Respirator filtration efficiency before and after decontamination by moist heat incubation: particle size dependence

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INTRODUCTION

Decontamination of Respirators

The decontamination and reuse of respirators have been proposed to mitigate the shortage of N95 or similar high-efficiency respirators during pandemics.

- Sterilization by vaporous hydrogen peroxide, ultraviolet germicidal irradiation, and moist heat incubation (MHI) are three decontamination methods recommended by the US Centers for Disease Control and Prevention[1] because they have been shown to disinfect respirators with less impact on their filtering performance and fitting than other methods, such as autoclaving and isopropyl alcohol soaking.[2]
- To support and ensure the safety of decontaminated respirators, the US National Institute for Occupational Safety and Health (NIOSH) filtration efficiency (FE) tests have been used to quantify the FE of decontaminated NIOSH- and non-NIOSH-approved respirators.[3,4]

Respirator Filtration Efficiency Test Procedure

N95-type respirators, with a minimum filtration efficiency of 95%, are tested and certified by NIOSH in North America, as per procedures listed in Title 42 CFR Part 84[5] that include:

- Preconditioning filters at 38°C and 85% relative humidity for 25 hours prior to the test
- A test flow rate of 85 ± 4 L/min through filters (face velocity of approx. 9.3 cm/s)
- Use of charge-neutralized sodium chloride test aerosol, with count median diameter of 0.075 ± 0.020 µm and a geometric standard deviation ≤ 1.86.

We hypothesized that the NIOSH test particle size range may not be sufficient to capture worst-case FE for decontaminated respirators, particularly if a decontamination technique negatively influences electrostatic properties of the respirator material.

METHODS

Respirator Selection

Three different respirator models were selected for testing: KimtechTM N95 (53358; Kimberly-Clark Corp., USA), Medstar KN95 (Anji Yuandong Medical Products Co., Ltd., China), and Safe Life N95 (B130; Safe Life Corp., USA). For each model, three individual respirators were randomly selected for the control group and another three for the decontaminated group.

Multiple Decontaminations by Moist Heat Incubation

For each decontamination cycle, respirators were decontaminated in an environmental chamber (Lunaire CEO910W-4; Thermal Product Solutions, USA) at an average temperature of 59 ± 1°C and relative humidity (RH) of 67 ± 2% for 30 minutes and dried at 59 ± 1°C and 11 ± 2% RH for another 30 minutes. Ten repeated cycles were conducted for respirators in the decontaminated group.

Filtration Efficiency Test

A FE test set-up was designed to consider a similar worst-case scenario as the NIOSH certification tests. Before each FE test, both control and decontaminated respirator samples were preconditioned at 38°C and 85% RH for 25 hours in the environmental chamber and tested within ten hours as per Title 42 CFR Part 84. Filtration efficiencies and pressure drop across respirators were measured using the experimental setup shown in Figure 1. NaCl droplets were nebulized, neutralized, and dried before entering a test plenum through a flow straightener. Respirator sample holders were designed such that the samples were subject to a face velocity of 10.6 cm/s. Concentrations of the blank line (i.e., particles in the plenum) and the filter line (i.e., particles penetrating the filters) were measured with an electrical low pressure impactor (ELPI; Dekati Ltd., Finland) to calculate filtration efficiency. The ELPI measured particle concentrations as a function of aerodynamic particle size in eight discrete bins ranging from 0.07 µm to 1.97 µm. A manometer was connected between the blank and filer lines to measure pressure drop across the sample.

SEM Images

Field emission scanning electron microscopy (control and decontaminated samples to investigate any possible physical deteriorations in respirator Zeiss Sigma FE-SEM; Carl Zeiss, Germany) was used take SEM images of filter layers.

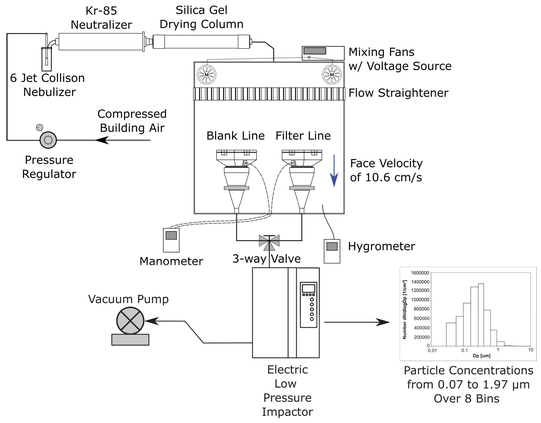

FIGURE 1. Experimental setup used to quantify respirator filtration efficiencies across a range of particle sizes.

RESULTS

- As shown in Table 1 and Figure 2, FE for the Kimtech™ N95 and Medstar KN95 respirators was not reduced at any size after ten cycles of MHI.
- For the SafeLife respirator, the minimum FE was below 95% before MHI cycles and decreased to 81% after MHI cycles. The most penetrating particle size for this respirator was outside the range defined in the NIOSH test protocol, and further increased after MHI cycles.
- With minimal change in pressure drop and no obvious visible changes to filter layers as shown in Figure 3, the aggregated reduction of FE at larger particle sizes may have been due to decreased electrostatic filtration after exposure to high temperature and humidity.
- This result suggests that for assessing protection against larger droplets like infectious aerosols, respirator FE should be measured at diameters larger than specified by NIOSH, especially after decontamination cycles that can reduce electrostatic filtration, and for non-certified respirators or homemade masks[6] that may underperform at larger particles sizes.

TABLE 1. Filtration efficiency (FE) at the most penetrating particle size (MPPS) before and after ten cycles of moist heat incubation.

		Kimtech™ N95	Medstar KN95	Safe Life N95
Control	FE	98.4±0.7%	94.2±3.3%	89.4±2.0%
	MPPS	0.12 µm	0.32 µm	0.32 µm
After Ten Cycles of MHI	FE	98.2±0.0%	96.8±1.0%	81.1±3.1%
	MPPS	0.12 µm	0.12 µm	0.49 µm

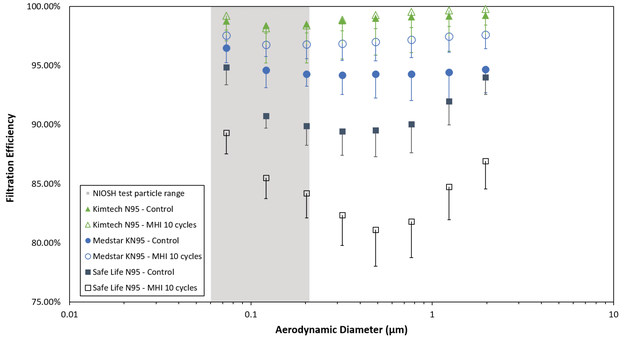

FIGURE 2. Filtration efficiencies from commercial N95s and KN95s before and after ten cycles of moist heat incubation. Grey area indicates typical NIOSH test particle sizes. For clarity, only negative error bars are depicted.

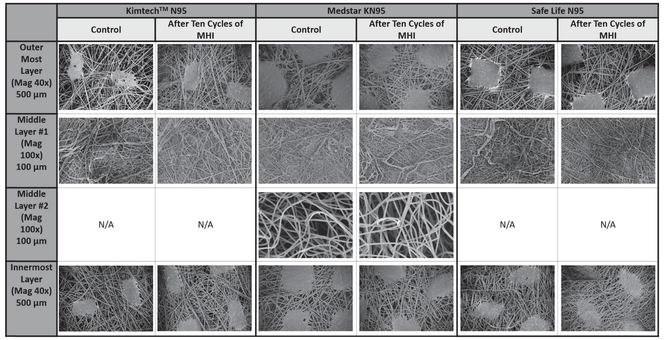

FIGURE 3. SEM images of commercial N95s and KN95s before and after ten cycles of moist heat incubation.

CONCLUSION

The encouraging results of the present study for two of three respirators studied support previous studies indicating MHI can provide an effective method for decontaminating N95s for reuse. However, it is recommended that a wider particle size range, including particle sizes up to the micrometer size range, be used when testing FE of respirators and facemasks used during pandemics. Reporting FE only within the NIOSH test particle range may not adequately characterize respirator performance against infectious aerosols, and not capture actual worst-case scenarios. The risk of disregarding respirator performance at larger sizes is notable in the context of filtering infectious aerosols where infectious load increases with size.

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