Disinfection and sterilization methods to reuse face masks and respirators: A systematic review

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Abstract

Background: In the context of COVID-19 pandemic, mask, or respirator wearing is considered one of the essential protection measures for healthcare workers to deal with infected patients. As the demand for face masks strongly increases during the pandemic leading to their shortages, our study aimed to review the current decontamination methods to reuse masks and respirators.

Method: On May 18th, 2020, a systematic search for articles reported the methods of disinfection and sterilization for reusing surgical masks or respirators was conducted in eight electronic databases including PubMed, Scopus, Web of Science (ISI), Google Scholar, Cochrane, WHO Global Health Library (GHL), Clinicaltrials and Virtual Health Library (VHL). Manual search was further performed by screening references of included articles and relevant reviews and their related articles in PubMed and Google Scholar. We excluded unreliable extracted data, non-original or secondary research, not available full texts or abstract only.

Results: There were 52 articles included in the qualitative synthesis. While hydrogen peroxide gas plasma (HPGP) (59%) degraded the mask filtration performance, vapor hydrogen peroxide (VHP) at varying concentrations and ethylene oxide (EtO) did not affect this. Moist heat incubation (MHI) (at 65 ± 5°C for 20 minutes) and microwave generated steam (MGS) (2 -3 minutes) caused > 4 log reduction of the H5N1 virus and did not degrade the mask filtration performance, while autoclave (at 121°C, 103 kPas) strongly affected this. The mask filtration efficacy was significantly reduced by ethanol 70% but recovered to 86% after the recharge process. Ultraviolet germicidal irradiation (UVGI) (4.32 – 7.2 J/cm^2) showed good biocidal efficacy and no degradation of filtration performance but had a poor effect with a dose of 3J/cm^2 and degraded the mask with a dose of 18 J/cm^2.

Conclusion: MHI and UVGI could be highly recommended decontamination methods for reusing masks. VHP could be considered but less effective due to the possible degradation in physical appearances.

Introduction

As of August 5, 2020, there have been over eighteen million COVID-19 infections globally with almost seven hundred thousand dead (1). In the short span of several months, COVID-19 has overwhelmed the hospitals worldwide causing shortages in PPE, such as surgical gowns, gloves, masks, and respirators (2). In the United States, the Centers of Disease Control and Prevention recommends to the public the use of masks to prevent symptomatic and asymptomatic COVID-19 transmission (3). With more states mandating the use of masks, the demand for masks increases, putting further strain on hospital supplies, since mask wearing for healthcare workers are required (4).

Filtering facepiece respirators (FFRs) are highly preferred for HCWs (5, 6). However, manufacturers of these FFRs recommended only a single use of these FFRs followed by their disposal due to potential contamination. For this reason, the demand for these FFRs has strongly increased during the pandemic leading to its shortage. Currently, almost half of US health care facilities are running out of face masks (7). The Association for Professionals in Infection Control and Epidemiology (APIC) announced that 20.4% of respondents to their survey on the availability of Personal Protective Equipment (PPE) reported that their facilities had no protective respirators and about 31.7% reported that their facilities were almost out of face masks (8). Thus, meeting hospital supply demands has become a critical issue, with re-use, extended use, and decontamination being explored as ways to make supplies last (7).

Among all the available sterilization and decontamination methods that showed promising results, none were approved for the decontamination of masks. Recently though, 4C Air Incorporation confirmed that five decontamination methods could disinfect more than 99% of *Escherichia coli*, including 70^{o}C hot air in the oven (30 min), ultraviolet light (30 min),

75% alcohol (soaking and drying), chlorine-based disinfection, and hot water vapor (10 min). However, 75% alcohol and chlorine-based disinfections dramatically degraded the filtration efficacy of masks (9). The efficacy of other types of decontamination methods was also reported including ultraviolet germicidal irradiation (UVGI), moist heat incubation (MHI) and microwave generated steam (MGS), ethylene dioxide, vapor hydrogen peroxide (VHP) (10). These other decontamination methods also have a risk of degrading the respirators with chemical treatment methods appearing to reduce the physical appearance and retain residual chemicals (10, 11).

Recently, CDC published a review that positively recommended some methods of sanitization for masks reuse, namely UVGI, MHI, or VHP (12). Europe and countries (Germany, Netherland, and US) also gave recommendations of the reuse of masks after decontamination to deal with the shortage of FFRs (13). However, no report sufficiently evaluates current methods. To find out the most suitable decontamination method to reuse masks and respirators, our study aimed to systematically review and compare current disinfection techniques in terms of their biocidal efficacy and filtration efficacy as well as any filter degradations after the decontamination process.

Methods

Protocol and registration

This study was conducted according to the recommendations of the 2009 Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) statement, with the detailed steps being shown in the PRISMA checklist (**Supplementary Table 1**) [14]. Our protocol was registered at PROSPERO with the registration number CRD42020177679.

Selection criteria

Our inclusion criteria were to include studies discussing disinfection and sterilization methods for reusing surgical masks or respirators with no restriction to language, age, sex, race, ethnicity. We excluded non-original studies or secondary research, unreliably extracted data, and non-available full texts.

Search strategy

On May 18, 2020, we conducted a search in eight electronic databases, including PubMed, Scopus, Web of Science (ISI), Google Scholar, Cochrane, WHO, Global Health Library (GHL), Clinicaltrials and Virtual Health Library (VHL). We used the key search terms as following for all databases: (mask OR masks OR facemask OR facemasks OR respirator OR respirators OR N95 OR N99 OR N100 OR R95 OR R99 OR R100 OR P95 OR P99 OR P100) AND (reuse OR disinfection OR pasteurization OR pasteurisation OR sterilization OR sterilisation OR inactivation OR decontamination OR recycle) AND (virology OR virus OR influenza OR coronavirus OR coronaviruses OR covid-19 OR antiviral OR antimicrobial). In the manual search step, we checked references of our included studies and their related articles in PubMed and Google Scholar or screening the references of relevant reviews.

Study selection

The search results were imported to Covidence (web-based tool), then duplicate studies were removed. The eligible articles were included after screening their title and abstract followed by the full text based on the inclusion/exclusion criteria stated above. Covidence tool was also used to conduct title and abstract screening. Two authors independently reviewed all the studies and a third senior one would solve the conflicts after discussion until reaching a consensus between members.

Data extraction

Data extraction was done by three independent reviewers. Any discrepancies were resolved through consulting senior reviewers. Also, the data extraction sheet contained basic reference information (title, authors, country, publication year and journal), study characteristics (study design, mask or respirator name/ model, number of mask/respirators, decontamination methods types, number of tests for each model, description of decontamination methods (dose/concentration/intensity, number of cycles, duration of exposure, and targeted organism), outcomes and evaluation of results of a study regarding disinfection efficiency (log reduction of contamination load, Median Tissue Culture Infectious Dose ($TCID_{50}$), percentage of viral reduction, the half-life of the virus), filtration efficacy (filter aerosol penetration, inert aerosol collection efficacy, biological aerosol collection efficacy, filter airflow resistance), masks function (fit factor), physical appearances and residual chemicals.

Data shown on graphs were then extracted using Web Plot Digitizer (https://automeris.io/WebPlotDigitizer/)

Quality assessment

Three independent reviewers assessed the quality of each article using the modified CONSORT checklist for reporting pre-clinical In vitro Studies (14). The included studies were classified and categorized according to the following criteria: good (10 - 14 points), fair (5 – 9 points), and poor (1 – 4 points). Any disagreements or differences were discussed and compared between authors until it was dissolved.

Results

Study selection

We obtained 3511 articles after searching in selected databases, in which 2861 articles were recorded after screening their title and abstract and removing 650 duplicates by Covidence. Full text screening step was conducted for 176 eligible studies using the inclusion/exclusion criteria. The qualitative synthesis is done through 52 articles. A detailed number of included studies for each step and reasons for exclusion could be found in **Figure 1**.

Baseline characteristics of articles in the review

Among the 52 included studies, the majority investigated the effect of decontamination methods on N95 filtering facepiece respirator models. In addition, twelve studies also used surgical and particulate masks (10, 11, 15-19). Few studies examined electret masks (20), elastomeric respirators (21), half-mask elastomeric respirator models, or powered air-purifying respirator models (22) besides using simple respirators from hospitals (23).

Ultraviolet germicidal irradiation (UVGI) method was the most used method which was reported in 22 articles (10, 11, 15-17, 19, 24-39). The second most used was VHP which reported 13 investigations (10, 16, 17, 19, 33-35, 39-44). Ten studies examined sodium hypochlorite of which one exerted the hype-wipes containing 0.9% sodium hypochlorite (10, 16, 17, 19-21, 29, 30, 45, 46). Eight investigations conducted the decontamination with MGS (10, 11, 15, 28, 31, 32, 45, 47). Other methods included MHI, autoclave, rice cooker, moist heat incubation, rice cooker generated steam, VHP, hydrogen peroxide gas plasma (HPGP), ozone gas, dry heat, microwave oven irradiation, and microwave steam bag. One study examined the combination of varied methods (UV irradiation and dry heat, UV irradiation, and low humidity heat, UV irradiation, and dry heat and VHP) (35). Chemicals used to clean masks included liquid hydrogen peroxide, ethanol, isopropanol, dimethyl dioxirane, and chlorine. There was one study that used wipes containing detergent solutions and one applied a washing machine (23, 46). Dose, filtration efficacy, and airflow resistance after each method of decontamination presented in **Supplementary Table 2.**

Log reduction, relative survival (%), virus recovery (%), and inactivation efficiency, viral RNA, and half-life of the virus were recorded to present the biocidal efficacy of each decontamination method (21, 26, 30, 33). The quality of masks after treatments were measured using the particle or biological penetration (%), filtration efficacy (%), filter airflow resistance (mm H_2O), fit factor score, quality pass rate (%), physical appearance, and filter quality.

Quality assessment

Twenty-six were concluded “good” quality while twenty-six reports were “fair”. All studies clearly stated the research questions and study population. The timeframe in all experiments was sufficient to investigate the association between the exposures and outcomes. However, the blind to the exposure or participants were almost absent in most of the studies due to their study designs (**Supplementary Table 3.**).

Efficacy of gaseous methods of decontamination

The summary data are presented in **Table 1**. HPGP (59%) appeared to degrade the filtration performance of mask models. A cycle 72-minutes appeared not to significantly affect the filtration performance of models 1860S, 8210, and 9210 (overall transmission < 1.5%) (39). However, in the third cycle the degradation was seen (39). After 55 minutes of the treatment, four among six models (N95 and SN95 masks) have increased the filter aerosol penetration (%) compared to controls, resulting in a maximum penetration of 7.3% (for N95 model) in addition to 8.76% (for SN95 model) (12). Five cycles 24- minutes even caused up to 26% of the reduction of filtration performance on the N95 model 1860 (35). All tested masks only remained their functions (fit factor > 100) after 1 cycle of 47 minutes and then degraded from the second cycle except the model Safety 1054S degraded from the 5^{th} cycle (43). There was leakage of models 1860S, 9210, and 8210 observed after five cycles 72-minutes (39). However, the filter airflow resistance (mm H_2O) and the physical appearance of all models were not significantly changed (10, 15). The benefit of the method was no recovery of MS2*,* Bacteriophage Phi6*,* influenza virus H3N2*,* and *Vesicular stomatitis* virus found after 24 - 47 minutes of the treatment (35, 43).

Meanwhile, the treatment of VHP (30%, 35%, 58%, 59% or 100% of hydrogen peroxide for 1 - 20 cycles) did not affect the fit factor of AO Safety N9504C model and N95 models (1860, 1860S, Aura 1870+, 8511), as well as the filter airflow resistance (mm H_2O), and the filter aerosol penetration (%) of N95, SN95, and particulate masks (e.g. P100) compared to control, as all filter aerosol penetration (%) values were below 5% (10, 16, 17, 19, 33-35, 39-42). The overall transmission after 10 cycles of the treatment was still below 1.5% (39). However, the elastic straps of N95 model 1860 became stiffer only if treated with 30 – 50 cycles of VHP (35%, 120 minutes) (40). No strong odor, and degradation of physical, fit, or seal were recorded (41). Interestingly, the exposure with every 120 minutes in up to 50 cycles of VHP (35%) did not degrade the filtration efficacy, as both inner aerosol collection efficiency (%) and biological collection efficiency (%) of tested masks were over 99.3% (40). The treatment completely reduced various microorganism species (T1 Bacteriophage, T7 Bacteriophage*, Pseudomonas,* phage phi-6, SARS-CoV-2*,* H3N2, mouse coronavirus murine hepatitis virus (MHV)*, Aspergillus niger, V. stomatitis, E. coli, Geobacillus spore, and Geobacillus stearothermophius*) growth after one cycle (20 – 180 minutes) of treatment, even either having a steam sterilization (135^{o}C, 5 minutes) afterward or not (35, 40, 42-44). A considerable inhibition was observed on MS2 and the poorer effect was shown on *Staphylococcus aureus* (37). It also had a rapid reduction of SARS-CoV-2 survival (half-life of the virus was approximate 1 minute) (33, 43). An exception was reported by Smith *et al.* (34) who indicated that N95 model 8511 directly infected SAR-CoV-2 from the patients did not have a complete clearance after the VHP (30%, 60 minutes). In addition, the short exposure (20 minutes) showed a poor effect on *S. aureus* (1 log of reduction) (35). Although long exposure (120 minutes) increased the efficacy (> 1.6 log reduction), there was still bacteria found (35). On the other hand, there were 0.04 – 1.77 mg of oxidant residuals on the masks after the treatment with 30% of hydrogen peroxide

(19). The high concentration of hydrogen peroxide (100%) also made the noseband of varied masks less shiny and tarnished (16).

Ethylene oxide (EtO) with varying doses for 1 hour (1 cycle) or 1 hour (3 cycles) did not affect the filtration performance, physical appearances (N95 model) or the functions of different masks as well as not leaving EtO residuals (10, 16, 17, 19, 35, 43). The increase in cycles of treatment (3 cycles) did not strongly change the average percent of filter aerosol penetration of N95 masks (0.101 – 1. 820%) (10, 16, 17). However, the increase in the filter aerosol penetration (%) along with increased cycles was observed on SN95 masks, by 0.498 – 0.9% (1 cycle) vs 0.25 – 2.55% (3 cycle) (10, 16). The filtration performance of P100 masks was also comparable between studies for both less aggressive and more aggressive conditions, ranging from 0.003 – 0.008% (16, 17). The filter aerosol penetration (%) and filter airflow resistance (mm H_2O) of all masks after treatment were not significantly different from controls (10, 16, 17, 19). Importantly, the method could entirely inhibit the growth of *V. stomatitis* and MS2 virus after treatment (35, 43). It should be considered that the method made P100 straps darken (17). More important, chemical impurities such as diacetone alcohol, 2-hydroxyethyl acetate, and cyclohexanone were found as traces in some tested models (19).

Ozone gas (120 ppm) was also a promising method, as after 1 or 5 minutes of exposure caused the entire inactivation of human coronavirus HCoV-22E, influenza A, H1N1, *and S. aureus* (48). However, the amount of RNA of the microorganism on the tested masks was not different from the control, indicating that the virus lost the infectivity, but the RNA was not fully degraded. The particulate filtration efficacy of KF94 masks after five cycles 1-minute was also comparable to the control (98.6 – 99.3%) (48). Other doses of ozone gas, including 10 ppm (60 minutes), 20 ppm (60 minutes), and 200 ppm (60 minutes), also did not cause the filter degradation of the filter material microfiber spun-bond polypropylene material (MSP) (49). The electrostatic charge condition before or after ozone exposure (20 ppm, 30 minutes – 36 hours) did not affect the filtration efficacy of MSP and melt-blown media material (MBM) (49). The mechanical integrity (toughness energy, strain energy, stiffness) of MSP, the physical appearance and structure of KF94 masks and MSP were also not damaged after the treatment (48, 49).

Vapor ethanol (70%) may not damage models 1860S, 8210 and 9210 after 1 - 3 cycles (aerosol penetration of 0.3 µm < 3%) (39).

Efficacy of heat and humidity methods of decontamination

Disinfection using MHI at 60 – 82^{o}C and 60 – 85% of relative humidity (RH) showed good effects on avian influenza virus H5N1, H1N1, MS2, phi6, H3N2, MHV, and *S. aureus* (sensitive strains to oxacillin and methicillin) on varied masks (N95, surgical and particulate masks). A short period of treatment at 65 ± 5°C for 20 minutes caused > 4.62 log reduction of H5N1 virus and < 0.5 $\log_{10}$ $TCID_{50}$ (32, 35, 50). In a longer duration of treatment (4 cycles, 30 minutes each), the MHI almost completely inhibited the survival of H5N1 virus on surgical and particulate masks, as the $TCID_{50}$ values on all masks after treatment were below detection levels, leading to the 4.5 – 6.58 log reduction in both aerosol application and droplet application (31). The high temperature (80^{o}C, RH > 60%, 15 minutes) also entirely inactivated MS2, Phi6, H3N2, and MHV on N95 model 1860 as well (35). However, the method failed to kill *G. stearothermophilus* (35). The filtration performances of fabrics, N95 (model 1860, 1860S, 1870, 8210 Plus), SN95, Chen Heng V9501 KN95, and HKYQ masks were not affected by the treatment (60 – 85^{o}C, 30 – 100% RH) (10, 32, 37, 51). The filter aerosol penetration (%) after the treatment of N95 masks was 0.49 – 1.04% and 0.16 – 0.99% for model 1860S and 1870, respectively (32, 51). The longer time of exposure (30 minutes, 3 cycles) only increased the filter aerosol penetration (%) to 2.16 ± 0.10% in maximum on masks N95 and SN95. After 3 cycles of the treatment (75^{o}C, 75% RH), the overall transmissions of models 1860S, 9210 and 8210 were < 1.5% (39). Even up to 50 cycles of 20-minutes of treatment at 85^{o}C and all conditions of RH, the filtration penetration of fabrics was still above 95% (37). Notably, the clear

degradation of filtration performance of melt-blown fabric occurred at high temperatures (125oC) and low RH 30% (37). Besides, the filter airflow resistance measures ranged from 7.5 ± 0.1 to 15.0 ± 0.3 mm H_2O and were not significantly different from the masks' controls for all models (10, 37). For the physical appearances after treatment, MHI at 60°C (3 cycles/15 min and 1 cycle/30 min) didn't affect any characteristics of the tested masks except for N95 model 1870, as it caused a slight separation in the inner foam nose cushion (11, 15). However, strong odor in N95 model 1860 was reported after 3 hours treatment (32). Fit factor of these masks was still ≥ 100 after the exposure showing its qualification for using, except the Chen Heng V9501 KN95, and HKYQ N95 (51).

Autoclave (at 121°C, 103 kPas, 15 – 30 minutes) caused the deformation of models Safe Worker 1016, 1860S, 8210 and strongly degraded the filter quality of models 8210, 1860, 8511, SH-2950, and UVEX-3200, as well as degraded the filtration performance of several models (N95, P100, Gauze, Spunlace, model 1805, 1870, 8511, UVEX-3200, San Huei 2920V, Safe Worker 1016) (17, 20, 52-54). For the filter quality, masks Aura 1862+, Maco Pharma ZZM002 were the exceptional ones that remained their integrity after treatment (17 minutes) (52). N95 models 1870, 1870+ were masks passed fit test after 1 – 4 cycles (43, 53, 55). Meanwhile, the failure in their functions (fit factor < 100) was observed in the 1860 and 8210 after varied conditions (115 – 130°C, 1 or 2 cycles) (43, 53). The treatment at 115^{o}C during 60 minutes (1 – 3 cycles) dramatically damaged the filtration performance of models 1862, 1805, 1870 and 1870+ (filtration efficacy of particles 0.3 µm ranging from 75.58 – 89.86%), although they were all retained > 95% particles 1.0 and 5.0 µm (53) Likewise, the increased cycles (2 cycles) or time of exposure (30 minutes, 2 cycles) could lead to the significant increase in filter aerosol penetration (%) up to 18.7% and 34.4%, respectively, which was dramatically larger than controls (0.7%) (17). The filter aerosol penetration (%) of P100, Gauze and Spunlace were significantly higher than the control after 1 – 2 cycles of treatment (15 or 30 minutes each) (17, 20). Only Aura 1862, 8210, 1860, SH-2950, 9210 preserved the filtration efficacy of 95.0% after one cycle (39, 52, 54). The treatment of autoclave after 15 minutes increased the most penetrating particle size values up to 364 nm compared to the control (118 nm), although the particle penetration (%) remained below 5% (2.4%) (20). Besides, the higher temperature (130^{o}C, 4 minutes) caused similar degradation on filtration efficacy of particle 0.3 µm of model 1860 (53). The advantages of this treatment were that completely inhibited the survival of *Bacillus subtilis, V. stomatitis virus,* and SARS-CoV-2 while only made the masks softer (17, 30, 43).

MGS (2 - 3 minutes) seemed to be an effective disinfection method on MS2, H5N1 and H1N1 showing 4 - 6 log reduction (16, 31, 32, 45, 47). For N95 models, fit factor in most N95 models were > 100 after treating with the method (2 - 3 minutes, 1 - 20 cycles) (31, 32, 47). Nevertheless, it only caused ≤ 3 log-reduction of MS2 virus for a short time of exposure (40 seconds) (28, 45). Moreover, if any components of the masks did not expose to the generated-steam, the viral growth had not been completely inhibited (47). On the other hand, no degradation of filtration performance was observed on N95 and SN95 masks (10, 32). Physical appearance in most models was not affected but the inner foam nose cushion lightly separated in N95 models 1870 and KC PFR95- 270 (15, 47). This method appeared to not be affected by the protective factor condition (45). Also, the microwave steam bag could reduce 99.86 – 99.99% of MS2 viral survival and remain the filtration efficiency > 95.5% (18). Recently, steam generated from rice cooker also proved > 5 log of reduction of methicillin-resistant *S. aureus* (MRSA) and MS2 virus while caused no observable changes in N95 model 1830, surgical masks, cotton cloth masks and quilted cloth mask after 5 cycles of treatment (56). For the steam generated from boiling water, 5 minutes exposure could completely inactivate the avian infectious bronchitis virus H120 shown by the RT-PCR assay, while all N95 mask models still retained > 96% of aerosols < 5 µm (57). However, the filtration efficacy of Venus 4420 mask was dropped to 77% in the same condition and just recovered to 86% with the aid of recharge (58). For the fabrics of masks treated with this method, their filtration efficacy for aerosol 0.3 µm only preserved after one cycle of treatment, then strongly reduced to 80.65% after 5 – 10 cycles (37).

Regarding dry heat treatment, varied conditions of the treatment (one cycle 60-minutes at 80°C, one cycle 30-minutes at 75^{o}C, or 10 cycles of 20 minutes at 82^{o}C) did not affect filtration performance on melt-blown fabric of masks, N95 and P100 masks compared to controls (17, 35, 37). The change in filtration performance after the treatment was little on N95 models as well (20). At high temperature (100^{o}C, 30 minutes, 3 cycles), the method also caused less than 1.5% of overall transmission of models 1860S, 8210, 9210 (39). However, the affection of dry heat varied on mask models. For instance, one or five cycle 30-minutes treatment at 75^{o}C did not reduce the fit factor of KN95 masks and 8210 masks (36). Also, N95 models Aura 9332+Gen3, Aura 9320+, 8833, 1873V+, 8835, 8810, S-3V treated dry heat at 65 - 86^{o}C during 34 – 56 minutes preserved the fit factors > 100 (59). In contrast, the fit factor of AO Safety N9504C respirators masks decreased below 100 after three cycles of the treatment at 70^{o}C (33). The dry heat at 70^{o}C (30 minutes) also had poor efficacy on *MS2* and phi6 (< 1 log reduction), and needed more time than other methods (4.7 or 8.85 minutes) to reduce half of SARS-CoV-2 survivals on N95 masks and their steel, respectively (33, 38). Dry heat at a higher temperature (70 – 100^{o}C) also saw poor efficacy on reducing the growth of phi6, MS2, MRSA*, S. aureus* and *G. stearothermophilus* testing on N95 1860 respirators (35, 56). For the rice cooker usage (149 – 164^{o}C, 3 minutes), it showed effective reduction of relative survival of *B. subtilis* and did not clearly change the filtration performance (20, 30). The filter aerosol penetration (%) of Gauze and Spunlace masks were 24.9% and 77.1% but were similar to the control masks (20).

Efficacy of chemical methods of decontamination

Liquid hydrogen peroxide 6% did not cause any change in filtration aerosol performance of N95 and P100 when compared to controls (17). Exposure for twenty-one minutes of aerosolized hydrogen peroxide (7%) caused the inactivation of HSV-1, CVB3, and phi6 on 55 of 58 masks (60). All masks 8511 passed fit test except one with the elastic straps broken. Dunking half-mask elastomeric respirators and powered air-purifying respirators with 0.5% Neutrawash detergent solution (containing potassium polyacrylate and ethylenediaminetetraacetic acid) then wiping with a sterile sponge almost entirely inhibited the growth of H1N1 with the $TCID_{50}$ values were below detection limit for all masks except the Scott Xcel, Sperian by Honeywell Survivair Blue, and Breathe Easy Turbo. When an additional step of disinfection with 0.1% of sodium hypochlorite was applied, the biocidal efficacy of the method was more effective with only Scott Xcel (22).

Treating with 70% ethanol did not show a significant biocidal effect against *B. subtilis* (30). After 10 minutes of treatment, the relative survival (%) was 73.5 ± 16.7, then was 22.8 ± 8% after 24 hours (30). The benefit was its fast reduction of SARS-CoV-2 (half-life = 0.647 minutes) and complete inhibition of this species after treatment (33, 34). However, the fit factor of N95 masks was below 100 after 1 – 3 cycles (33, 34). Regarding the filtration performance, 10 minutes of treatments of 70% ethanol, 100% isopropanol, or long-treatment of 1g/l soap and water notably reduced the filter aerosol penetration (%) of N95, P100, Gauze and Spunlace masks (17, 20, 30). Particularly, N95 masks treated with ethanol and isopropanol penetrated 39.0% and 37.5% particles 445 nm, respectively (20). The retained of particulate 300 nm of N95 masks also decreased to 70% after dipping in ethanol (58). A similar effect was observed on the melt-blown fabric of masks, as the filtration penetration dropped to 56.33% after treating with 75% ethanol (37). It should be noted that the penetrations (%) of Spunlace and N95 masks, for particle sizes 300 and 34 nm respectively, insignificantly increased for 70% ethanol treatment indicating the variation of penetration (%) for different particle sizes (20). The filtration efficacy of N95 masks could be recovered to 86% after the recharge process (58). In contrast, Nazeeri *et al.* (61) have recently reported that the filtration efficacy of N95 masks (8200, 8210, 8511) could be preserved (> 95%) even after 5 cycles of 70% ethanol treatment if they were dried in the vacuum condition. By the treatment of 70% isopropanol, the degradation of filtration performance still happened for N95 and P100 masks, as the filter aerosol penetration (%) was significantly higher compared to the controls (17). Treating with soap and water in a short time (2

minutes) only did not significantly changed the filtration performance of P100 mask while it still powerfully increased the aerosol penetration (%) of N95 mask up to 38.8% (17).

Regarding sodium hypochlorite (bleach), it was effective against MS2 virus, H1N1, and *B.subtilis have variable concentration and time of exposure* (0.25 – 10%, 10 – 30 minutes) (29, 30, 45). However, its effect depends on the concentration and number of disinfection cycles that each mask had to pass through. By a concentration ranging from 0.25% to 0.75%, it could achieve more than 3log reduction of MS2 virus while its lower doses (0.005% to 0.1%) led to less than 3log reduction of MS2 virus within the same duration of 10 minutes (1 or 3 cycles) (29, 45). However, if the aerosol-generating medium containing 1% ATCC medium (referring as the low-protective-factor), the reductions achieve more than a 3-log of MS*2* virus even at very low doses 0.0006% to 0.06%. The method with 0.5 – 0.6% of sodium hypochlorite (10 – 30 minutes) did not significantly change the filtration performance of SN95 and P100 masks when compared to control masks whereas increasing the pressure drop (10, 16, 17, 20). The increase in the concentration of sodium hypochlorite to 5.25% appeared to degrade the filtration efficacy of P100 masks as the aerosol penetration (%) increased after treatment, but these values were still comparable to the controls (17). The filtration efficacy of N95 after treating with 0.5 – 0.6% of sodium hypochlorite solution (10 – 30 minutes) was inconsistent between studies. Three studies showed N95 masks after the treatment (0.5 – 0.6% of sodium hypochlorite, 10 – 30 minutes) did not degrade its penetration (%) of sodium chloride aerosol compared to control, while the penetration (%) of potassium sodium tartrate tetrahydrate droplets strongly increased after 10 minutes treating with 0.5% solution (10, 16, 17, 20). Meanwhile, the filter layers of Gauze masks were strongly damaged that no further penetration test could be done (20). The disadvantages of this treatment were that it made nosebands less shiny and tarnished as well as the smell of bleach, sometimes it causes the discoloration of nose pads or ink faded (15). Also, the oxidants still remained even after treating with 10% solution (19). Similarly, treatment with five cycles of laundering (water and detergent) without electrostatically charged afterwards caused > 60% loss of filtration performance of filter material MSP (49). However, the following charging could recover the filtration efficacy of this material.

The fog of peracetic acid (10%) during 1 hour of exposure saw no growth of *V. stomatitis* virus and SARS-CoV-2 and did not affect the functions of five N95 models even after 10 cycles (fit factor > 100) (43).

The immersion of simple respirators collected from a hospital with 500 mg/l of chlorine and then rinsing them with water resulted in 93.75% of the outer and 91.25% of the inner of tested masks passing the qualified standards (total bacteria $\leq$ 5 cfu/cm^2 and no detection of pathogens) (23). However, melt-blown fabrics of mask immersed in 2% chlorine showed a decrease in filtration efficacy to 73.11%, indicating the degradation of filtration performance after treatment (37).

Efficacy of energetic methods of decontamination

Microwave oven irradiation (1100 W) appeared not to affect the filtration performance of N95, SN95 and P100 masks (16, 17). Although the filter aerosol penetration (%) increased 2-fold or 10-fold after 2 minutes of the treatment, they were comparable to control and below 1.5%. A significant amplification of filter aerosol penetration was seen for more aggressive condition of treatment for 4 minutes (17). Moreover, the method did not observably change in physical appearance of all masks except two models SN95-E and P100-I melted after the treatment (16).

UVGI appeared to be an effective disinfection method due to its good biocidal efficacy and no degradation of filtration performance failure in mask functions was detected (10, 11, 15, 17, 19, 26, 27, 29, 31, 37, 39). The decrease in fit scores of N95 masks was insignificant for the high dose of 18 J/cm^2, and only became problematic for long treatment (10 cycles) of the high dose 30.32 J/cm^2 (34, 36). Considering the biocidal efficacy, the decontamination of virus varied depending on the UV doses, tested systems, models of masks and the virus used. UV low doses ranging from 0.0917 to

0.1125 J/cm^2 led to around 3-log reduction of MS2 virus if the aerosol-generating medium was 1% ATCC medium (low soil load) (24). When using 100% ATCC medium (high soil load), the UVGI of the dose 0.024 J/cm^2 only caused 0.7 – 1.3 log reduction, and showed the similar effect on the same used virus (> 3-log reduction) only from the higher doses of 4.32 – 7.2 J/cm^2 (29, 35). The affection of soil load conditions was reported in another study as well (28). Despite that, this study reported that a UV dose of 3 J/cm^2 resulted in < 3 log reduction even with low soil load conditions. With the low dose of 0.024 J/cm2, the log reduction was also < 3 for other virus strains (Bacteriophage Phi6, influenza virus H3N2, MHV), and < 1 for *S. aureus or G. stearothermophilus* (35). The culture media DMEM was shown to reduce the biocidal efficacy of UVGI compared to culture media PBS, which raised the impact of deposition solution in these tests (35). The dose of 0.63 J/cm^2 also did not completely inhibit the growth of SAR-CoV-2 after the treatment on N95 mask model 1860 and 8511 (34). More important, the biocidal efficacy of the method also decreased when the process of contamination/decontamination repeated 2-3 times (28). This result revealed that the UVGI should not be applied many times on the same masks for the decontamination. On the other hand, the method appeared to be more effective when testing on H1N1 virus, as the needed UV doses were much lower. Of 15 N95 models testing, UVGI dose of 1 J/cm^2 resulted in > 3 log reduction on all models except the VFlex 1805, Alpha Protech 695, Moldex EZ 22, and U.S. Safety AD2N95A for the testing system of mucin-soiled FFRs; and the 1860, Alpha Protech, Moldex EZ 22 for the testing system of sebum-soiled FFRs (27). The log reduction were also more significant when testing with respective straps of each respirators (27). Additionally, the doses of 1.44 – 1.8 J/cm^2 reduced 4.08 – 5.08 log $TCID_{50}$ on three models of particulate and surgical masks showing its efficacy on H1N1 disinfection (31). For the *B. subtilis*, Lin *et al.* (30) reported that the relative survival was only 0.84% after the treatment of UV dose of 1.134 J/cm^2. The needed dose to reach > 4.65 log reduction of H5N1 was only 0.18 J/cm^2 on N95 models 1860S and 1870 (32). For SARS-CoV-2, UVGI had a slow speed to kill the virus (viral half-life was 6.12 minutes for the intensity of 55 μW/cm^2) (33). However, fit factors were above 100 after 1 – 3 cycles of the treatment with the doses 0.33 J/cm^2 - 1.98 J/cm^2 (33). The biocidal efficacy of UVGI method also depended on test systems (26). Using diluted water as the spraying media gave 4.3 – 5.8 log reduction of MS2 by all doses while the spraying medias beef extract and saliva led to lower efficacy by 2.5 – 3.3 log reduction. Relative humidity in the viral loading process and UV treatment did not clearly affect the results (26).

The filtration performance of various masks models was not significantly affected by low or high UV doses (0.18 J/cm^2 to 6.912 J/cm^2). The filter aerosol penetration (%) after UV treatments ranged from 0.005 – 0.012% for models P100 (16, 17), 0.34 – 1.86% for models SN95 (10, 16), and < 5% for models N95 (10, 16, 17, 29, 32, 39). Even at very high doses (120 – 950 J/cm^2), UV treatment caused insignificant increases (up to 1.25%) in the filter aerosol penetration (%) of N95 models compared to controls except the Kimberly-Clark 46727 (25). Nevertheless, the filtration efficacy of fabric of masks appeared to be more vulnerable, as its efficacy was above 95% after one cycle at the dose of 30.32 J/cm^2, then, the strong degradation (93%) happened after 20 cycles exposure (37). For the filter air flow resistance (mm H_2O), there were little changes ranging from 0.1 – 5.4% (25). Although Viscusi *et al.* (16) record no visible changes observed on masks N95, S95 or P100 by the dose of 0.176 – 0.181 J/cm^2, extremely high dose of 120 J/cm^2 would break the strength of mask straps by 20 – 51% and photochemical damages were observed on model 8210 at the dose 1 J/cm^2 (16, 39).

Recently, Cadnum *et al.* (38) reported that the exposure of UV-C box (Advanced Ultraviolet Systems, South Hill, VA) during 1 minute reduced > 3 log reduction of MRSA, phi6, and MS2 on the outer top of masks model Moldex 1517 and Kimberly-Clark 46727, while the activity on model 1860 was less effective (< 3 log reduction). The longer exposure (15 minutes for each side of model Moldex 1517) showed better biocidal efficacy, and low-pressure mercury device was stronger active than the pulsed-xenon device. No notable changes in the appearance of masks were recorded. However, the authors did not report the used dose of UV-C in these experiments.

Treatment of gamma irradiation (^{60}Co; 10, 25, 30, 50 kV) was not a promising method, despite model 8210 and 9105 passed the fit tests after treatment (62). The decontamination reduced the filter quality and caused a strong effect on the aerosol penetration (11.9 – 75.2%) of models 9105, 8210, 1860, 2950, 8511, and UVEX-3200, although the filter airflow resistance was not influenced (54, 62). The retentions of aerosols 0.5 and 1 μm of models 9510 and 8210 were also significant compared to the control (62).

Efficacy of cleaning wipes

Cleaning with wipes containing benzalkonium chloride, OCL wipes containing 0.9% sodium hypochlorite and INERT (the pampers wipes with no antimicrobial agents) did not affect the filter aerosol penetration and physical appearances of N95 masks (models 1860S, 1870, and Kimberly-Clark PFR) (46). The biocidal efficacy of OCL wipes were more effective than INERT. OCL wipes reduced > 98.98% of *S. aureus* while the reductions ranged from 59.37 (the exterior of Kimberly-Clark PFR) to 96.53% (the fabric of Kimberly-Clark PFR) by cleaning with INERT. The OCL wipes also cleaned mucin on masks better INERT, as no mucin detected after cleaning with OCL wipes. Wipes containing benzalkonium chloride also reduced > 95.37% of *S. aureus* survivals on the exterior and fabric of N95 masks. All masks had < 5% of filter aerosol penetration (%) with one exception of Kimberly-Clark. There were individual masks penetrating 5.6% of particles at maximum, although the mean value was < 5%.

Wipes containing the mixture of 0.28% 2–2-pdiisobutylphenoxyethoxyethyldimethyl ammonium chloride (QAC) and 17.2% isopropanol, wipes of 10% sodium hypochlorite could also completely inhibit the growth of H1N1 while wipes of 70% isopropanol was less effective (75% of viral recovery) (21). Although the results from PCR method showed more positive presence of viral RNA, the authors argued that these results were inconclusive for the virus present.

Other methods of decontamination

The ionized hydrogen peroxide at 7% (15 minutes) and at 7.8% reduced > 9 log reduction of *G. stearothermophilus* spores and completely inhibited of H1N1, respectively, showing its disinfecting efficacy (63, 64). The filtration performance of five models 1860, Kimberly-Clark [KC]/Halyard 46767 “duckbill,” Gerson 2130, 8210, and 9210/37021 also remained > 95% after five cycles (7%, 15 minutes). The tested masks could filter at least 99.05% of particles size 1 μm and 98.9% of particle size 0.5 μm. Meanwhile, the particle size 0.3 μm could be retained from 95.17% (Gerson 2130) to 99.91% (KC/Halyard 46767). All tested masks (KC/Halyard 46767, 3M 1860, 3M 8210) passed fit test with fit factor scores > 200 (63).

When using the machine for purpose of cleaning with a program of slowly increased temperature of water yielded the percent of masks passing the qualified standard test up to 100% for both the outer and inner parts of masks, defined as total bacteria <5cfu/cm2 and no detection of pathogens (23).

The combination of UV irradiation (0.024 J/cm^2) and dry heat (82^{o}C), the combination of UV irradiation (0.024 J/cm^2) and low humidity heat, the combination of UV irradiation (0.024 J/cm^2) and dry heat and VHP did not cause the significant filtration performance (filtration efficacy > 97.5%) or filter airflow resistance after 10, 2, and 4 cycles respectively (35). All tested masks after UV irradiation and low humidity heat passed fit test. Regarding the biocidal efficacy, the combination of UV irradiation and moderate humidity (62 – 66%) appeared to be more effective than the combination of UV irradiation and low humidity (8 – 10%) (35). All tested virus species (MS2 virus, Bacteriophage Phi6, virus H3N2, virus MHV) was completely inhibited after treating with UV irradiation and moderate humidity, while the combination with low humidity only showed the same effect on virus H3N2 and MHV. On bacterial species, the combination of UV irradiation (0.024 J/cm^2) and heat (82^{o}C) led to the poor effect on *S. aureus* and *G.*

stearothermophilus. The efficacy against *S. aureus* only improved when moderate humidity was created (> 2.7 lo reduction) (35).

Cadnum *et al.* (38) tested the biocidal efficacy on Moldex 1517 respirator of a high-level disinfection cabinet which generated the droplets containing 0.88% hydrogen peroxide, 0.18% peracetic acid, and 0.36% acetic acid. The given results indicated > 6 log reduction of MS2 and phi6 after three cycles 21 minutes or one cycle 31 minutes. Also, no visible changes of physical appearance were seen. Another disinfection system generated droplets containing peracetic acid (0.18%), hydrogen peroxide (0.88%), water (98.58%) also led to > 6 log reduction of *G. stearothermophilus* (8 or 12 minutes-dwell time) and > 6 log reduction of MS2 (12 minutes-dwell time) (65). The method did not degrade the structure and filtration performance of N95 model 1860, as the penetration ranged from 0.31 – 1.57% (3 – 5 cycles).

There were no experiments examining the filtration performance and biocidal efficacy of masks after the disinfection with dimethyl dioxirane or mixed oxidants (10% oxone, 6%, sodium chloride, 5% sodium bicarbonate). However, the decontamination with dimethyl-dioxirane remained significant weights of oxidants (4.53 – 7.72 mg) on both surgical and particulate masks while the residuals were smaller for the mixed oxidants treatment (19).

We briefly presented the advantages and disadvantages of these methods in **Table 2**.

Discussion

In this study, we considered decontamination methods leading to over 3 log reduction in contamination had good biocidal efficacy. Although the AOAC International validated Method 2008.05 (69) required > 6 log reduction in contamination, we agree with Fisher et al. (68) that a > 3 log reduction was effective for influenza disinfection. We considered particulate sizes ≤ 0.3 µm to be the best for testing the efficacy of particulate masks because the NIOSH considers that this size or smaller is the maximum penetrating aerosol size in the filter certification (70).

Our findings showed that decontamination methods such as VHP, EtO, MHI, MGS, UV irradiation, and cleaning with wipes had an acceptable anti-microbial effect with little to minor effect on the filtration performances of the varied masks. On the other hand, disinfection using autoclave or sodium hypochlorite (bleach) appeared to be effective against varied organisms; however, they potentially caused unacceptable degradation of filtration quality or retained chemical residuals (for sodium hypochlorite). Other methods were reported randomly but insufficiently regarding their biocidal efficacy and filtration performances of masks after treatment.

In general, soaking masks with chemical solutions (ethanol, isopropanol, soap and water, dimethyl-dioxirane) either degraded the filtration performances of most of the masks (N95, P100, Gauze, Spunlace) or retained a small amount of chemical solution. There were also some methods that although did not show a decrease in quality of masks after decontamination, no experiments on biocidal efficacy were done. For example, peracetic acid fogging was efficient as a decontamination method against *V. stomatitis* and SARS-CoV-2, but no particle penetration (%) after treatment was recorded (45). Therefore, such decontamination methods are hard to comment on due to a lack of information.

Regardless of the biocidal efficacy, the disinfecting methods that strongly reduced the filtration performance of masks after the treatment, cannot be used as decontamination methods. They included HPGP (59%, 24 – 72 minutes, 1 – 5 cycles), autoclave (115 – 121o C, 15 – 60 minutes, 1 – 2 cycles), ethanol, isopropanol, soap and water, chlorine, gamma irradiation, and steam generated by boiling water. HPGP is considered as an effective sterilization of medical devices due to its ability to inhibit a broad range of organisms in low temperature and short time (45, 71). Recently, the FDA acknowledged the emergency use of this method for sterilization of used masks with the expectation of 480 decontaminated masks per day (72). However, the findings from our review showed that this decontamination process is unsuitable as it reduced the filtration performances of masks and caused leakage on various models. In the

experiments of Bergman et al. (12), the authors realized that masks that were highly exposed to the HPGP treatment would significantly degrade more than the others, without a clear explanation for this problem. A possible explanation is that the free radicals generated from the plasma phase disrupted the electrostatic charges on the filter which strongly increased particle penetration (22). For the same reason, chemicals (ethanol, isopropanol, and soap) resulted in the strong reductions of filtration efficacy possibly due to the removal of the charge on masks surface (19, 22). This theory was reinforced when recharging the masks increased or recovered the filtration efficacy of masks that were degraded by ethanol or laundering (51, 60). However, Nazeeri *et al.* (63) suggested that the degradation of masks treated with ethanol was attributed to the water absorbed in the decontamination process rather than the discharge, as the drying in the vacuum condition preserved the filtration efficacy > 95%. Further studies are needed to resolve this conflict.

Due to its ability to clean off charges on masks, sodium hypochlorite's (bleach) should not be recommended for its usage. Additionally, the reductions in filtration efficacy using bleach are still inconsistent between studies depending on the applied concentration. Regarding sodium hypochlorite's good efficiency in killing micro-organisms at low concentrations, it should also be noted that the experiment was conducted in the low-protective-factor condition (1% ATCC). This means that these concentrations could be not efficient in real situations, as organic molecules (referred to high-protective-factor) strongly prevented the efficacy of the decontamination of sodium hypochlorite (47).

The autoclave cannot be recommended at this time due to its ability to temperature degrade non-woven polypropylene material, which N95 filters are made from (73,74). Although Lin *et al.* (22) suggested that autoclaving for 15 minutes and 1 cycle did not strongly affect the particle penetration of N95, particles of the most penetrating particle size passed through the masks still slightly increased. Subsequent cycles of autoclave cause a drastic degradation in the filtration efficacy (19), which makes sense as non-woven polypropylene cannot be persistent in the temperature > 100^{o}C and this material was also reported to be degraded with using the steam autoclave (73, 74).

Our findings reinforce CDC's recommendation for using VHP, MHI, and UVGI to decontaminate used masks (14). These methods inhibited the microorganism and had a negligible impact on the particle penetrations as well as the fit factor. However, there are some concerns raised by these methods. For instance, the short time exposure of VHP can restrict the biocidal efficacy of this method, especially for *S. aureus*. Although one study showed a positive effect against SARS-CoV-2, a concern is that VHP may not effectively inactivate the virus if the viral load is extremely high (34), which raises a concern for the efficacy of this method. Additionally, the high dose of UVGI also can reduce the fit factor score, with less efficacy was shown repeating UVGI for contamination as seen by Fisher et al (14, 30). Finally, VHP is a high cost and not always available in laboratories (45).

For other decontamination methods such as microwave oven irradiation, and liquid hydrogen peroxide (3-6%), seem promising since they did not affect the filtration performance. However, more studies are needed to test their biocidal efficacy. Microwave steam bag, rice cooker steam, and submersion of masks in Neutrawash detergent solution, on the other hand, showed a good effect on the growth inhibition of MS2, but there is insufficient evidence of its effect on mask quality (18, 20). Aerosolized hydrogen peroxide had good biocidal efficacy and preserved the functions of masks, but no filtration performance was investigated. Ozone gas exposure (20 ppm, 60 minutes) we recommend however because this decontamination method showed the inactivation of the human coronavirus and did not cause any damage to the fabric material. Studies that combined different methods also seemed promising, such as the combination of UVGI (0.024 J/cm2) and moderate RH, or high-level disinfection cabinet containing the mixture of hydrogen peroxide, peracetic acid, and acetic acid. However, they are not always available in laboratories.

Compared to VHP and MHI, UV irradiation did not affect the physical appearance of masks as much as VHP or MHI. The dilemma of UV irradiation was the variation of effective doses depending on the mask's model. A conflict between results related to the effective doses against MS2 should be marked (26, 30). Due to the differences in results, doses ≥

4.32 J/cm2 but not over 30.32 J/cm2 would be highly recommended. The high dose (30.32 J/cm2) degraded the functions of N95 masks and 120 J/cm2 of UV irradiation made masks less strong while low dose (0.63 J/cm2) had poor efficacy against SAR-CoV-2 (27, 36, 38). Moreover, proteins or organic materials absorb UV irradiation, and the high soil load condition also led to the less effective inhibition of viral survival (30, 75). Despite the soil load, the nature of models themselves also affected the biocidal efficacy of UV irradiation. Mills et al. (29) indicated that hydrophilic materials that absorbed the liquid inoculate or horizontal ridges on the masks would prevent the affection of UV irradiation as this method only worked on the mask's surface. Thus, UV irradiation should be considered only for specific cases to show the best effect, and masks should be cleaned before applying UV as a decontamination method to acquire the highest efficiency.

For EtO method, although the experiments of Salter et al. (21) showed that no EtO residual found by headspace solid-phase microextraction analysis as well as other chemicals found as trace, the safety is put into question as EtO is harmful to human health as reported by the CDC (14, 76). Although diacetone alcohol and 2-hydroxyethyl acetate were detected as traces, they are known as harmful chemicals with the available recommended exposure limit and the permissible exposure limit (21, 77).

MGS has short time requirements, uses simple equipment, but has effective viral growth inhibition and did not cause degradation of penetration. Nevertheless, the inconsistency of construction and power between microwaves and the ability to melt various masks models should be concerned (14). Apart from that, its capacity to load many masks for the contemporary decontamination is an advantage as well as its inadequacy.

Finally, cleaning masks three times with wipes containing 0.9% sodium hypochlorite has advantages for the reuse of masks because it is a more convenient physical method. Additionally, this method did not affect the masks' appearances and filtration, does not retain that much chemicals, and still could inactivate the micro-organism. However, the antimicrobial agent or cleaning solutions contained in wipes should be still appraised. For example, tween (in INERT wipes) or benzalkonium chloride (quaternary ammonium compound) and sodium hypochlorite also could interact with the charge on the mask's surface resulting in the reductions of filtration performance in some cases. Wipes containing benzalkonium chloride randomly resulted in the particle penetration exceeding 5%. Further studies could test other antimicrobial agents or cleaning solution applying this technique to have the best choice.

Conclusion

In conclusion, our findings reinforce the CDC's recommendations for using VHP, MHI, and UVGI to decontaminate used masks. Ozone gas could be highly recommended in the case the reuse of masks is obligatory due to the shortage. UVGI is recommended for only one application on used masks. Ethylene oxide should only be applied if there is an analysis to ensure the removal of chemicals residuals.

Abbreviations

AOAC	The Association of Official Analytical Chemists
APICE	Association for Professionals in Infection Control and Epidemiology
ATCC	American Type Culture Collection
CDC	Centers for Disease Control and Prevention
COVID-19	Corona Virus Disease 2019

EtO	Ethylene Oxide
FDA	Food and Drug Administration
FFRs	Filtering Facepiece Respirators
FSL	Face seal leakage
GHL	WHO Global Health Library
H1N1	Hemagglutinin Type 1 and Neuraminidase Type 1
H5N1	Hemagglutinin Type 5 and Neuraminidase Type 1 (Avian Influenza A)
HCWs	Healthcare Workers
HPGP	Hydrogen Peroxide Gas Plasma
ISI	Web of Science
MGS	Microwave Generated Steam
MHI	Moist Heat Incubation
MSB	Microwave Steam Bag
N95	Negativity at Approximately 95 Milliseconds
NIOSH	National Institute for Occupational Safety and Health
P100	Filters at least 99.97% of airborne particles
PPE	Personal Protective Equipment
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
SARS-CoV-2	Severe acute respiratory syndrome coronavirus 2
TCID50	50% Tissue Culture Infective Dose
UV	Ultraviolet
UVGI	Ultraviolet Germicidal Irradiation
VHL	Virtual Health Library
VHP	Vapor Hydrogen Peroxide
WHO	World Health Organization

Declarations

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Conflict of interest

The authors had no conflict of interest to conduct this study.

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Tables

Table 1. Biocidal efficacy, filtration performance and physical appearances of masks after treatments

Methods	Biocidal efficacy	Filtration performance		Physical appearance	Safety concerns
	Reduction of survival (organism)	Filter aerosol penetration (%) (mask)*	Filter air flow resistance (mm H_2O) (mask)		
Gaseous					
HPGP (59%, 24–72 min, 3 cycles) (10, 35, 39, 43)	No recovery (*V. stomatitis*) > 7.9 log reduction (*Phi6*) > 3.8 log reduction (*influenza*) 5.6 log reduction (MS2)	1.71 - 7.3 (N95) 2.5 - 8.76 (SN95) 0.029 – 14.274 (1860S) < 26 (1860) 0.013 – 42 (8210) 0.027 – 10.108 (9210)	7.7 - 11.5 (N95) 9 - 14.4 (SN95) Little changes after treatment (1860S, 8210, 9210)		
VHP (30%, 125 min, 3 cycles) (10)		0.5 – 1.18 (N95); 0.44 – 2.35 (SN95)	7.5 – 11.8 (N95); 8.2 – 16.4 (SN95)		0.04-1.77 mg of oxidant residuals
VHP (58 – 59%, 25 min, 1 cycle) (17, 39, 43)		0.004 - 0.01 (P100) 0.287 - 0.916 (N95) 0.118 – 0.887 (1860S) 0.109 – 0.277 (8210) 0.098 – 0.541 (9210)	Little changes after treatment (1860S, 8210, 9210)		
VHP (100%, 55 min, 1 cycle) (16, 19)		0.071 - 1.47 (N95); 0.542 - 0.727 (SN95); 0.006 - 0.1 (P100)	6.5 - 9.6 (N95) 6.5 - 8.6 (SN95) 13.4 - 16.2 (P100)	Less shiny and light tarnish nosebands	Trace of oxidant residuals but not significant
VHP (35%, 120 min, 10 – 50 cycles) (40)	> 6 log reduction (*Geobacillus stearothermophius*)		9 - 10	Made elastic straps stiffer after 30, 40, 50 cycles	
VHP (35%, 20-180 min × 1 cycle OR 120 min 10 – 50 cycles, 3 hours ×	No recovery (T1 bacteriophage, T7 Bacteriophage, *Pseudomonas* phage phi-6, *V. stomatitis* and	< 1 (1860, 8210, Moldex 1511) 0.99 – 1.50 (1860S)	17.5 (1860, 8210, Moldex 1511)	Made elastic straps stiffer after 30, 40, 50 cycles but no physical degradation or	No residual hydrogen peroxide

1 cycle) (35, 41-44)	SARS-CoV-2, *Geobacillus* spores) > 6 log reduction (*G. stearothermophius*) ≥ 2 log reduction (MS2, Bacteriophage phi6, influenza A virus, MHV, *E. coli, A. niger*) > 1.0 log reduction (*S. aureus*)		9.4 – 10.6 (1860S)	odour observed	
EtO (725 - 883 mg/L, 1 hour, 1 – 3 cycles) (10, 16, 17, 19, 43)	No recovery (*V. stomatitis*) >5.8 log reduction (MS2)	0.101 - 1.77 (N95) 0.003 - 0.008 (P100) 0.25 - 2.55 (SN95) < 1 (1860)	6.9 - 12 (N95) 12.8 - 15.9 (P100) 6.3 - 16.9 (SN95)	Made P100 straps light dark, no affection for N95 and SN95	No EtO detected; diacetone alcohol, 2-hydroxyethyl acetate, cyclohexanone found as traces
Vapor EtOH (70%, 1-3 cycle) (39)		0.972 – 1.246 (1860S) 0.633 – 1.424 (8210) 1.014 – 2.228 (9210)	Little changes after treatment (1860S, 8210, 9210)		
Ozone gas (120 ppm × 1-5 min, 10 – 200 ppm × 60 min) (48, 49)	No recovery (HCoV-229E-influenza A – H1N1 and *S. aureus*)	0.7 – 1.4 (KF94) >5 (9210)		No visible discoloration or loss of fibres integrity. No affection of mechanical integrity.	
iHP generated by (7.8%, 90 min, 1 – 5 cycles) (63, 64)	9-log reduction (*G. stearothermophilus* spores) No recovery H1N1	0.53 – 0.67 (1860) 0.11 – 0.22 (KC/Halyard 46767) 1.31 – 2.57 (Gerson 2130) 0.18 – 0.24 (8210) 0.23 – 1.32 (9210/37021)	9.10 – 10.35 (1860) 14.10 – 15.2 (KC/Halyard 46767) 7.90 – 9.3 (Gerson 2130) 8.85 – 8.95 (8210)	No colour change following seven days of incubation in Releasat medium	H_2O_2 residual lower than the safety limit
Heat and Humidity					
MHI (60 - 82°C, 60 - 85% RH, 20 - 30 min × 1 cycle or 15 min × 3 cycles or 1 hour × 1 – 10 cycles)	> 3.4 - 6.8 log reduction (H1N1, H5N1, MS2, phi6, influenza virus)	0.43 - 1.04 (N95) 0.58 - 2.16 (SN95)	7.5 - 10.7 (N95) 7.9 - 15.0 (SN95)	A detachment of the inner foam nose cushion on varied models, Stronger odour	

(11, 15, 32, 35, 39, 50)	> 2.9 log reduction (*S. aureus* oxacillin-sensitive strain) > 5.3 log reduction (MRSA) >1.4 log reduction (MHV) <0.3 log reduction (*G. stearotherophilus*)	0.43 - 1.04 (N95) 0.58 - 2.16 (SN95) 0.151 – 0.584 (1860S) 0.231 – 0.7 (8210) 0.945 – 3.239 (9210)		for N95 model 1860
MHI (80-82°C, <10% RH, 30 min × 10 cycles) (35)	0.05 – 2.3 (*MS2*) 0.8 – 3.3 (*phi6*) < 1.0 log reduction (*S. aureus, Geobaccilus*)	0.43 - 1.04 (N95) 0.58 - 2.16 (SN95) 0.151 – 0.584 (1860S) 0.231 – 0.7 (8210) 0.945 – 3.239 (9210) 2.1 - 2.27 (Chen Heng V9501 KN95) .02 – 1.12 (HKYQ N95) .37- 1.09 (3M 8210 Plus) .03 - .16 (3M 1870)	7.5 - 10.7 (N95) 7.9 - 15.0 (SN95)	A detachment of the inner foam nose cushion on varied models, Stronger odour for N95 model 1860
Autoclave (121°C, 103 kPa, 15 - 60 min, 1 – 10 cycles) (17, 20, 39, 43, 52-54)	No recovery (*V. stomatitis, B. subtilis and* SARS-CoV-2)	2.4 (1 cycle), 18.7 - 34.4 (2 cycles) (N95) 0.059 - 1.426 (P100) 0.195 – 0.315 (1860S) 0.488 – 0.057 (8210) 0.789 – 0.071 (9210) 0.04 (SH-2950) 3 (8511) 5.6 (Aura1862) 10 (San Huei 2920V)	11 (SH-2950) 7 (8511) 12 (UVEX-3200) Little changes after treatment (Aura1862, San Huei 2920V, Safe Worker 1016, 1860S, 8210, 9210)	No remarkable visual changes were observed in the P100 respirators, though the respirator media itself felt softer. Degraded appearances were observed for N95 masks

		19 (UVEX-3200) 39.7 (Safe Worker 1016) 49.8 (GAUZE) 81.6 (SPUNLACE)		
Dry heat (80-85°C, 30 – 60 min) (17, 37, 38)	< 1 log reduction (MS2, Phi6, *S. aureus and G. stearothermophillus*) > 4 log reduction (MRSA)	0.008 ± 0.001 (P100) 0.84 ± 0.258 (N95)		
Dry heat (100°C , 15-30 min × 1 – 3 cycles) (39, 56)	< 3 log reduction (MRSA, MS2)	0.029 – 0.310 (1860S) 0.010 – 0.156 (8210) 0.036 – 0.024 (9210)	Little changes after treatment (1860S, 8210, 9210)	
Dry heat (100°C , 15-30 min × 5 – 10 cycles) (39)	< 3 log reduction (MRSA, MS2)	0.562 – 9.259 (1860S) 6.638 – 8.107 (8210) 0.046 – 0.265 (9210)	Little changes after treatment (1860S, 8210, 9210)	
MGS (1100 – 1150 W, 2 - 75 min) (11, 15, 28, 30-32, 45, 47)	> 4 log reduction (H5N1) 4.23 - 5.94 (H1N1) 4.1 - 6 (MS2)	0.08 - 1.77 (N95) 0.52 - 2.14 (SN95) 0.006 - 0.009 (P100)	9.5 - 11.1 (N95) 8.8 - 14.4 (SN95)	A detachment of the inner foam nose cushion on varied models, sometimes caused melting
MGS (1100 W, 0 – 40 seconds) (28, 45)	< 3 log reduction (MS2)	< 4.5		
Microwave steam bag (18)	> 99.86% reduction (MS2)	0.33 - 0.38 (2810) 0.38 - 0.72 (1860) 1.4 - 4.23 (Moldex 2200) 0.12 - 4.5 (KCPFR95) 0.3 - 1.48 (1870)		Not significantly change the filtration performance
Boiling water steam decontamination (20 – 120 min) (57)	No detection of H120	0.046 – 3.627 (MM) 0.018 – 0.038 (N95)		
Rice cooker steamer (13-15 min) (56)	>5 log reduction (MRSA, MS2)			No visible changes after 5 cycles

Rice cooker (149 – 164˚C, 3 min) (20, 30)	> 99.7% reduction (*B. subtilis)*	2.5 (N95) 24.9 (GAUZE) 77.1 (Spunlace) 23(Venus 4420)			
Liquid/chemicals					
Liquid hydroperoxide (3 - 6%, 30 min) (17)		0.49 - 1.52 (N95) 0.005 - 0.006 (P100) 0.12 - 3.35 (SN95)	6.2 - 11.0 (N95) 9.0 - 11.7 (SN95)	No affection if treating with 3% and ink faded if treating with 6%	Trace of oxidant residuals
Dimethyl-dioxirane (19)				Metal oxidized and strong odour	4.53 - 7.72 mg of oxidant residuals
Ethanol (70%, 10 min) (20, 30, 34)	22.3 ± 8% of survival *(B. subtilis*) No detection of SAR-CoV-2 after treatment	39 for particle size 445 nm (N95) 61.4 for particle size 496 nm (GAUZE) 80.7 for particles size 400 (Spunlace)			Impaired mask integrity
Ethanol 70% followed by vacuum drying (5 cycles) (61)		4.8 (8200) 3 (8210) 2.8 (8511)			
Isopropanol (70 - 100%, 10 - 30 min) (17, 20)		17.8 - 21.6 (N95) 0.412 - 0.805 (P100) 71.1 for particle size 414 nm (GAUZE)		Ink faded	
Mixed oxidants (19)				Metal oxidized and strong odour	0.08 - 8.1 mg of oxidant residuals
Soap and water (1 g/l, 2 - 20 min) (17)		34.9 - 38.8 (N95) 0.014 - 0.147 (P100)		No affection	
0.5% Neutrawash detergent solution (Potassium polyacrylate and EDTA) (22)	Below detection limit (H1N1) for varied models.				
Chlorine-based (2%, 5 min) (37)		26.9 (N95)	9		

Sodium hypochlorite 5-10% (19)					0.32 - 1.66 mg of oxidant residuals
Sodium hypochlorite 0.25 - 5.25 % , 10 - 30 min (10, 16, 17, 20, 29, 45)	> 3.13 log of reductions (MS2) No survival (*B. subtilis*)	0.262 – 18.3 (N95) 0.233 – 4.01 (SN95) 0.004 – 0.027 (P100) 89 for particle size 429 (Spunlace)	0.68 – 11.4 (N95) 5.9 – 12.1 (SN95) 13.6 – 17 (P100)	Made nosebands tarnished and less shiny, remained bleach smell. Sometimes discoloured and dissolve nose pad, ink faded Strongly damage the structure of Gauze leading to unavailable test for penetration	
Sodium hypochlorite 0.005 - 0.1%, 10 - 30 min (45)	0.66 - 2.8 log reduction (MS2)	0.262 - 18.3 (N95) 5.9 - 12.1 (SN95) 0.009 - 0.01 (P100)	6.9 - 11.4 (N95) 5.9 - 12.1 (SN95) 13.6 - 17 (P100)		
Peratic acid (10%), 1 h / cycle (45)	No growth of *V. stomatitis* and SARS-CoV-2	No affection of function (N95)			
Aerosolized hydrogen peroxide 7%, 21 min	Inactivation of HSV-1, CVB3, Phi6. Greater loss of infectiousness with HSV1 and CVB3				
Aerosolized containing 0.18% peracetic acid, 0.88% hydrogen peroxide, 98.58% water (76 – 87 min) (65)	> 6 log reduction (*G. stearothermophilus* spores, MS2) .	≤ 5.0 %		Preserved structural integrity, strap elasticity. Bubbles on the surface increase with cycles No change contact angle	No detectable off-gassing of peracetic acid
High-level disinfection cabinet 1-3 cycles (40)	6 log reduction (MRSA) 2-6 log reduction (Bacteriophage MS2)				
Energy					
UVGI (120 - 950 J/cm^2) (25)		Increased ≤ 1.25% (1860, 9210, GE 1730)	Less changed		

UV (18.4 J/cm^2) (34)				Impaired mask integrity and straps
UVGI (4.32 - 14.4 J/cm2) (10, 11, 15, 17, 19, 26, 29)	> 3 log (MS2)	0.072 - 1.77 (N95) 0.34 - 1.86 (SN95) 0.005 - 0.012 (P100)	7.1 - 11.1 (N95) 6.6 - 17.6 (SN95) 13.1 - 16.5 (P100)	No affection except randomly leading to intolerant odour in N95 MOLDEX 2200
UVGI (1.44 - 3 J/cm^2) (28, 29)	0.9 - 2.8 log (MS2)			
UVGI (1 - 1.8 J/cm^2) (27, 31)	> 3 - 5.75 log (*H1N1*) < 1% of relative survival (*B. subtilis*)			Photochemical damages on model 8210
UV 0.024 J/cm^2 (37)	< 3 log reduction (H3N2, phi6, MHV) < 1 *S. aureus, G. stearothermophilus*			
UV 0.18 J/cm^2 (34)	> 4.65 log reduction (H5N1)			
UVGI (30.32 J/cm^2, 1 cycle)		< 5 (N95)		
UVGI (30.32 J/cm^2, > 20 cycle)		7 (N95)		
UV (0.63 J/cm^2) (34)	Positive detection of SAR-CoV-2 (mask 1860, 8511) No detection of SAR-CoV-2 (1870)			
UV irradiation (0.024 J/cm^2) + dry heat (82°C) (10 cycles) + VHP (37)	2.5-5 log inactivation (MS2) 2.7-3.9 log inactivation (phi6) 2.3-3.1 log inactivation (Influenza) 1-2.1 (MHV)	< 2.5		
Gamma irradiation (10, 25, 30, 50 kGy) (54, 62)		14.1 – 75.2 (9105) 20 (UVEX-3200) 30 (SH-2950) 50 (8511) 11.9 – 64.8 (8210)	13 (UVEX-3200) 11 (SH-2950) 9 (8511) 11 (8210) 10 (1860)	Taste the saccharin mist Slight unrecognizable odour

		52 (1860)		
UV-C box (Advanced Ultraviolet Systems, South Hill, VA) (15 min) (38)	1.12 – 2.16 (MRSA) (1860s) 3.0 – 4.0 (MRSA) (Moldex 1517) 1.3 – 3.7 (MRSA) (Kimberly-Clark 46727) 0.4 – 1.8 (Phi6) (1860s, Moldex 1517) 0.5 – 3.4 (Phi6), (Kimberly-Clark 46727) 0.15 – 3.0 (MS2) (1860s, Moldex 1517, Kimberly-Clark 46727)			No visible changes were observed
UV-C box (Advanced Ultraviolet Systems, South Hill, VA) (38)	≥ 3 log10 reduction (MRSA) (Moldex 1517)	2.5%		No visible changes were observed
UV-C (2 cycles) 15 min/ cycle using the pulsed-xenon device device (35, 38)	< 3 log10 reduction for (MSRA, Phi6 & MS2) (Moldex 1517)	2.5%		No visible changes were observed
Microwave oven irradiation (1100 W, 2 min × 1 cycle) (16, 17)		0.105 - 1.460 (N95) 0.652 - 0.711 (SN95) 0 - 0.002 (P100)	6.2 - 9 (N95) 5.4 - 8.7 (SN95) 13.1 - 15.8 (P100)	No affection on N95, some SN95s and P100s melted during treatment
Cleaning Wipes				
504/07065 Respirator Cleaning Wipes containing benzalkonium chloride (30 seconds) (46)	Exterior: > 99.72% reduction Interior > 68.92% reduction Fabric > 95.37 (*S. aureus*)	1.9 – 4.1 (N95)		No affection
Hype-Wipes containing 0.9% sodium hypochlorite (OCL wipes) (30 seconds) (46)	Exterior: > 99.99% reduction Interior > 98.98% reduction Fabric > 99.99% (*S. aureus*)	0.4 – 1.6 (N95)		No affection
Pampers wipes with no active	Exterior: 59.37 - 98.5% reduction	0.1 – 2.4 (N95		No affection

antimicrobial ingredients (INERT) (30 seconds) (46)	Interior: 69.28 - 90.95 % reduction Fabric: 90.01 - 96.53% reduction (*S. aureus*)	Kimberly-clark)	
Wipes containing 70% isopropanol (21)	75% survival (H1N1)		
Wipes containing 0.28% QAC and 17.2% isopropanol (21)	No survival (H1N1)		
Wipes containing 10% sodium hypochlorite and detergent (21)	No survival (H1N1)		
Combinations of methods			
UV irradiation (0.024 J/cm^2) + dry heat (82^{o}C) (10 cycles) (35)	0.06 – 1.2 log reduction (*S. aureus, G. stearothermophilus*)	< 2.5 (1860)	17.5 (1860)
UV irradiation (0.024 J/cm^2) + dry heat (82^{o}C) + low humidity (8% RH) (10 cycles) (35)	0.3 – 2.1 log reduction (MS2, Phi6) > 3.8 log reduction (influenza) 1.1 (MHV)	< 2.5 (1860)	17.5 (1860)
UV irradiation (0.024 J/cm^2) + moist heat (82 ^{o}C, 60 – 66% RH) (35)	> 6.8 log reduction (MS2, Phi6) > 3.3 log reduction *(*influenza) > 1.4 log reduction (MHV) > 2.7 log reduction (*S. aureus*)	2.5 (1860)	17.5 (1860)
* Measured with particle size 300 nm EDTA: Ethylenediaminetetraacetic acid; EtO: Ethylene oxide; HPGP: Hydrogen peroxide gas plasma; VHP: Hydrogen Peroxide Vapor; MGS: Microwave-generated steam; MHI: Moist heat incubation; QAC: 2–2-pdiisobutylphenoxyethoxyethyldimethyl ammonium chloride (a quaternary ammonium chloride)			

Table 2. Advantages and disadvantages of methods of decontamination

Method	Advantages	Disadvantages	Notes
Gaseous			
HPGP	Good biocidal efficacy against MS2, Bacteriophage Phi6, influenza virus H3N, and *V. stomatitis* Did not affect the filtration performance of masks N95, SN95, models 1860, 1860S, 8210, 9210.	Strongly affected the particle penetration (%) of N95 and SN93 masks (55 minutes) Caused leakage (5 cycles)	No experiments showing the physical appearance of masks after the treatment.
VHP	Good biocidal efficacy against *Geobacillus stearothermophius,* T1 Bacteriophage, T7 Bacteriophage, *Pseudomonas* phage phi-6*, V. stomatitis,* MHV*, A. niger, Geobaccilus spores and* SARS-CoV-2 Did not affect fit factors (AO Safety N9504C and models 1860, 1860S, Aura 1870+, 8511) Did not affect the filtration performance of masks N95 and SN95.	Leading the stiffness of straps, less shine and tarnish of nosebands. Exceeding 20 cycles leading to the stiffer straps Still remained insignificant oxidant residuals after treatment. possibly high cost	
EtO (725 - 883 mg/L, 1 – 3 cycles, 1 hour)	Good biocidal efficacy against *V. stomatitis* Did not affect the filtration performance, physical appearance of masks N95 and SN95. No chemical residuals. fit test passed after 1 - 3 cycles	Traces of contaminants	EtO might be harmful to the human health
Ozone gas	Good biocidal efficacy against HCoV-22E, H1N1, *S. aureus* Did not affect the filtration performance of fabric materials, physical appearance, and the mechanical integrity		
Vapor ethanol	Did not affect the filtration performance of model 1860S and 8210		Degraded the filtration performance of model 9210
Heat and humidity			
MHI	Good biocidal efficacy against H1N1, H5N1, MS2, phi6, H3N2, MHV, and *S. aureus* Did not affect the filtration performance of fabrics and masks N95 and SN95, Chen Heng V9501 KN95, HKYQ Fit factors ≥ 100 for most models	Failed to kill *G. stearothermophilus* High temperature ($125^{o}C$) damaged the filtration performance A detachment of the inner foam nose cushion on varied models. Stronger odour for N95 model 1860	Fit factors of Chen Heng V9501 KN95, and HKYQ N95 were strongly decreased

Autoclave	Good biocidal efficacy against *B. subtilis, V. stomatitis* and SARS-CoV-2 No remarkable visual changes were observed in the P100 respirators, though the respirator media itself felt softer.	Strongly decreased the filtration performance of most models Deformed models Safe Worker 1016, 1860S, 8210 Fit test failed (N95 models 1860 and 8210) Degraded appearances of N95 masks	The filtration performance of masks N95 were varied and inconsistent across studies. Aura 1862, 8210, 1860, SH-2950, 9210 still had > 95% of filtration efficacy. Still effectively retained particles 0.5 – 1.0 μm.
Dry heat (70 - 100°C, 15 - 60 min)	Slow clearance of SARS-CoV-2 strain Not effective against MS2 *and* MRSA Did not affect the filtration performance of fabrics and masks N95, P100. No visible changes in N95, surgical masks, cotton masks, quilted masks (at 100°C, 15 minutes) Preserve fit factors of varied models	Poor efficacy against MS2, phi6, MRSA, *S. aureus* and *G. stearothermophilus*	Reduce fit factor of AOSafety N9504C respirators
MGS (2 - 75 min)	Good effect against H5N1, H1N1 Good effect against MS2 if treatment duration > 45 min. Did not affect the filtration performance of masks N95, SN95 and P100. Fit test passed for all tested masks. No visible physical characteristics on N95 model 1860	A detachment of the inner foam nose cushion on model 1870, sometimes caused melting.	All components of masks should completely be exposed the steam
Microwave steam bag	Good effect against MS2 Not significantly change the filtration performance.	Water retention	
Rice cooker generated steam	Good effect against MRSA, MS2 Did not cause physical changes		
Boiling water generated steam	Good effect against H120	Degraded the filtration performances of fabric and Venus 4420 mask	Recharge after treating could recover the filtration efficacy
Rice cooker (149-164˚C, 3 min)	Good effect against *B. subtilis*. Did not affect the filtration performance of masks N95.	Strongly reduced the filtration performance of masks Gauze, Spunlace.	No experiments showing the physical appearances after treatment.
Liquid/chemicals			

Hydrogen peroxide	Aerosolized hydrogen peroxide inactivated HSV-1, CVB3 and phi6 Liquid hydrogen peroxide did not affect the filtration performance of masks N95, SN95 and P100. Fit test passed (model 8511)	Still remained oxidant residuals after treatment.	No experiments showing the biocidal efficacy after treatment. (liquid hydrogen peroxide)
Dimethyl dioxirane		Still remained oxidant residuals after treatment. Metal oxidized and strong odour	No experiments showing the biocidal efficacy and filtration performance after treatment.
Ethanol (70%, 10 min)	Quite good effect against *B. subtilis*. Quick reductions of SARS-CoV-2 Less changes in filter air flow resistance	Strongly reduced the filtration performance of masks N95 and Gauze Decreased fit factor scores	Quick reductions of microorganisms but the maximal reduction was lower than other methods No experiments showing the physical appearances after treatment. Recharge or dried in vacuum condition after treating could recover the filtration efficacy
Isopropanol (100%, 10 - 30 min)		Strongly reduced the filtration performance of masks N95, GAUZE, Spunlace. Ink faded	No experiments showing the biocidal efficacy after treatment.
Mixed oxidants		Still remained oxidant residuals after treatment. Metal oxidized and strong odour	No experiments showing the biocidal efficacy and filtration performance after treatment.
Laundering	Soap and water showed no affection of physical appearance	Treatment of soap and water strongly reduced the filtration performance of masks N95and P 100 Treatment of water and detergent reduced the filtration efficacy of fabrics	No experiments showing the biocidal efficacy after treatment. Recharge after treating could recover the filtration efficacy
Sodium hypochlorite (0.006 – 10%, 10 -30 min)	Good biocidal effect from the concentration of 0.25% against H1N1, MS2*, B. subtilis.* Did not affect the filtration performance of masks P100.	Significantly reduced the filtration performance of masks N95, SN95. Strongly degraded physical appearance of N95 and SN95 Strongly damage the structure of Gauze	The filtration performance of N95 after treatment were varied and inconsistent across studies.
Energy			
UVGI	Good biocidal effect against MS2		Repeated the

	from the doses of 4.32 J/cm^2. Good biocidal effect against H1N1, H5N1 from the doses of 1 J/cm^2. Did not affect the filtration performance, physical appearances of masks N95, SN95 and P100. Fit test passed for all models	Dose of 30.32 J/cm^2 reduced fit factor scores and filtration performance of fabrics Dose over 120 J/cm^2 reduced the strength of masks Could cause phytochemical damages	contamination/decontamination reduce the efficacy Low dose showed poor biocidal efficacy Soil load affected the decontamination of UVGI
Microwave oven irradiation (1100 W, 2 min, 1 cycle)	Did not affect the filtration performance, physical appearances of masks N95 and P100.	Some masks SN95 and P100-I melted during treatment.	No experiments showing the biocidal efficacy after treatment.
Gamma irradiation	Fit test passed	Reduced the filtration efficacy	
Cleaning Wipes			
Wipes containing disinfecting agents	Good effect against *S. aureus* and H1N1 by different agents (Benzalkonium chloride, sodium hypochlorite, QAC) Mostly did not affect the filtration performance, physical appearances of masks N95.	Some masks cleaning by wipes containing benzalkonium chloride had particle penetration > 5%	

EtO: Ethylene oxide, HPGP: Hydrogen peroxide gas plasma, HPV: Hydrogen Peroxide Vapor, MGS: Microwave-generated steam, MHI: Moist heat incubation, QAC: 2–2-pdiisobutylphenoxyethoxyethyldimethyl ammonium chloride (a quaternary ammonium chloride).

Figures

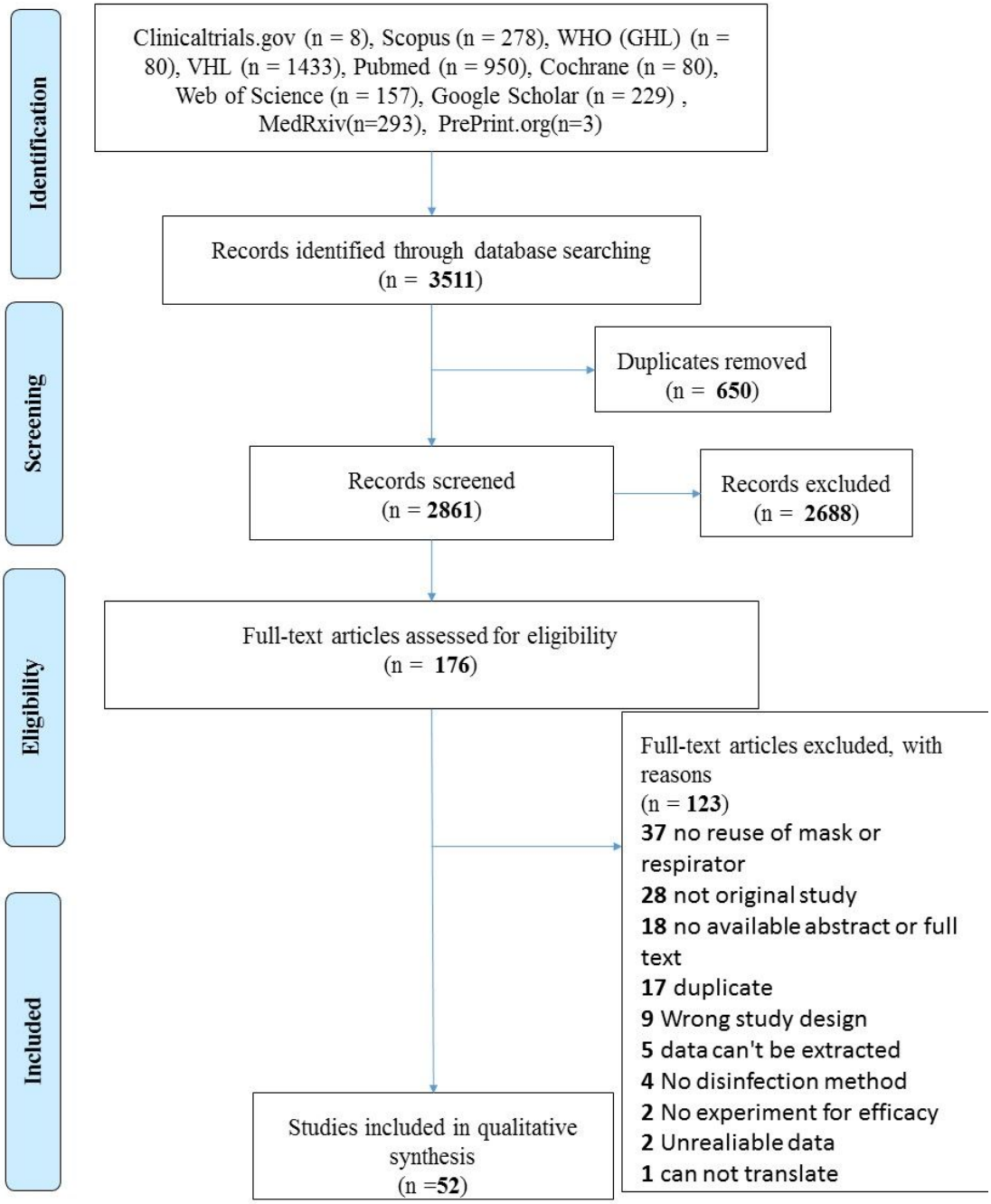

Figure 1

PRISMA flow diagram of the inclusion of articles

Supplementary Files

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