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## Major Article

## Evaluation of the effects of wiping decontamination for filter cartridges of elastomeric half-mask respirators (EHMRs)

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## Key Words:

EHMR P100 filter cartridges  
Quaternary ammonium wipes  
Sodium hypochlorite wipes  
Filter performance  
EHMR reuse**Background:** A major concern among health care experts is a shortage of N95 filtering facepiece respirators during a pandemic. If the supply of N95 filtering facepiece respirators becomes limited, reusable elastomeric half-mask respirators (EHMRs) may be used to protect health care workers. The focus of this study was to evaluate the effects on the filter performance of wiping decontamination for EHMR P100 filter cartridges.**Methods:** The filter cartridge exterior of EHMR Honeywell, Moldex, and Mine Safety Appliance (MSA) models was wiped using quaternary ammonium and sodium hypochlorite wipes. These filter cartridge properties were assessed including observational analysis and filter performance tests. These wiping and assessing procedures were repeated after each set of wiping cycles (50, 100, 150, 200, and 400 cycles) to determine the effects of wiping decontamination.**Results:** For sodium hypochlorite wipes, Honeywell, Moldex, and MSA models passed the National Institute for Occupational Safety and Health (NIOSH) liquid particulate penetration criteria for all wiping cycles from 50 to 400 (penetrations < 0.014%). For quaternary ammonium wipes, filter penetrations of Moldex failed (penetrations > 0.03%) after 150 cycles, while the filter penetrations of Honeywell and MSA passed for all wiping cycles (penetrations ≤ 0.013%).**Conclusions:** Wiping decontamination methods using sodium hypochlorite and quaternary ammonium wipes could be considered promising decontamination candidates for Honeywell, Moldex, and MSA reuse, except for the wiping number selection for Moldex (< 150 cycles) when using the quaternary ammonium wipe.

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## BACKGROUND

Elastomeric half-mask respirators (EHMRs) are a type of air-purifying respirator and are reusable devices with exchangeable filter elements (cartridges or filters). EHMRs can be used to protect against gases, vapors, and particles if equipped with the appropriate filter and/or sorbent materials. In pandemic situations, a shortage of N95 filtering facepiece respirators (N95 FFRs) may be encountered. Thus, reusable EHMRs may be used to protect health care workers from respiratory infections. However, unless a decontamination process is employed, the reuse of EHMRs raises the risk of contamination of the wearer or the environment by pathogens already present on the respirator surface or on the

filter cartridges. The facepiece of reusable EHMRs (not cartridges or filters) used in health care under normal conditions are cleaned using disinfectant wipes and alcohol swabs.<sup>1</sup> Although Bessesen et al<sup>2</sup> used chemical solutions for disinfecting EHMRs, they applied disinfectant wipes only to the outside surface of the hardcase filter cartridge.

From the above circumstances and studies, the following questions have arisen: (1) What are the effects on filter performance (filter penetration and airflow resistance) of an EHMR particulate filter after disinfectant wipes are used on the outer surface of the filter cartridges? (2) What is the maximum number of wiping cycles before degradation of filter cartridges or damage to the enclosed filters occurs [to yield the filter penetration above the National Institute for Occupational Safety and Health (NIOSH) allowed maximum penetration of 0.03% for P100 filters]? (3) What are the effects of repeated wiping decontamination on the filter cartridges including filter performance, odor, and filter appearance as a function of individual wiping cycles?

The goals of this study were as follows: (1) to conduct a wiping decontamination method for P100 filter cartridges of EHMRs using

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disinfectant wipes; (2) to assess the EHMR filter properties (observational analysis and evaluation of the filter performance) before and after conducting the wiping decontamination method; and (3) to determine the effects of repeated wiping decontamination on the filter cartridges including filter performance, odor, and filter appearance.

## METHODS

### EHMR selections

Three EHMR models: Honeywell North 7700 Series ([www.fishersci.com](http://www.fishersci.com), Cat. #: 17-620-2), Moldex 7800 Series ([www.fishersci.com](http://www.fishersci.com), Cat. #: 19-384-387), and Mine Safety Appliance (MSA) Advantage 200LS ([www.fishersci.com](http://www.fishersci.com), Cat. #: 18-999-3897) were selected based on their common use in the health care workplace for protection against particulate hazards.<sup>1</sup> Honeywell 7580P100, Moldex 7940, and MSA 815369P100 filter cartridges used for Honeywell North, Moldex, and MSA respirators, respectively were selected for this study. These filters are all class P100 respirators (containing a filter with a 99.97% filtration efficiency). A sample of EHMR and 3 P100 filter cartridge models used in this study are shown in Figure 1.

### Disinfectant wipe selections

Quaternary ammonium disinfectant wipes also named as Sani-Cloth AF3 Germicidal Wipes, Model #: P13872 (PDI, Inc) and sodium hypochlorite disinfectant wipes also named as Sani-Cloth Bleach Germicidal Wipes, Model #: P54072 (PDI, Inc) were used for the wiping decontamination study. These wipes were selected based on the respirator manufacturers' guidance regarding disinfecting filter cartridge exterior,<sup>3–5</sup> their common use in health care settings, and their decontamination efficacy against severe acute respiratory syndrome coronavirus 2 (SARS-CoV2).<sup>6</sup> These wipes are registered with the Environmental Protection Agency (EPA) for decontamination against SARS-CoV2 (EPA registration # 9480-9 for quaternary ammonium wipes and EPA registration # 9480-8 for sodium hypochlorite wipes).<sup>6</sup>

### Analyzing the EHMR filter media properties and wipe-chemical polarity

#### EHMR filter media properties

The purpose of evaluating the hydrophilicity or hydrophobicity of the filters was to investigate filter media properties that would uptake or repel any vapor molecules from disinfectant wipes used in the wiping decontamination process, resulting in producing any sign of changing the physical and mechanical properties of the filters and changing the filter penetrations. Hydrophilic and hydrophobic filter media properties for Honeywell, Moldex, and MSA models were analyzed. Three filter coupons ( $1.5 \times 1.5 \text{ cm}^2$ ) of each layer from each EHMR filter cartridge model were cut with scissors. To determine the hydrophilicity or hydrophobicity, a 10- $\mu\text{l}$  droplet of water was applied to each filter media and visually examined for 5 minutes. The hydrophilic filter was determined when the deposited water droplet spread over and wet the filter media layer, while the hydrophobic filter was determined when the deposited water droplet remained as a droplet on the filter surface.

#### Wipe-chemical polarity

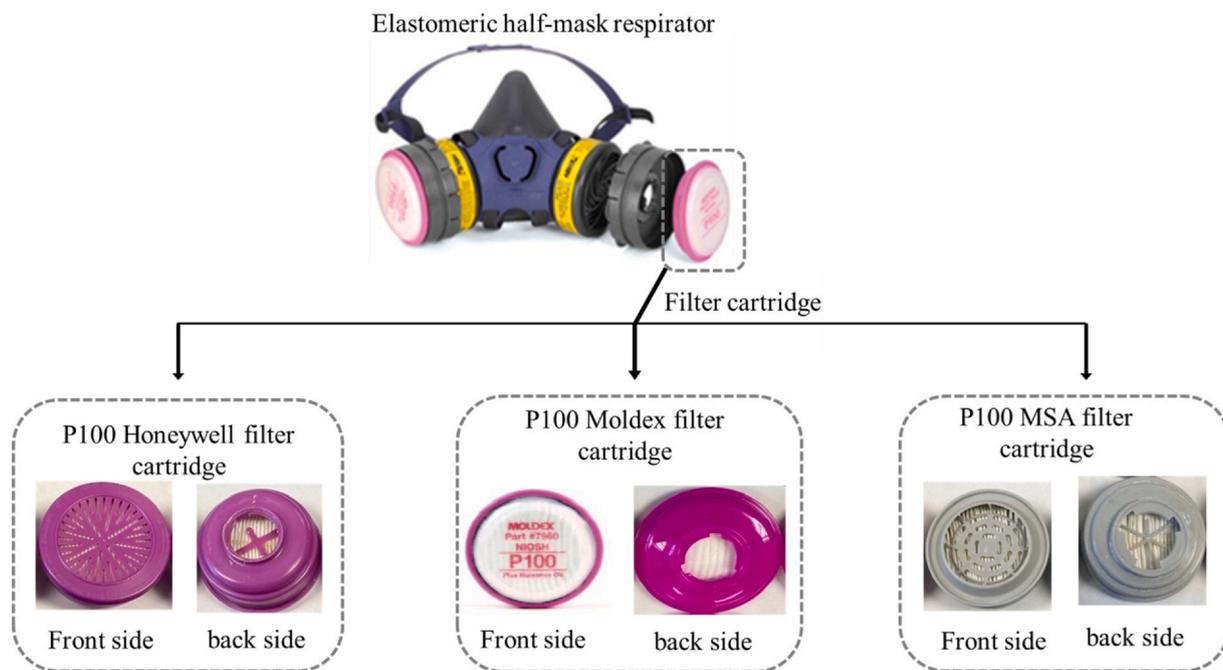
The liquid chemical composition was extracted from the sodium hypochlorite and the quaternary ammonium wipes. The polarity of each wipe-chemical solution was analyzed by mixing it with the same volume of non-polar cyclohexane and visually examining it for 5 minutes. The mixing levels of the 2 substances (cyclohexane and wipe-chemical solution) indicated their polar characteristics.

#### Wiping decontamination method and filter cartridge evaluation

##### Pre-evaluation of filter cartridges before wiping decontamination

An initial inspection of the filters and filter cartridges was conducted to assess the characteristics detailed below.

**Observational analysis.** Pre-decontamination EHMR filters and filter cartridges were carefully inspected for any visible sign of degradation using the following steps.



**Fig 1.** A sample of elastomeric half-mask respirator and 3 P100 filter cartridge models used in this study. MSA, Mine Safety Appliance.

**Table 1**  
A visible inspection checklist for EHMR filters and filter cartridges

1. Do the EHMR filters and filter cartridges have an odor?	<input type="checkbox"/> YES	<input type="checkbox"/> NO	<input type="checkbox"/> NA
2. Do the EHMR filters and filter cartridges have any signs of damage?	<input type="checkbox"/> YES	<input type="checkbox"/> NO	<input type="checkbox"/> NA
3. Are the shapes of the EHMR filters and filter cartridges deformed in any way?	<input type="checkbox"/> YES	<input type="checkbox"/> NO	<input type="checkbox"/> NA
4. Are the EHMR filter cartridges detached from other EHMR components?	<input type="checkbox"/> YES	<input type="checkbox"/> NO	<input type="checkbox"/> NA
5. Do the EHMR filters and filter cartridges appear moldy?	<input type="checkbox"/> YES	<input type="checkbox"/> NO	<input type="checkbox"/> NA

*EHMR*, elastomeric half-mask respirator.

- i. Pre-decontamination EHMR filter cartridges were removed from sealed packages with scissors.
- ii. Filters and filter cartridges were carefully inspected using a visual inspection checklist (Table 1) for any visible sign of degradation (coarseness, roughness, etc) and checked for any discernible smell.
- iii. The filter cartridges were reinstalled onto the EMHR prior to conducting the filter performance tests described below.

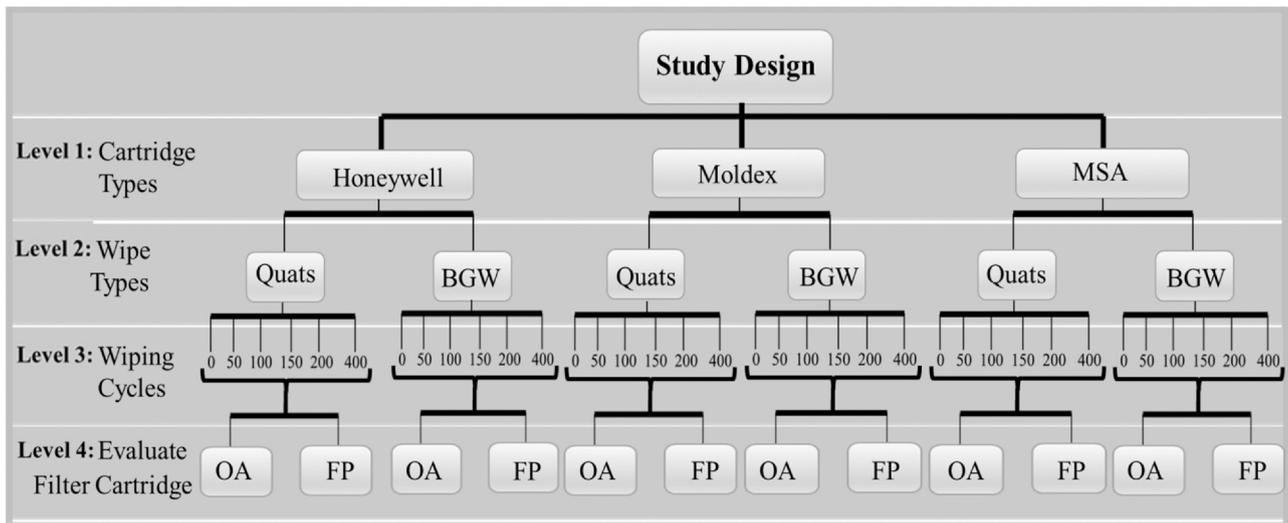
**Filter performance.** The purpose of evaluating the filter performance of respirators was to ensure vapors from disinfectant wipes used in the wiping decontamination process did not alter the physical and mechanical properties of the filters and the filter cartridges. A Model 8130 Automated Filter Tester (TSI, Inc) equipped with a motorized polydisperse dioctyl phthalate generator was used to evaluate the EHMR filter performance (filter aerosol penetration and filter airflow resistance) for all pre-decontamination EHMR P100 filter cartridges. All tests were conducted at ambient conditions with a continuous airflow of 42.5 L/min for each filter cartridge (85 L/min for an EHMR with 2 filter cartridges) in accordance with NIOSH TEB-APR-STP-0051 standard test procedure,<sup>7</sup> which meet the criteria established in 42 CFR 84 for challenging P100 series with a running time of 10 minutes for each cartridge.

**Wiping decontamination and filter cartridge evaluation procedures**

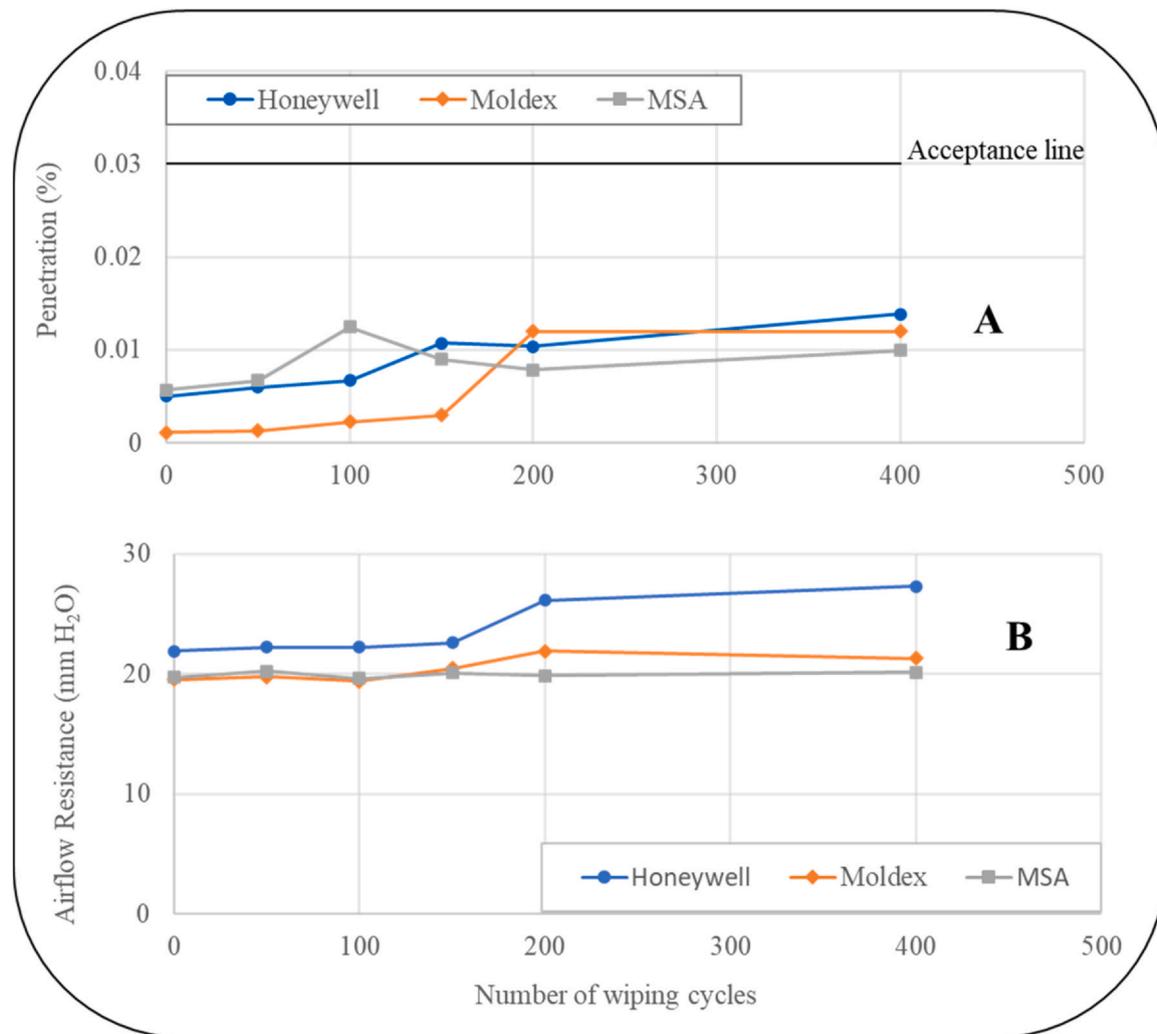
A study-design schematic diagram of the wiping decontamination method for the EHMR filter cartridges and the process of filter cartridge evaluation, including an observational analysis and filter performance is shown in Figure 3.

**Conducting wiping decontamination method.** The wiping decontamination method was conducted as described below.

- i. Personal protective equipment (gloves, goggles, lab coat) was used as required when working on the wiping decontamination and other chemical tests in this study.
- ii. The filter cartridges were removed from the EHMR by unscrewing or turning them to the left.
- iii. Only the outer surface of the filter cartridges was wiped with disinfectant wipes, which were then placed in the clean bin for a minimum contact time of 4 minutes to inactivate viruses or bacteria. This minimum contact time was selected based on the effectiveness of the disinfectant wipes (inactivated viruses or bacteria in 4 minutes or less) as recommended by the wipe manufacturers.<sup>9</sup> The total time for wiping each filter cartridge and its contact time are referred to as decontamination time. The completion of each cartridge decontamination process is named one wiping cycle.
- iv. Wiping procedures were repeated for each cartridge (0, 50, 100, 150, 200, and 400 cycles; control = 0 cycles) as shown in the study design chart (Fig 2) to determine the effects of repeated wiping decontamination on the filter cartridges. During the wiping decontamination process, a new wipe needs to be changed when the using wipe does not remain visibly wet. It should be noted that respirator manufacturers typically recommend that filter cartridges be discarded after each use, while another recommends the filter cartridge be disposed of no later than 30 days after the first use if no oil mists are present.<sup>3,4</sup> However, in accordance with the Centers for Disease Control and Prevention recommendations it was acceptable to repeatedly use these filter cartridges for up to 12 months as a contingency capacity strategy during anticipated respirator shortages.<sup>5</sup> Therefore, the maximum wiping cycles of 400 were selected for this study based on: (1) as a crisis capacity strategy, the particulate filters may be changed after 1 year provided the filters are not visibly soiled, wet, or damaged, (2) working days: 200 d/y (5 working days per



**Fig 2.** A study-design schematic diagram of wiping decontamination method and filter cartridge evaluation: (1) P100 filter/filter cartridge types (level 1), (2) disinfectant wipe types: quaternary ammonium wipe (level 2, Quats) and sodium hypochlorite known as bleach germicidal wipe (level 2, BGW), (3) wiping cycle sets (level 3; 0 cycles = control), and (4) filter cartridge evaluation (level 4; OA, observational analysis; FP, filter performance). MSA, Mine Safety Appliance.



**Fig 3.** Filter filtration performance after wiping decontamination with sodium hypochlorite wipes. (A) Average filter penetration values  $\pm$  SD ( $n=3$ ) for each EHMR model as a function of individual wiping cycles. (B) Average filter airflow resistance for each EHMR model as a function of individual wiping cycles. Acceptance line: The NIOSH allowed maximum penetration of 0.03% (filtration performance  $\geq 99.97\%$ ) for P100 filters.<sup>8</sup> EHMR, elastomeric half-mask respirator; MSA, Mine Safety Appliance; SD, standard deviation.

week, minus holidays and vacations), and (3) 2 clean cycles per day assuming disinfection is occurring at the end of a meal break and a work shift.

- v. The filter cartridges and other EHMR components were re-assembled before assessing the EHMR filter performance for each set of wiping cycles.

*Evaluation of filter cartridges after the wiping decontamination method.* After each set of wiping cycles (0, 50, 100, 150, 200, and 400 cycles), the EHMR filters and filter cartridges were inspected using an observational analysis as described in the [Observational analysis](#). The EHMR performance was then evaluated by conducting filter aerosol penetration and filter airflow resistance as described in the [Filter performance](#).

*Evaluation procedure of filter cartridges after spiking wipe-chemical solutions*

To validate the filter performance data from the wiping decontamination method, known volumes of chemical solutions from the wipes (0.125, 0.25, 0.5, and 1.0 mL) were spiked directly onto the surface of each EHMR filter model (open spaces from the front side

of a filter cartridge; these open spaces allow inhalation air to pass in; [Fig 1](#)) to determine if the wipe chemical solutions would directly react with the filter's materials and produce any sign of damage. The detailed procedure for the chemical-spiking evaluation is described below:

- i. Chemical solutions from each wipe type (quaternary ammonium or bleach germicidal wipe) were extracted into a 10-mL vial and the vial was covered with the vial cap.
- ii. Known volumes of each wipe-type solution (0.125–1.0 mL) were spiked directly onto the surface of each EHMR filter model using a micropipette. These filter cartridges were set at room ambient conditions overnight before undergoing the filter performance tests.
- iii. The filter cartridges and other EHMR components were re-assembled before assessing the EHMR filter performance for each spiking volume level.

*Data analysis*

All tests from this study were replicated 3 times. The mean and standard deviation were calculated using Microsoft Excel for Office

365 software (Microsoft Corporation). To compare the filter aerosol penetration and filter airflow resistance through each EHMR filter cartridge model, obtained from the wiping decontamination with different wipe types and chemical-spiking evaluation, paired t tests with 2-tailed distribution were run, also using Microsoft Excel for Office 365 software. *P*-values of  $\leq .05$  were considered significant.

## RESULTS

### Analyzing the EHMR filter media properties and wipe-chemical polarity

The hydrophobicity or hydrophilicity of the filter media (all layers of filter) properties of Honeywell, Moldex, and MSA models are shown in Table 2. The filter media for each EHMR cartridge model has different characteristics, such as the number of layers, the thickness of each layer, and different hydrophilic and hydrophobic materials (Table 2). The Honeywell and MSA models have a thick hydrophobic layer composed of polypropylene fibers; however, the Moldex model has 3 layers (Table 2). The outer layer of Moldex is a thin hydrophobic layer composed of polypropylene fibers while the Moldex filter media in the middle and inner layers are amphiphilic, meaning they have hydrophobic polypropylene fibers and hydrophilic electret charges. For simplicity, the amphiphilic layer with hydrophobic polypropylene fibers and hydrophilic electret charges was designated as “hydrophilic/hydrophobic layer” (Table 2).

The wipe-chemical polarity of quaternary ammonium and sodium hypochlorite was investigated by mixing wipe chemicals with the same volume of non-polar cyclohexane. The results showed that sodium hypochlorite did not dissolve in cyclohexane, so sodium hypochlorite is clearly a polar solution; however, quaternary ammonium was partly soluble in cyclohexane, so quaternary ammonium solution had both polar (quaternary ammonium cations) and non-polar (alkyl or aryl groups) characteristics in its molecular structure. The results showed that the sodium hypochlorite solution had a higher degree of polarity than the quaternary ammonium solution.

### Evaluation of the effects of disinfecting filter cartridges of EHMRs

Results from the observational analysis method showed that all pre-wiping and post-wiping decontamination for EHMR filter cartridges of Honeywell, Moldex, and MSA models yielded no visible signs of damage before and after each set of wiping cycles. Results also showed that no odor changes and no mold formation was observed at the end of each set of wiping cycles (0, 50, 100, 150, 200, and 400 cycles).

The average percent penetrations in the sodium hypochlorite wiping decontamination method were not significantly different between pre-decontamination (0.001%, 0.005%, and 0.006%) and post-decontamination at the end of 50 cycles (0.001%, 0.006%, and 0.007%) for Honeywell, Moldex, and MSA filter cartridge models, respectively (Fig 2A), with all *P* > .05. The changes in penetration

were not significant when increasing the number of wiping decontamination cycles from 50 to 400 (all *P* > .05) when using the sodium hypochlorite wipes. The results also showed that the filter penetration for all 3 EHMR respirator configurations passed the NIOSH penetration criteria (all penetrations < 0.014%; Fig 2A) because these penetrations were below the NIOSH-allowed maximum penetration of 0.03% for P100 filters.<sup>8</sup> Results of filter airflow resistance tests were not significantly different between pre-decontamination (19.5, 21.9, and 19.7 mmH<sub>2</sub>O) and post-decontamination of 50 cycles (19.8, 22.2, and 20.2 mmH<sub>2</sub>O) for Honeywell, Moldex, and MSA respirator configurations, respectively (Fig 2B) with all *P* > .05. Results of filter airflow resistance after increasing the number of wiping cycles for each Honeywell, Moldex, or MSA respirator configurations were also not significantly different (Fig 2B) with all *P* > .05.

In the quaternary ammonium wiping decontamination method, both Honeywell and MSA models showed no significant difference in average percent penetration between pre-decontamination (0.007% and 0.008%) and post-decontamination for 50 cycles (0.008% and 0.011%), respectively (Fig 4A), with all *P* > .05. The results also showed that filter penetrations increased with increasing wiping cycles from 50 to 400 for both Honeywell and MSA models. However, the changes in penetrations were not significant, and both Honeywell and MSA models passed the penetration criteria for each specified number of wiping cycles from 50 to 400 (all penetrations < 0.013%; Fig 4A). Results of filter airflow resistance tests for both Honeywell and MSA models showed no significant difference between pre-decontamination (23 and 19.5 mmH<sub>2</sub>O) and post-decontamination of 50 cycles (24 and 19.7 mmH<sub>2</sub>O), respectively (Fig 4B) with all *P* > .05. Results of filter airflow resistance among the different number of wiping cycles for both Honeywell and MSA models were also not significantly different (Fig 4B) with all *P* > .05.

Filter penetrations of the Moldex model after wiping decontamination with the quaternary ammonium wipes were > 0.03% after 150 wiping cycles. The Moldex model passed the penetration criteria for each specified number of wiping cycles of 50 and 100, but it failed after disinfecting  $\geq 150$  cycles using the quaternary ammonium wipes (Fig 4A). Interestingly, the results of filter airflow resistance tests for the Moldex model showed no significant difference among different numbers of wiping cycles (Fig 4B), with all *P* > .05.

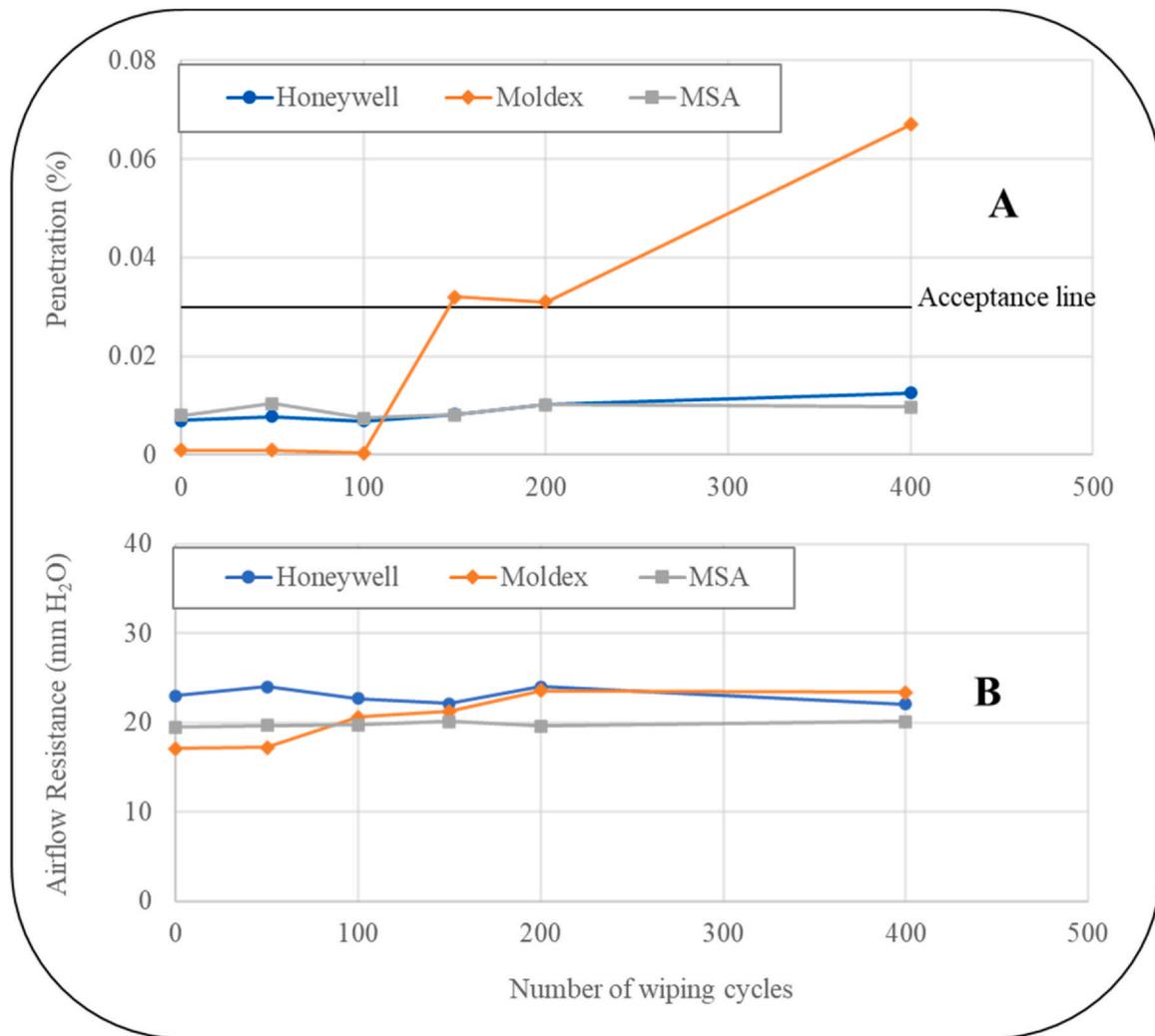
### Evaluation of filter cartridges after spiking wipe-chemical solutions

When spiking sodium hypochlorite solution on each Honeywell, Moldex, or MSA filter, no visible signs of filter damage were observed, and there were no significant differences in penetrations among chemical-spiking levels of 0.125–1.0 mL (Fig 5A) with all *P* > .05. All penetration data of Honeywell, Moldex, and MSA models passed the spiking penetration criteria for all sodium hypochlorite levels (all penetrations < 0.01%) (Fig 5A). Results of filter airflow resistance among different chemical-spiking levels for all EHMR models were also not significantly different (Fig 5B), with all *P* > .05.

**Table 2**  
Hydrophobic and hydrophilic filter media properties of EHMR filters

Filter cartridge model	Class of filter	Filter features	Number of filter layers
Honeywell 7580P100	P100	Accordion folding	One single layer: thick hydrophobic materials
Moldex 7940	P100	Accordion folding	Three layers: outer layer: thin hydrophobic Middle layer: thick hydrophilic/hydrophobic Inner layer: thick hydrophilic/hydrophobic
MSA 815369P100	P100	Accordion folding	One single layer: thick hydrophobic materials

*EHMR*, elastomeric half-mask respirator.



**Fig 4.** Filter filtration performance after wiping decontamination with quaternary ammonium wipes. (A) Average filter penetration values  $\pm$  SD ( $n = 3$ ) for each EHMR model as a function of individual wiping cycles. (B) Average filter airflow resistance for each EHMR model as a function of individual wiping cycles. Acceptance line: The NIOSH allowed maximum penetration of 0.03% for P100 filters. EHMR, elastomeric half-mask respirator; MSA, Mine Safety Appliance; SD, standard deviation.

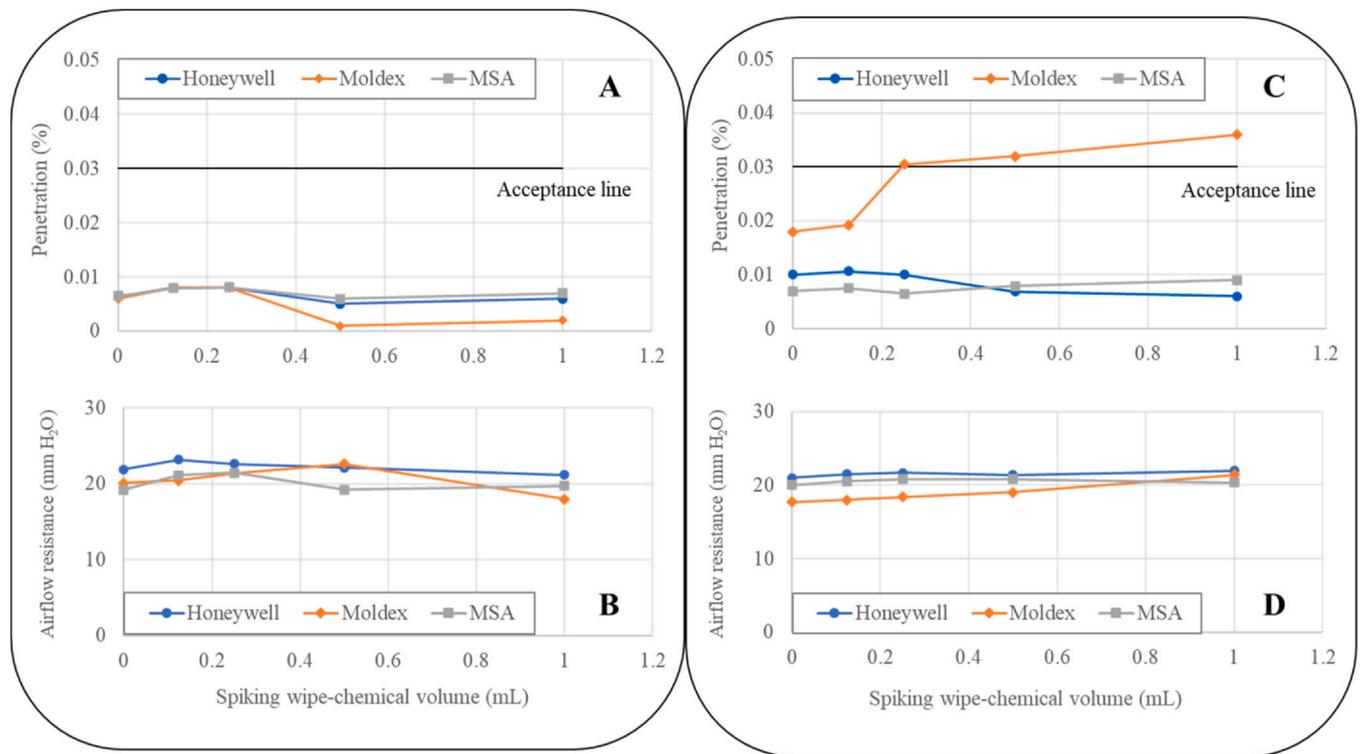
When spiking quaternary ammonium solution on the Moldex filter, the Moldex model failed the penetration criteria, with all penetrations  $> 0.03\%$  for volume levels of 0.25, 0.5, and 1 mL (Fig 5C). However, when spiking quaternary ammonium solution on Honeywell and MSA filters, both these models passed the penetration criteria for these chemical-spiking levels (all penetrations  $< 0.011\%$ ; Fig 5C). Results of filter airflow resistance among different chemical-spiking levels for all EHMR models were not significantly different (Fig 5D) with all  $P > .05$ .

## DISCUSSION

The wiping decontamination methods using sodium hypochlorite and quaternary ammonium wipes yielded no visible signs of damage, no odor changes, and no mold formation to filters and filter cartridges for all of the tested EHMR respirator configurations (Honeywell, Moldex, and MSA models). The possible explanation for no visible signs of damage to filter cartridges is that these disinfectant wipes contain low chemical concentration levels (0.63% sodium hypochlorite in water for sodium hypochlorite wipes and 0.28% ammonium cations in water for quaternary ammonium wipes). Both sodium hypochlorite and quaternary ammonium wipes contained chemicals that can remove

molds and mold stains,<sup>10,11</sup> so no mold formation after using the wiping decontamination methods was not surprising. Although sodium hypochlorite solution has a characteristic odor at a high concentration level of  $\geq 5\%$  sodium hypochlorite with a pH of about 11, sodium hypochlorite is an unstable compound and evaporates at a rate of 0.75 g/d of active chlorine from the solution.<sup>12,13</sup> This could be an explanation as to why there were no odor changes after wiping filter cartridges with sodium hypochlorite wipes.

Average penetrations before decontamination and post-decontamination or among different numbers of wiping cycles were not significantly different, and all tested EHMR configurations passed the penetration criteria when using the sodium hypochlorite disinfectant wipes. A possible explanation for that is, all tested EHMR configurations have a hydrophobic filter outer layer, while the sodium hypochlorite has high-polar characteristics; therefore, hydrophobic filter materials could repel any sodium hypochlorite molecules, resulting in no significant effect on filter penetrations. These results are similar to the filter penetrations obtained from the spiking sodium hypochlorite method for all EHMR configurations (Honeywell, Moldex, and MSA models). Thus, the suggested wiping decontamination method for all tested configurations (Honeywell, Moldex, and MSA models) would be to use sodium hypochlorite wipes.



**Fig 5.** Filter penetrations using spiking wipe-chemical solutions directly on filters. (A) Filter penetrations for each EHMR model as a function of spiking sodium hypochlorite wipe-chemical volume. (B) Filter airflow resistance for each EHMR model as a function of spiking sodium hypochlorite wipe-chemical volume. (C) Filter penetrations for each EHMR model as a function of spiking quaternary ammonium wipe-chemical volume. (D) Filter airflow resistance for each EHMR model as a function of spiking quaternary ammonium wipe-chemical volume. Acceptance line: The NIOSH allowed maximum penetration of 0.03% for P100 filters. EHMR, elastomeric half-mask respirator; MSA, Mine Safety Appliance.

In general, when using the sodium hypochlorite, results of either filter airflow resistance or penetration among different numbers of wiping cycles and among different chemical-spiking levels for all EHMR configurations tested were not significantly different. Two possible explanations are that (1) there would be no filter damage because changing filter shapes or making holes in the filter would decrease airflow resistance and increase filter penetration; (2) there would be no major contaminant buildup on the filter because the buildup of contaminants could clog the airflow through the filter media (increase airflow resistance), resulting in decreased penetration.

In the quaternary ammonium wiping decontamination method, although Honeywell and MSA penetrations were below the NIOSH-allowed maximum penetration for all wiping cycles, Moldex penetrations exceeded the NIOSH-allowed maximum penetration of 0.03% for P100 filters after 150 wiping cycles. In addition, Moldex penetrations significantly increased when increasing the number of wiping cycles from 100 to 400. Two possible explanations for the Moldex filter degradation are that (1) the hydrophobic outer layer of the Moldex filter is very thin; (2) both the quaternary ammonium wipe and Moldex filter media in the middle and inner layers are amphiphilic, meaning they have hydrophobic and hydrophilic properties.<sup>14–17</sup> The quaternary ammonium contains cations with positively charged polyatomic ions in the molecular structure center and 4 alkyl or aryl side groups, which are either very weakly polar or hydrophobic side chains,<sup>14,15</sup> while Moldex filter media contains electret fibers embedded with electrostatic charges and hydrophobic filter materials.<sup>16,17</sup> Similar filter-degradation findings have been reported for hydrophobic aerosol loading of an electrically active fibrous filter.<sup>15,17,18</sup> The Moldex filter degradation results obtained in the spiking quaternary ammonium solution showed a similar trend as the Moldex filter degradation values obtained in the wiping decontamination.

Interestingly, when using the quaternary ammonium, results of either filter airflow resistance or penetration among different numbers of wiping cycles and among different chemical-spiking levels for the EHMR Honeywell and MSA configurations were also not significantly different. Additionally, Frund et al<sup>19</sup> reported that there is little change in the filtration performance and breathing resistance of MSA Advantage Low Profile P100 respirator filter cartridges after undergoing repeated use over a 12-month period of use in the described health care settings. However, filter penetrations of the Moldex configurations were significantly different among different numbers of wiping cycles and among different chemical-spiking levels, while their filter airflow resistance showed no significant difference. A possible explanation for that is, quaternary ammonium contains cations with positively charged polyatomic ions that may reduce electret charges on the filter, resulting in lower electric charges on the filter and increasing particle penetrations. These results indicate that quaternary ammonium wipes degraded the amphiphilic Moldex filter, so the wiping decontamination method for amphiphilic filter media would not use the quaternary ammonium wipes. Thus, the decontamination method for the exteriors of the EHMR filter cartridges with the amphiphilic filter materials would use the sodium hypochlorite wipe.

## CONCLUSIONS

The findings presented herein demonstrate that the wiping decontamination method using sodium hypochlorite and quaternary ammonium wipes yielded no visible signs of damage, no odor changes, and no mold formation to filter cartridges of all tested EHMR configurations (Honeywell, Moldex, and MSA models).

The results show that filter performance after wiping decontaminations depended on the wipe types (ie, the chemicals in the

disinfectant wipes), P100 filter model (number of filter layers, thickness of each layer, and different hydrophilic and hydrophobic materials), and numbers of wiping cycles on the filter cartridges. In the sodium hypochlorite decontamination method, all EHMR configurations (Honeywell, Moldex, and MSA models) passed the penetration criteria for all tested cycles (400 cycles by wiping). In the quaternary ammonium wiping decontamination method, only the Honeywell and MSA configurations passed their penetration criteria for all wiping cycles, while the Moldex configuration failed after wiping  $\geq 150$  cycles. Thus, sodium hypochlorite and quaternary ammonium wipes could be considered as promising decontamination candidates for Honeywell, Moldex, and MSA reuse, except for wiping number selection for Moldex ( $< 150$  cycles) when using the quaternary ammonium wipe. The results from this study also inform the selection of wipe types and numbers of wiping cycles for the decontamination exteriors of the EHMR filter cartridges with specific filter materials, such as hydrophobic filters, hydrophilic filters, or amphiphilic filter media.

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