 8. Moist heat incubation/pasteurization	Observational physical changes Odor Filtration performance: filter aerosol penetration and filter airflow resistance	6
Lindsley 2015[167	None	1. UVGI	Filter penetration Flow resistance	4
Lin 2017[9]	None	1. Dry heat (rice cooker) 2. Moist heat (autoclave) 3. Ethanol 4. Isopropanol 5. Bleach	Filtration performance: Filter aerosol penetration, most penetrating particle size	1
Viscusi 2011[8]	None	1. UVGI	Respirator Fit Odor Comfort Donning Ease	6
Schwartz 2020 [15]	G. *stearothermophilus*	2. 1. Hydrogen Peroxide Vapor	Decontamination Filter performance Respirator fit	1