Decontamination Methods for Respiratory Protection Mask Model N95: A Rapid Review

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Research

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Abstract

Background: N95 respiratory protection masks are used by healthcare professionals to prevent contamination with infectious microorganisms transmitted by droplets or aerosols.

Methods: We conducted a rapid review of the literature analyzing the effectiveness of decontamination methods for mask reuse. The review was carried out in April 2020 using a simplification of the formal systematic review process. A total of 166 articles were retrieved of which 17 laboratory-based studies were selected.

Results: Two of the studies only examined the effectiveness of decontamination methods, seven only reported on the maintenance of mask integrity, and eight considered both outcomes. Twelve decontamination methods were included in the studies.

Conclusions: Positive results should be considered with caution as they represent a small number of studies, reflect ideal laboratory conditions, and may have limited applicability in realistic situations and for health systems. Nonetheless, five methods appear promising: hydrogen peroxide vapor, ultraviolet irradiation, dry heat, wet heat/pasteurization, and microwave ovens.

Background

The world is facing a pandemic of coronavirus disease (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).[1–5]

Respiratory transmission routes of these viruses between humans are well established and based on transport via aerosols, droplets, secretions or through direct contact with nasal mucosa.[6] The use of respiratory protection masks, particularly model N95, by health professionals in the care of infected patients is recommended in aerosol-producing procedures (tracheal intubation, non-invasive ventilation, tracheotomy, cardiopulmonary resuscitation, manual ventilation, before intubation, collections of nasotracheal secretions and bronchoscopies).[7–9]

During the current COVID-19 pandemic, governments have found it difficult to acquire adequate amounts of Personal Protection Equipment (PPE) including respiratory protection masks; this has been accompanied by a high level of infection of health professionals on the front lines of services.[10–14] The COVID19 pandemic has not only exposed the need for health professionals to have access to the most effective PPE, it has exposed the inability of many health systems to meet this need. In this context and with the goal of enabling reuse of protective masks, research on alternatives for their decontamination has been carried out.

Why is this Review needed?

The recent epidemics and pandemics caused by respiratory viruses have been characterized by a shortage of N95 masks. In this scenario health care professionals seek alternatives, including the decontamination and reuse of PPE.[15] However, there is concern about disease transmission as there are no best practices for mask decontamination and reuse.[16] In critical circumstances, rapid analyses are recommended by WHO[17] to provide guidance for timely decision making. This quick review examines the knowledge base on the effectiveness and safety of decontamination methods for N95 masks for reuse as protection against COVID-19 and other respiratory viruses.

Methods

Search strategy and selection criteria

This rapid review follows the principles outlined by Haby et al.[18] and a previous protocol (Supplementary material 1) which simplified the stages of a complete systematic review, including the exclusion of an assessment of study methodology. Searches were conducted on Medline and Cochrane Library databases on April 15, 2020. Search terms were related to decontamination (e.g., “Sterilization”, “Disinfection” and “Decontamination”), reuse (e.g., “Equipment Reuse” and “Reuse”), device failure (“Equipment Failure”) and masks (e.g., “N95” and “filtering facepiece respirators”). The complete search strategies can be found in Table 1 of Supplementary material 2. The language of references was not an exclusion criterion. Articles were included that evaluated methods for decontamination of N95 masks for reuse. Initial searches retrieved 166 articles. Manual searches detected several additional recent publications without peer review. Mendeley citation management software was used for automatic removal of duplicate articles. Two reviewers screened the remaining 134 studies using the Rayyan systematic review application to screen abstracts and titles.[19] Of these, 114 were excluded for not meeting the inclusion criteria. The full texts of twenty studies were screened by two reviewers and three additional studies were excluded. Excluded full text studies and the reasons for exclusion are listed in Table 2 of Supplementary material 3.

Seventeen studies were selected for the full review process (Fig. 1).

The main considerations in the review were the two issues:[20]

1. Whether the device maintains its structural characteristics and provides an adequate level of protection after the decontamination method, without any risk of exposure for the health professional, either to contamination or to exposure to inhalable chemical residues that may have remained after the method used.
2. Whether the decontamination method used was effective in reducing or completely eliminating the infectious capacity of the target organism.

Results of the studies were summarized based on decontamination method and results for the two criteria. The specifics of each method (cycles, temperatures, protocols, densities, exposure time,

technology used and results) are described in Table 3 of Supplementary material 4.

Results

Twelve methods were assessed in the 17 papers: hydrogen peroxide, ultraviolet irradiation, ethylene oxide, dry heat, moist heat/pasteurization, ethanol, microwaving, sodium hypochlorite (NaClO), autoclaving, electric rice cooker, cleaning wipes, and isopropanol solutions.

1. Hydrogen peroxide

Hydrogen peroxide was evaluated in its liquid, plasma and gas/vapor forms by six laboratory studies.[21–26] The effect of hydrogen peroxide on the filtering capacity varied according to the method used. Hydrogen peroxide plasma led to changes in the masks' metallic nasal clips[21] and degradation in their filtering performance.[23] Treatment with liquid hydrogen peroxide caused oxidation of the metal clips[23] but also inactivated the influenza H1N1 virus.[24] When used as steam, hydrogen peroxide did not leave residual chemical products,[22] the integrity and filtering capacity of the mask were maintained,[23,25,26] and the method was effective in eliminating SARS-CoV-2[25] and spores of *Geobacillus stearothermophilus*.[26]

2. Ultraviolet germicidal irradiation (UVGI)

The effect of ultraviolet germicidal irradiation on the functional integrity of the masks was evaluated by 11 studies[22,23,25,27–34] and its effect on the elimination of microorganisms by six studies[20,25,29,30,33,34], with power calculations with different doses and application times. UVGI did not affect the integrity and ability of the masks to filter aerosols or adapt to the face, nor did it leave a smell, irritating/toxic residues, or create important changes in appearance even when multiple cycles were performed.[22,23,25,27–34] The method was effective against the influenza virus H5N1,[20] SARS-CoV-2,[25] bacteriophages MS2,[29] and influenza virus H1N1.[30,33] However, even after 20 min of irradiation with 365 nm UVA the relative survival of *Bacillus subtilis* spores remained above 20%.[34]

3. Ethylene oxide

Evaluated by three studies,[21–23] the effectiveness of ethylene oxide (EtO) depended on the type of sterilization equipment used, whether there was a hot cycle, and exposure to EtO. The process did not affect the filtration, resistance, odor or appearance of the masks. The main limitations of the method were the processing time and the presence of toxic residues and by-products. None of the studies reported the effectiveness of EtO treatments on microorganisms.

4. Dry heat

The use of dry heat (temperatures between 70 and 85 °C) as a decontamination method did not affect the structural characteristics of the masks under various humidity conditions (≤ 100% RH).[25,27] The

filtering efficiency remained acceptable up to 50 cycles.[27] At 70 ºC the method was effective against the SARS-CoV-2.[25]

5. Moist heat / pasteurization

Five studies[20,23,27,30,31] evaluated the effect of moist heat between 60 and 100 °C. The method did not alter mask fit, odor or comfort.[20,23,27,30,31] In one study[27] filtering capacity was reduced to 80% after 10 cycles. Moist heat (65±5 °C for 3 h) was also effective in eliminating H1N1[30] and H5N1[20] viruses.

6. Ethanol

Different methods of decontamination with ethanol were tested: spray,[25] immersion,[27,35] and pipette drips.[34] Results were divergent between methods. The filtration efficiency of masks was degraded to unacceptable levels when they were immersed in alcohol.[27,35] Mask filtration performance was not significantly reduced after single ethanol sprays which were also effective in eliminating SARS-CoV-2.[25] Subsequent rounds of spraying caused sharp drops in filtration performance.[25] Pipette drips were not effective in eliminating *Bacillus subtilis* spores.[34]

7. Isopropanol solution

The filtering capacity of N95 masks was changed after 10 minute immersions in 100% isopropanol solution.[35] Effects on microorganisms were not evaluated.

8. Microwave oven

Six studies tested the use of microwave ovens in the disinfection of N95 masks.[20,21,23,30,31,36] The type of commercial furnace, maximum temperature, and time protocols varied between the studies (Table 3, Supplementary material 5). When masks were placed directly on the rotating plate of the microwave without protection, two commercial models of the tested masks melted.[21] When the masks were placed in containers with water[20,23,30,31] or in steam bags specifically marketed for microwave ovens[36] no residual odor was observed. In addition, there were no structural changes affecting adjustment on the face, filtration capacity, or resistance to airflow and none of the metal components melted or combusted. Microwaving the masks was effective in eliminating H5N1[20] and H1N1 influenza viruses[30] and bacteriophage MS2.[36]

9. Sodium hypochlorite (NaClO)

Six studies[21–23, 27,34,35] evaluated the use of hypochlorite at different concentrations and application methods (Table 3, Supplemental material 5). The maintenance of mask integrity and filtering capacity varied between studies. One study found that one round of disinfection drastically degraded filtration efficiency to unacceptable levels.[27] A second found that application of sodium hypochlorite discolored the metallic components of the masks and left a characteristic smell of bleach.[21] Finally, one treatment caused the release of low levels of hydrochloric gas.[22] On the other hand, two studies[23,35] reported that

the method did not affect the filtration or airflow resistance performance of the masks. Only one of the studies tested sodium hypochlorite as a disinfectant, reporting that it was effective in eliminating *Bacillus subtilis* spores.[34]

10. Autoclave

Autoclave disinfection was effective in eliminating *Bacillus subtilis* spores,[34] however, it visibly altered the structural integrity of the masks.[35]

11. Electric rice cooker

Despite showing 99–100% biocide efficacy against *Bacillus subtilis*[34] spores after using dry heat for 3minutes (149–164 °C, without adding water), the method visibly changed the structural integrity of the mask.[35]

12. Cleaning wipes

The effectiveness of commercial wipes containing 0.9% hypochlorite, benzalkonium chloride or no active antimicrobial ingredients was evaluated in masks contaminated with *Staphylococcus aureus* and mucin.[37] The three mask models withstood handling and abrasion during the disinfection process. All were successfully disinfected against atypically high microbe levels by wipes containing antimicrobial agents but the inert wipes did not produce adequate disinfection.

Discussion

Twelve decontamination methods were identified in the 17 studies[20–27,29–36] included in this review. All reports were based on laboratory tests, with ten addressing the infectious capacity of microorganisms and fifteen studying the structural integrity of the masks after the decontamination process.

The studies included in this review used different methodologies. This makes it difficult to summarize the results. This review reveals the inadequacy of the evidence supporting the use of N95 mask decontamination methods. In particular concern, if the elimination of an organism's infectious capacity has not been proven then a mask that retained its structural integrity is still a potential vehicle of transmission. This concern is reinforced by a recent study showing that pathogens may be present on the external surface of about 10% of used masks, and that the risk of infecting the user increases with prolonged use. The number of viral particles and their survival time are key determining factors when consideration of reuse becomes necessary.[38,39]

So far the evidence does not indicate a method that is consistently safe and effective to decontaminate N95 respiratory protection masks. Several of the published results are promising, in particular, hydrogen peroxide vapor, germicidal ultraviolet irradiation, dry heat ≤ 85 °C, moist heat/pasteurization, and microwaving. However, the studies are not comparable and have methodologies that will be difficult to apply globally and safely on a large scale. In particular, hydrogen peroxide vapor and ultraviolet

germicidal irradiation require specific equipment and environments; cost will be a major consideration. Dry heat, wet heat/pasteurization, and microwave ovens also showed positive results and are more accessible methods in scenarios of scarce financial resources. Studies are needed that assess the feasibility of these methods, especially by health systems in developing countries.

The disinfection protocols that used hydrogen peroxide (solution and plasma), ethylene oxide, ethanol, sodium hypochlorite, autoclaves, electric rice pots, and isopropanol solution interfered with the integrity of the masks within the test conditions used in the studies. Commercial cleaning wipes were effective antimicrobial agents and did not degrade the masks but were only evaluated by a single study and for two microorganisms.

In the case of serious emerging infections such as COVID-19 the principle of universal precaution must be considered.[15,40] The present study has limitations, given that it was carried out as a quick response in the midst of the COVID-19 pandemic and we adopted a series of methodological simplifications that may affect the findings and our interpretations. Eliminating the evaluation of the studies' methodological qualities was among the simplifications and calls for caution in interpreting the results presented. The strengths of this review, however, are the number of identified methods, the multiple approaches used to search for relevant studies, and the participation of a team of multi-disciplinary specialists in all stages of the project.

Conclusion

Health care workers on the front lines of pandemics must be guaranteed access to effective PPE. There is currently insufficient evidence to recommend any method as being safe and effective for the decontamination and reuse of respiratory protection masks. There are several promising methods worth further study. However, it is important to emphasize that all need further evaluation and validation in real-life scenarios and with consideration of economic issues of implementation.

List Of Abbreviations

COVID-19 coronavirus disease

EtO ethylene oxide

SARS-CoV-2 severe acute respiratory syndrome coronavirus 2

PPE Personal Protection Equipment

Influenza A virus subtype H5N1

Influenza virus A subtipo H1N1

NaClO sodium hypochlorite

UVGI Ultraviolet germicidal irradiation

UVA Ultraviolet A

MS2 bacteriophage

WHO World Health Organization

Declarations

Ethical Approval and Consent to participate

Not applicable

Consent for publication

Not applicable

Availability of supporting data

All data are included in the manuscript

Competing interests

The authors declare that they have no competing interests

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Authors' contributions

All authors read and approved the final manuscript

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Figures

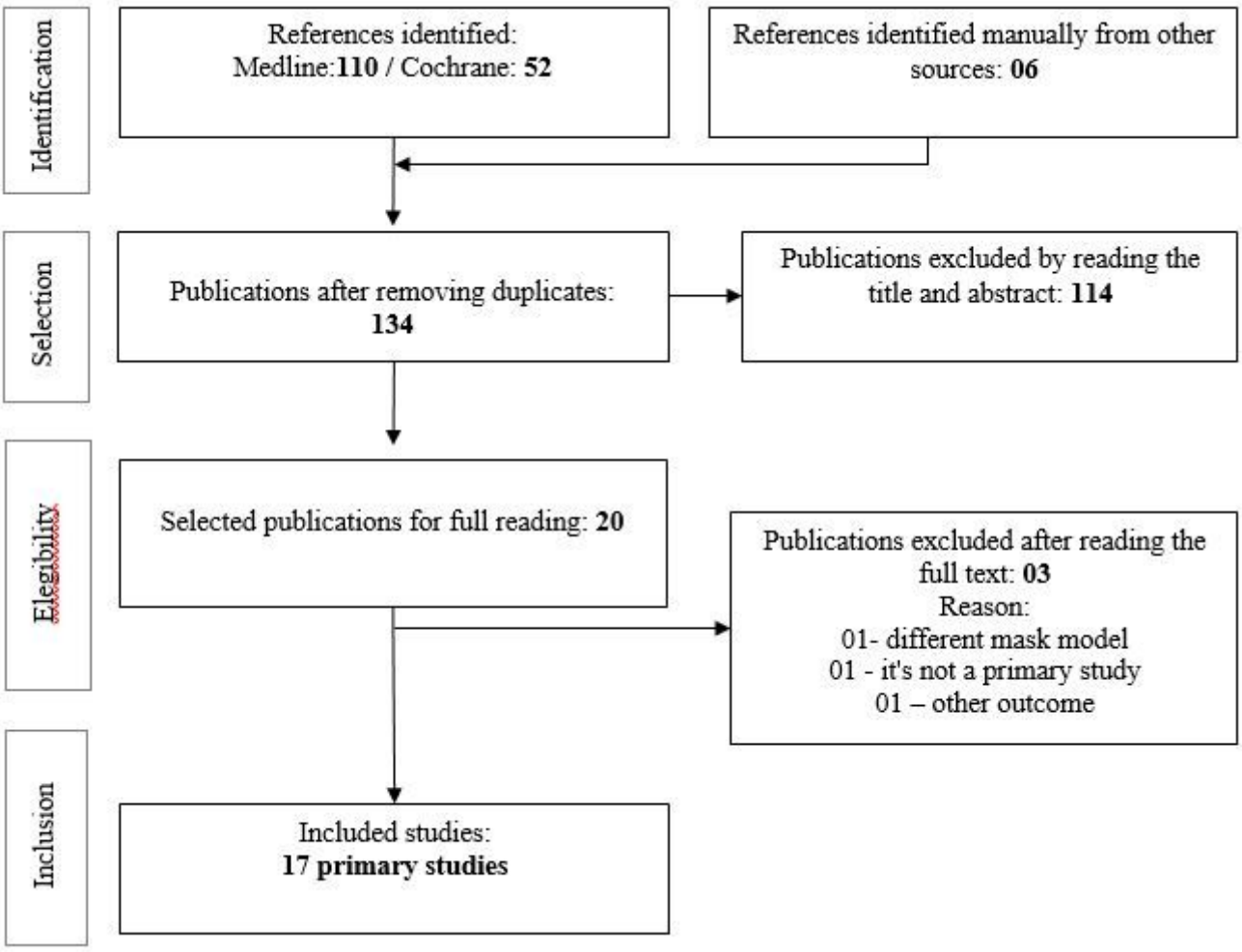

Figure 1

Flowchart of the study selection process

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