

Reusing and/or reprocessing the N95 face respirator mask or equivalent: An integrative review

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Objective: to analyze the scientific evidence available on the different reprocessing methods and the necessary conditions for reuse of the N95 face respirator mask or equivalent. **Method:** an integrative literature review. The PICO strategy was used to elaborate the question. The search was conducted in four databases: PubMed, Sci Verse Scopus, Web of Science and EMBASE, considering any period of time. **Results:** a total of 32 studies were included from the 561 studies identified, and they were presented in two categories: "Conditions for reuse" and "Reprocessing the masks". Of the evaluated research studies, seven (21.8%) addressed the reuse of the N95 face respirator mask or equivalent and 25 (78.1%) evaluated different reprocessing methods, namely: ultraviolet germicidal irradiation (14); hydrogen peroxide (8); vapor methods (14); using dry heat (5) and chemical methods (sodium hypochlorite [6], ethanol [4] and sodium chloride with sodium bicarbonate and dimethyldioxirane [1]). We emphasize that different methods were used in one same article. **Conclusion:** no evidence was found to support safe reprocessing of face respirator masks. In addition, reuse is contraindicated due to the risk of self-contamination and inadequate sealing.

Descriptors: Personal Protective Equipment; Pandemics; Coronavirus Infections; Facial Masks; Respiratory Protective Devices; Review.

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Introduction

The world faces a pandemic regarded as the biggest health problem of the 21st century. The first cases of the disease due to coronavirus 2019 (COVID-19), caused by coronavirus 2 of the Severe Acute Respiratory Syndrome (SARS-CoV-2) were reported at the end of 2019 in China⁽¹⁾. The unprecedented spread of SARS-CoV-2 led to the declaration of a pandemic by the World Health Organization in March 2020⁽²⁾. In just over a year, until June 8th, 2021, there were 173,271,769 confirmed cases worldwide, 3,733,980 deaths and 1,900,955,505 vaccine doses were administered⁽³⁾.

The Americas region experienced a rapid increase in the number of COVID-19⁽³⁾ reported cases. In Brazil, the first cases began in February 2020⁽⁴⁾. Since then, the pandemic has so advanced in the country, computing 16,947,062 confirmed cases and 473,404 deaths by June 8th, 2021⁽³⁾, becoming the third country with the highest number of cases and the second in deaths in the world⁽³⁾.

High rates of infection caused harms in the health systems around the world, collapsing many of them⁽⁵⁾. Given this global problem, protection of the health professionals engaged in combating and controlling the pandemic emerges as a core issue, as they are at high risk for infection⁽⁶⁾. The spread of COVID-19 in the health services is worrying, with health professionals representing a disproportionately high percentage of the confirmed cases⁽⁷⁾.

An epidemiological study conducted in Brazil from March to May 2020 identified 17,414 suspected cases, 5,732 confirmed cases and 134 deaths in Nursing professionals⁽⁸⁾.

Data from the Pan American Health Organization of September 2nd, 2020, indicate that approximately 570,000 health workers were infected and that 2,500 died due to COVID-19 in the Americas⁽⁹⁾.

For the safety of these professionals, it is necessary to ensure policies and best practices that minimize exposure to respiratory pathogens, including SARS-CoV-2, ensuring sufficient and good quality Personal Protective Equipment (PPE). However, the pandemic caused by SARS-CoV-2 resulted in a global shortage of PPE, including face respirator masks (FRMs)⁽¹⁰⁾. As the need for FRMs has increased on a global scale, prices and demand have significantly gone up to the point that many health institutions are unable to replenish their inventories.

In fact, with the advent of the COVID-19 pandemic, the supply of FRMs was compromised in many countries. Lack of PPE or the use of unsuitable materials for patient care has been reported by health professionals from all the Brazilian regions⁽¹¹⁾. Given this crisis, when lack of

PPE cannot be solved by reducing their use or increasing production⁽⁸⁾, the WHO has recommended measures for the rational use of PPE in the health services⁽¹²⁾.

According to this organization, the global stock of PPE is insufficient, given the global demand not only due to the number of COVID-19 cases, but also due to disinformation and panic buying and stocking, which aggravates the global shortage of PPE, especially for respiratory protective masks with a minimum particular filtration efficiency of 95%, such as the N95 type or equivalent⁽¹²⁾.

The global shortage of FRMs led the health centers around the world to extend the use of these masks, although they were designed for single use⁽¹³⁾. In addition, the persistence and infectiousness of the infectious agents in the FRMs, such as the pandemic influenza A virus (H1N1)⁽¹⁴⁾, other coronaviruses⁽¹⁵⁾ and more recently SARS-CoV-2, show the importance of developing guidelines and protocols related to decontamination of this PPE and stress the importance of proper handling of personal protective equipment during and after use in high-risk environments to minimize the probability of transmission by fomite⁽¹⁶⁾.

While there is no recommendation for reprocessing and reusing FRMs, such as N95 or equivalent, as a routine standard of conventional care, these measures may be needed during periods of scarcity to ensure continuous availability during a pandemic. However, it is noted that, for reprocessing FRMs, it is fundamental that the method is effective and able to reduce the load of pathogens, that it preserves the function of the face mask, and that it does not present any residual chemical risk⁽¹⁷⁾.

In Brazil, and in the face of the COVID-19 pandemic, the National Health Surveillance Agency (*Agência Nacional de Vigilância Sanitária*, ANVISA) recommends that the health institutions are to establish their protocols on the use of PPE based on the exposure risks (for example: type of activity) and on the dynamics of pathogen transmission (for example: contact, droplet or aerosol). As for the N95 or equivalent masks, ANVISA has instructed the health professionals to use them for a longer period of time than that indicated by the manufacturers, as long as the mask is intact, clean and dry; and it points out that such an indication is required, as many professionals are reporting low inventories to treat critically-ill patients in the Intensive Care Unit⁽¹⁸⁾.

The search for solutions to meet the challenge of scarcity of FRMs is urgent⁽¹⁹⁾. In the literature, there is a variety of potential disinfection methods for FRMs, such as: (1) energy methods (for example: dry and moist ultraviolet heat and microwave-generated vapor) or (2) chemical methods (for example: alcohol, ethylene oxide, bleach and vaporized hydrogen peroxide)⁽²⁰⁻²¹⁾ and some methods, such as ultraviolet germicidal irradiation,

hydrogen peroxide vapor and moist heat, have been regarded as promising⁽¹⁷⁾, while others such as alcohol and ultraviolet light cause functional degradation in different degrees in the FRMs⁽²⁰⁾.

Given this context, the need is evidenced for a comprehensive literature review to identify the evidence on the safe methods for reprocessing and evidence that support or not reuse of N95 or equivalent masks.

Objective

To analyze the scientific evidence available on the different reprocessing methods and the necessary conditions for reuse of N95 face respirator masks or equivalent.

Method

Type of study

An integrative literature review developed in accordance with the following stages: selection of the review question; sampling (search for studies according to the inclusion and exclusion criteria); extraction of the characteristics of the primary research studies (data extraction); data analysis; interpretation of the results; and review report⁽²²⁾.

In addition, the recommendations of the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses* (PRISM)⁽²³⁾ were followed. Registration on the *Fig Email* platform was made, with DOI: <https://doi.org/10.6084/m9.figshare.14515251>.

The PICO strategy⁽²⁴⁾ was used to outline the guiding question, where: P (Patient/Population): N95 face respirator mask or equivalent, I (Intervention): reuse or reprocessing of N95 face respirator masks or equivalent, C (Comparison): Not applicable, O (Outcomes): Necessary conditions for reuse and reprocessing methods indicated for the N95 mask or equivalent, giving rise to the following guiding question: Which is the scientific evidence available on the different reprocessing methods and the necessary conditions for reusing N95 face respirator masks or equivalent?

Selection criteria

The criterion for inclusion and selection of the studies was based on research studies that used some method to reuse and/or reprocess N95 face respirator masks or equivalent. There was no language restriction. The reprocessing techniques do not necessarily need to test the SARS-CoV-2 microorganism to be a potential method for reprocessing masks. It was for this reason that we decided not to limit the time for the search and not to restrict the search only to tests with SARS-CoV-2.

Data collection

The search for the studies occurred by peers in June 2020, in the PubMed (US National Library of Medicine), Scopus, Web of Science and EMBASE databases by using controlled descriptors and keywords with the aid of boolean operators AND and OR. The search strategy used for all databases was [("Respiratory Protective Devices" OR "N95 respirator" OR "N95 mask" OR "filtering facepiece respirator" OR "FFP2" OR "PPE") AND ("reprocessing" OR "reuse" OR "decontamination" OR "disinfection" OR "sterilization")].

The search results were inserted into the Ayres web application for selecting the studies. Two researchers read the titles and abstracts and selected the articles. Disagreements related to selection were resolved by a third reviewer. Subsequently, full-reading of the articles selected in the first stage was also carried out by two reviewers. A third reviewer assessed the disagreements of the articles included. Consensus meetings were held in two stages.

For evaluating the evidence level of the studies, the methodological design of each of them was considered and, as all the descriptive studies addressed clinical issues on intervention/treatment or diagnosis/diagnostic test, the classification used was that of seven levels, as follows: Level I - Evidence from systematic reviews or meta-analyses of multiple controlled clinical and randomized studies; Level II - Evidence from at least one well-designed randomized controlled clinical trial; Level III - Evidence from well-designed non-randomized clinical trials; Level IV - Evidence from well-designed cohort and case-control studies; Level V - Evidence from systematic reviews using descriptive and qualitative methodologies; Level VI - Evidence from only one descriptive or qualitative study; Level VII - Evidence from concepts of authorities and/or expert committees' reports⁽²⁵⁾.

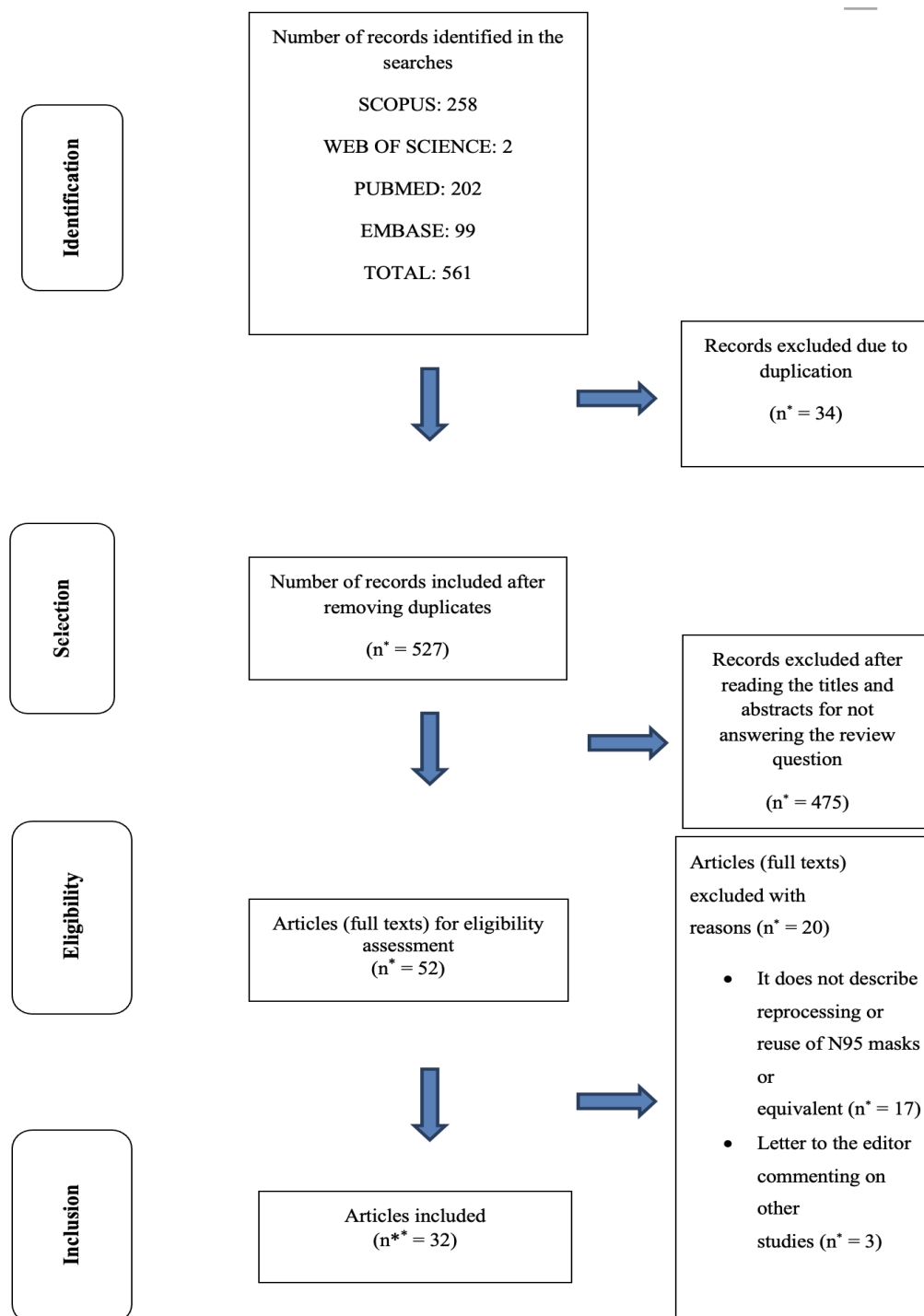
Data extraction

The articles involved in the analysis had their information extracted with the aid of a proposed roadmap⁽²⁶⁾, determining the main data to be extracted. In this study, the following information was extracted: title; year of publication; reuse/reprocessing; method employed in reprocessing; authors' recommendations and level of evidence of the studies.

Data synthesis was descriptive. The reuse and reprocessing conditions identified were analyzed, grouped and compared. In this stage, two independent reviewers were responsible for extracting, analyzing and synthesizing the information.

Results

Selection of the studies followed the PRISMA⁽²³⁾ recommendations (Figure 1).



*n = number of articles

Figure 1 - Diagram corresponding to the search and selection of the studies according to PRISMA⁽²³⁾

A total of 32 studies that evaluated reuse and reprocessing of N95 respirator masks or equivalent were included, with most of the studies being conducted in the United States (26 = 81.3%). The level of evidence was mostly VI (25 = 78.1%). As for the language of the

articles, 31 (96.9%) were in English. Figure 2 shows the characteristics of the studies according to the authors, year of publication/country, method employed in reprocessing, study type and level of evidence.

Authors	REPROCESSING			
	Year/ Country	Method employed	Type of study	Level of evidence
Viscusi, et al. ⁽²⁷⁾	2009/ United States	Ultraviolet germicidal irradiation: Sterilgard III laminar flow cabinet equipped with UV-C [†] light. Fifteen-minute exposure to either side (external and internal) 176-181 mJ/cm ² for each side of the FRMs [†] ; Ethylene oxide: Steri-Vac 5XL - exposure to ethylene oxide for 1 hour followed by 4 hours of aeration; hydrogen peroxide vapor: STERRAD [®] 100S; irradiation for microwave oven - 2 minutes of total exposure (1 minute on each side of the FRMs [†]) and bleach: thirty minutes of immersion in 0.6% sodium hypochlorite aqueous solution.	Descriptive study	VI
Bergman, et al. ⁽²⁸⁾	2010/ United States	Ultraviolet germicidal irradiation: Bench Lamp (UV-C [†] , 254 nanometer, 40 W). 45 minutes of exposure and intensity of 1.8 mW/cm ² ; ethylene oxide: Amsco [®] Eagle [®] 3017 (STERIS Corp.) 1 hour of exposure to ethylene oxide (736.4 milligrams per liter), followed by 12 hours of aeration; plasma gas with hydrogen peroxide: STERRAD [®] 100S; hydrogen peroxide vapor; microwave-generated vapor; sodium hypochlorite; liquid hydrogen peroxide and incubation by moist heat (pasteurization). Four-hour immersion of Filtering Facepiece Respirator (FFR [†]) in deionized water was performed three times for comparison purposes (control).	Case-control study.	IV
Rengasamy, Fisher, Shaffer ⁽²⁹⁾	2010/ United States	In the first set of experiments, circular samples of approximately 5 cm of the masks were removed and stored at 22°C [§] and 30% relative humidity and virus particles were retrieved at 0, 8 and 20 hours. A second set of samples was stored at 37°C [§] and 80% HR for 0, 2 and 4 hours.	Descriptive study	VI
Salter, et al. ⁽³⁰⁾	2010/ United States	3% hydrogen peroxide; 0.6% sodium hypochlorite; Mixed oxidants: 10% oxone, 6% sodium chloride and 5% sodium bicarbonate solution; Dimethyldioxirane: 10% oxone, 10% acetone, 5% sodium bicarbonate; Ethylene oxide: AmscoEagle 3017; Hydrogen peroxide vapor: STERRAD [®] 100S; UV light.	Descriptive study	VI
Heimbuch, et al. ⁽³¹⁾	2010/ United States	Six models of commercially-available FRMs [†] were infected with the H1N1 influenza virus in aerosols or droplets that are representative of human respiratory secretions. A subset of FRMs [†] was decontaminated using microwave-generated vapor: 1250 W, by moist heat: 65°C [§] and by ultraviolet germicidal irradiation (254 nm): 1.6-2.0 mW/cm ² .	Descriptive study	VI
Fisher, Shaffer ⁽³²⁾	2010/ United States	Decontamination by ultraviolet-C light (UVC [†] , 254 nanometers). The model-specific exposure times to achieve this dose varied from 2 to 266 minutes.	Descriptive study	VI
Fisher, Williams, Shaffer ⁽³³⁾	2011/ United States	The FRMs [†] were decontaminated with microwave-generated vapor, following the manufacturer's instructions and then evaluated for water filtration and absorption efficiency in up to three exposures to vapor.	Descriptive study	VI
Viscusi, et al. ⁽³⁴⁾	2011/ United States	Ultraviolet germicidal irradiation, incubation by moist heat or decontamination using microwave-generated vapor. The participants' subjective evaluations about the odor, comfort and ease of wearing an FRM [†] were captured using a visual analog scale research.	Descriptive study	VI
Lore, et al. ⁽³⁵⁾	2012/ United States	Ultraviolet germicidal irradiation: a lamp was placed in a laminar flow cabinet; the wavelength of the UV-C [†] lamp varied from 1.6 mW cm ² to 2.2 mW cm ² ; microwave-generated vapor: 1,250 W (2,450 MHz) with 2-minute irradiation at full power and moist heat: a 6l (19 x 19 x 17 centimeters) sealable container was filled with 1 liter of tap water, placed in an oven and heated to 65 ± °C [§] for 3 hours. The FRM [†] was treated in the oven for 20 minutes.	Descriptive study	VI
Heimbuch, et al. ⁽³⁶⁾	2014/ United States	Three FRM [†] models were contaminated with mucin aerosols or viable <i>Staphylococcus aureus</i> and then cleaned with hypochlorite, benzalkonium chloride or antimicrobial towels. After cleaning, the FRMs [†] were separated into components (nasal cushion, fabrics and strips) and the contaminants were extracted and quantified. Filtration performance was evaluated when the FRMs [†] were clean.	Descriptive study	VI
Lindsley, et al. ⁽³⁷⁾	2015/ United States	Four N95 FRM [†] models were decontaminated with UV doses of 120-950 J/cm. Subsequently, particle penetration was tested, as well as flow resistance, the breaking forces of the individual layers of the FRM [†] and the breaking force of the straps of these masks.	Descriptive study.	VI
Lin, et al. ⁽³⁸⁾	2017/ China	Physical decontamination using a traditional rice cooker made in Taiwan to provide dry heat; physical decontamination using an autoclave to provide moist heat; chemical decontamination using low temperature ethanol; chemical decontamination using low temperature ethanol and isopropanol; and low temperature chemical decontamination using ethanol and bleach.	Descriptive study	VI
Lin, et al. ⁽³⁹⁾	2018/ China	Ethanol at several concentrations and volumes was added to the center of the N95 mask surface; bleach: a volume of 0.4 ml of chlorine-based bleach with several concentrations; UV-C [†] : an N95 mask was placed 10 cm below a hand-held UV-C [†] with a 6 W lamp emitting a wavelength of 254 nm or 365 nm. Both sides of the N95 were exposed at different times - 1, 2, 5, 10 and 20 minutes; Autoclave: The N95 was heated for 15 minutes at 121°C [§] ; Traditional electric rice cooker: The N95 was placed in an electric rice cooker to be heated for 3 minutes (149-164°C [§] , without adding water).	Descriptive study	VI
Mills, et al. ⁽⁴⁰⁾	2018/ United States	The facepiece and the handle of the N95 mask were covered with a staining agent: artificial saliva or artificial oil skin. For each staining agent, three masks were contaminated and treated with 1 J/cm ² of ultraviolet germicidal irradiation for approximately 1 minute.	Descriptive study	VI
Cadnum, et al. ⁽⁴¹⁾	2020/ United States	Three methods: UV-C light (UV-C [†]), a high-level disinfection cabinet which generates peracetic acid and hydrogen peroxide aerosol and dry heat at 70°C [§] for 30 minutes.	Descriptive study	VI
Grossman, et al. ⁽⁴²⁾	2020/ United States	Disinfection with hydrogen peroxide vapor. A closed and sealed room with hydrogen peroxide vapor. The Bioquell Z-2 disinfection cycle is started (the initial settings are 20°C [§] , 40% relative humidity and 10 grams per volume unit of hydrogen peroxide, Bioquell), lasting 4.5 hours to reach at least 700 parts per million of hydrogen peroxide vapor.	Descriptive study	VI

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REPROCESSING				
Authors	Year/ Country	Method employed	Type of study	Level of evidence
Xiang, Qifa, Gu ⁽⁴³⁾	2020/ China	Dry heat was applied at 60°C [§] and 70°C [§] for 1 hour on the used masks. Subsequently, decontamination extent was evaluated by the sterility testing for 7 pathogenic bacteria. Fit and filtration efficiency tests were also carried out using bacteria in aerosols for the masks that had been decontaminated.	Descriptive study	VI
Perkins, et al. ⁽⁴⁴⁾	2020/ United States	Hydrogen peroxide vapor.	Descriptive study.	VI
Fischer, et al. ⁽⁴⁵⁾	2020/ United States	Ultraviolet light (260-285 nm), dry heat at 70°C [§] , 70% ethanol and hydrogen peroxide vapor.	Descriptive study	VI
Schwartz, et al. ⁽⁴⁶⁾	2020/ United States	The N95 masks were arranged in racks and exposed to hydrogen peroxide vapor with a level of 480 parts <i>per</i> million with a "gassing" time of 25 minutes and a dwell time of 20 minutes.	Descriptive study	VI
Ozog ⁽⁴⁷⁾	2020/ United States	The internal and external surfaces of the N95 mask were irradiated by <i>Daavlin Desktop</i> - Germicidal ultraviolet irradiation at a dose of 1.5 J/cm ² for each side.	Descriptive study	VI
Boop, et al. ⁽⁴⁸⁾	2020/ United States	Exposures in 115°C [§] autoclave for 60 minutes or 121°C [§] for 30 minutes.	Descriptive study	VI
Li, et al. ⁽⁴⁹⁾	2020/ United States	Vapor rice cooker, including 8 to 10 minutes of heating and 5 minutes of vapor <i>versus</i> dry heat at 100°C [§] for 15 minutes in a decontamination oven.	Descriptive study	VI
Carrillo, et al. ⁽⁵⁰⁾	2020/ United States	Decontamination with immediate-use vapor, using <i>SterisAmsco</i> . The masks were packaged in plastic-paper packaging compatible with the equipment used.	Descriptive study	VI
Liao, et al. ⁽⁵¹⁾	2020/ United States	Ethanol (75%) – immersion and dry air until dry; chlorine-based solution (2%) – spray and dry air; dry heat (75°C [§]) – static air oven; vapor – boiling water cup; ultraviolet germicidal irradiation (254 nm, 8 W) – decontamination cabinet.	Descriptive study	VI

*Face Respiratory Mask; [†]UV-C; [‡]Filtering Facepiece Respirator; [§]Degrees Celsius; ^{||}MS2 Bacteriophage

Figure 2 - Description of the studies regarding authors, year of publication, country, method employed in reprocessing, study type and level of evidence. Ribeirão Preto, SP, Brazil, 2020

Figure 3 lists the data of the authors, year of publication/country, data on reuse, type of study and level of evidence.

REUSE				
Authors	Year/Country	Data on reuse	Type of study	Level of evidence
Duarte, et al. ⁽⁵²⁾	2010/ Brazil	Standardized observations were made on the conditions of the PFF-2 type FRMs [*] collected after being used by nursing assistants after five, 15 or 30 consecutive days of use.	Descriptive study	VI
Sakaguchi, et al. ⁽⁵³⁾	2010/Japan	The influenza A virus (0.5 milliliters) was deposited on the surface of a rubber glove, a mask with an N95 filter, a surgical mask made of non-woven fabric, an apron made of <i>Tyvek</i> , a coated wooden table and a stainless steel table. Each sample was left for 1.8 to 24 hours. Hemagglutination and infectious dose were measured.	Descriptive study	VI
Roberge, et al. ⁽⁵⁴⁾	2012/ United States	Three N95 models were tested for placing and removal for 15 minutes and wear out was evaluated.	Descriptive study	VI
Bergman, et al. ⁽⁵⁵⁾	2012/ United States	Consecutive placements were made and the fit factor was evaluated.	Descriptive study	VI
Fisher, et al. ⁽⁵⁶⁾	2012/ United States	The FRMs [*] were infected using bacteriophages as a substitute for pathogenic viruses in the air. Bacteriophages were applied to the masks as droplets or droplet nuclei. The concentration of the bacteriophages applied on the mask was 10 ⁴ or 10 ⁵ colony-forming units <i>per</i> cm ² . They were performed to quantify the total number of suspended virus on the mask during cough simulation.	Descriptive study	VI
Brady, et al. ⁽⁵⁷⁾	2017/ United States	The N95 masks were sprayed five times in approximately 10 seconds with spray containing 100 milliliters suspension of MS2 . The masks were placed in an exhauster to dry for 1 hour. After they have been dried, the masks were sealed in plastic bags and stored at 4°C [§] for the night. Four masks were contaminated for each subject. Three of the four masks were used to simulate usage scenarios and the fourth mask was used to determine viral load.	Descriptive study	VI
Suen, et al. ⁽⁵⁸⁾	2020/ Hong Kong	One hundred and four Nursing students participated and performed Nursing procedures for 10 minutes when using FRMs [*] . Mask fit and the perceived usability of the FRMs [*] were evaluated.	Descriptive study	VI

*Respirator Face Mask; [§]Degrees Celsius; ^{||}MS2 Bacteriophage

Figure 3 - Description of the studies regarding authors, year of publication/country, reuse on data, type of study and level of evidence. Ribeirão Preto, SP, Brazil, 2020

Descriptions of the studies regarding authors, objectives, type of mask, reprocessing method, type and size of the microorganisms, efficacy of each type of reprocessing, effect of reprocessing on the structure of the masks and chemical risk were presented, as shown in Figure 4.

REPROCESSING							
Author/ Year	Objective	Type of mask	Reprocessing method	Types and sizes of the microorganisms tested	Efficacy of each type of reprocessing for decontamination of the FRMs	Effect of reprocessing on the tissue structure of the FRMs	Chemical risk
Viscusi, et al. ⁽²⁷⁾ /2009	To evaluate five decontamination methods using nine FRM ^o models to determine which must be considered for future research studies.	Nine mask models were tested, six FRMs ^o [three models: N95 FFR ^o (N95-A, N95-B and N95-C) and three N95 surgical respirators (SN95 ^o -D, SN95 ^o -E and SN95 ^o -F)].	Irradiation in microwave oven; ultraviolet germicidal irradiation; ethylene oxide; hydrogen peroxide vapor; chlorine-based bleach.	Not applicable.	Not tested.	Irradiation in microwave oven melted samples of two FRM ^o models. Three FRM ^o tested samples showed penetrations of filter aerosols >5%. The rest of the FRM ^o samples that were decontaminated had expected levels of filtration and resistance to the air flow of the filter.	The noticeable bleach smell remained after drying and chlorine gas levels also remained. Ultraviolet germicidal irradiation, ethylene oxide and hydrogen peroxide vapor were the most promising decontamination methods; however, concerns remain about the residues left after decontamination.
Bergman, et al. ⁽²⁸⁾ /2010	To investigate processing by means of eight different methods.	Nine mask models were tested, six FRMs ^o [three models: N95 FFR ^o (N95-A, N95-B and N95-C) and three N95 surgical respirators (SN95 ^o -D, SN95 ^o -E and SN95 ^o -F)].	Ultraviolet germicidal irradiation; ethylene oxide; plasma gas with hydrogen peroxide; STERRAD [®] 100S; hydrogen peroxide vapor; microwave-generated vapor; sodium hypochlorite; liquid hydrogen peroxide and incubation by moist heat.	Not applicable.	Not tested.	Only gas plasma with hydrogen peroxide resulted in mean penetration levels >5% for four of the six FRM ^o models. The FRMs ^o that were treated by other methods had penetration levels of the filter aerosol (<5%) and resistance to the air flow of the filter. Hydrochloride damaged the mask's structures. Decontamination by ultraviolet light was the only method that did not cause observable physical changes in the FRMs ^o .	Hypochlorite left residual odor.
Salter, et al. ⁽³⁰⁾ /2010	To measure the amount of residual chemicals created or deposited in six FRM ^o models after treatment by each of the 7 simple decontamination technologies.	N95 FRMs ^o and surgical respirators.	Hydrogen peroxide; sodium hypochlorite; mixed oxidants: oxone, sodium bicarbonate and sodium chloride; dimethyldioxirane: oxone, acetone, sodium bicarbonate; ethylene oxide; hydrogen peroxide vapor; UV light.	Not applicable.	Not tested.	Bleach, mixed oxidants and dimethyldioxirane corroded the metal parts of the FRMs ^o .	The data from this study show that none of these methods, except for ethylene oxide, deposit significant amounts of toxic waste on the FRMs ^o . All FRMs ^o treated with bleach, mixed oxidants and dimethyldioxirane remained with odors.

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REPROCESSING							
Author/ Year	Objective	Type of mask	Reprocessing method	Types and sizes of the microorganisms tested	Efficacy of each type of reprocessing for decontamination of the FRMs	Effect of reprocessing on the tissue structure of the FRMs	Chemical risk
Heimbuch, et al. ^{(31)/} 2010	To evaluate the ability of microwave- generated vapor, moist heat and ultraviolet germicidal irradiation at 254 nm to decontaminate the influenza H1N1 ^s virus.	Six FRM [®] models.	Microwave- generated vapor; moist heat and ultraviolet germicidal irradiation.	H1N1 ^s virus. The H1N1 ^s virus was diluted in 30 ml of buffer solution. Concentration was 8 log ₁₀ . Using an infectious dose assay of tissue culture - 50/ml.	All methods provided reduction >4 log of the H1N1 ^s virus. In 93% of the masks, the virus was reduced to levels below the detection limit of the method used.	Not evaluated.	Not evaluated.
Fisher, Shaffer ^{(32)/} 2010	To develop a method to evaluate decontamination parameters for FRMs [®] by ultraviolet-C light.	Cardinal N95-ML model; Wilson SAF-T-FIT Plus model; 3M 8210; 3M 1860; 3M 1870, and Kimberly-Clark PFR95-174.	Decontamination by ultraviolet-C light.	Aerosolized particles containing MS2 ^{ll} .	The information presented in this study provides an effective method for calculating UV doses for decontamination of the FRMs [®] .	Not applicable.	Not applicable.
Fisher, Williams, Shaffer ^{(33)/} 2011	To evaluate the use of two vapor bags for decontamination of FRMs [®] .	3M 1860; 3M 8210; Cardinal Health N95; 3M 1870; Kimberly- Clark PFR95, and Moldex 2200.	Vapor bags for decontamination.	MS2 ^{ll} virus. Initial titre from 10 ⁷ and 10 ¹⁰ by mask.	The tested vapor bags showed 99.9% efficacy in inactivation of the bacteriophage for decontamination of FRMs [®] .	Vapor had little effect on the performance of the FRMs [®] , since filtration efficiency remained above 95%.	Not applicable.
Viscusi, et al. ^{(34)/} 2011	To determine whether ultraviolet germicidal irradiation, incubation by moist heat or decontamination by microwave- generated vapor affect the characteristics of fit, odor, comfort or ease of use of the FRMs [®] .	3M 8000; 3M 8210; Moldex 2200; 3M 1860; 3M 1870; Kimberly-Clark PFR95-270.	Ultraviolet germicidal irradiation; moist heat; microwave- generated vapor.	Not applicable.	Not performed.	Two of the six FRMs [®] showed a statistically significant reduction in fit after incubation decontamination by moist heat. However, for these two FRM [®] models, the mean factors for post- decontamination fit were still ≥100.	One of the masks showed a relatively small increase, although statistically significant, in response to odor after incubation decontamination by moist heat.
Lore, et al. ^{(35)/} 2012	To assess the virulence capacity of three energy decontamination methods: ultraviolet germicidal irradiation, microwave- generated vapor and moist heat.	Conventional N95; N95; P100; FRM [®] with exhalation valve; FRM [®] treated with iodine-based antimicrobial.	Ultraviolet germicidal irradiation; microwave- generated vapor and moist heat.	MS2 ^{ll} bacteriophage virus; <i>Bacillus</i> <i>atrophaeus</i> vegetative bacteria and <i>B. atrophaeus</i> spores.	The three decontamination methods were effective, reducing virus load by more than 4 log. Ultraviolet germicidal irradiation resulted in lower levels of detectable viral RNA in the other two methods.	No profound reduction in the filtration of the masks was identified. Sealing and fit of the masks were not tested.	Not performed.

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REPROCESSING							
Author/ Year	Objective	Type of mask	Reprocessing method	Types and sizes of the microorganisms tested	Efficacy of each type of reprocessing for decontamination of the FRMs	Effect of reprocessing on the tissue structure of the FRMs	Chemical risk
Heimbuch, et al. ⁽³⁶⁾ / 2014	To evaluate the capacity of the cleaning products available in the market to clean FRMs contaminated by infectious or non-infectious agents	3M 1860; 3M 1870; Kimberly-Clark PFR.	Hypochlorite; benzalkonium chloride or antimicrobial towels.	<i>Staphylococcus aureus</i> was inoculated in a soy agar plate and there was dilution in an artificial saliva buffer.	Mucin removal was less than 1 log for all the cleaning products in all the components. Inert wipes achieved an attenuation of approximately 1 log to viable <i>S. aureus</i> in the tissues of all the FRM models: removal was less effective from the nasal pads and edges. Both antimicrobial wipes achieved a 3-5 log attenuation in most of the components, with minor reductions in the nasal pads and greater reductions in the straps.	Particle penetration after cleaning yielded mean values <5%. Hypochlorite generated oxidation on the masks.	Hypochlorite created odor-related problems.
Lindsley, et al. ⁽³⁷⁾ /2015	To study the effects of ultraviolet germicidal irradiation in filtration performance and structural integrity of N95 FRMs.	3M 1860; 3M 9210; GE 1730; KC 46727; Kimberly-Clark.	Ultraviolet germicidal irradiation.	Not applicable.	Not performed.	Exposure to ultraviolet light led to a small increase in particle penetration (up to 1.25%) and had little effect on flow resistance. At higher ultraviolet doses, the strength of the material layers of the FRMs was substantially reduced (in some cases >90%). The maximum number of disinfection cycles will be limited by the mask model and the UV dose required to inactivate the pathogen.	Not performed.
Lin, et al. ⁽³⁸⁾ / 2017	To investigate the effects of five decontamination methods in filter quality of three FRMs available in the market: N95, Gauze and Spunlace masks.	N95, Gauze and Spunlace.	Traditional rice cooker to provide dry heat; Autoclave to provide moist heat; Ethanol; Ethanol with isopropanol; and Ethanol with bleach.	Not applicable.	Not performed.	Decontamination increased the pressure drop, except for the N95 and Gaze masks that were decontaminated using an autoclave. Decontamination reduced filter quality, except when using an autoclave or rice cooker, but this process created observable folds in the masks.	Not performed.

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REPROCESSING							
Author/ Year	Objective	Type of mask	Reprocessing method	Types and sizes of the microorganisms tested	Efficacy of each type of reprocessing for decontamination of the FRMs	Effect of reprocessing on the tissue structure of the FRMs	Chemical risk
Lin, et al. ⁽³⁹⁾ / 2018	To determine the relative survival of <i>Bacillus subtilis</i> spores in FRMs' after five decontamination methods.	N95 (8210, 3M).	Ethanol; chlorine- based bleach with several concentrations; UV-C; autoclave; traditional electric rice cooker.	<i>Bacillus subtilis</i> spores.	The relative survival of <i>Bacillus subtilis</i> dropped to 20% with 80% ethanol. No colony was retrieved at all concentrations of bleach and UV-C for 5 minutes. Relative survival remained above 20% after 20 minutes of irradiation by ultraviolet-A light. The traditional electric rice cooker showed efficacy in 3 minutes.	Not performed.	Not performed.
Mills, et al. ⁽⁴⁰⁾ /2018	To evaluate decontamination efficiency by ultraviolet germicidal irradiation of FRM', contaminated by influenza in the presence of dirt.	15 models were used, as follows: N95 FFR'; 3M 1860, 3M 1870, 3M VFlex 1805, Alpha Protech695, Gerson 1730, Kimberly- Clark PFR, Moldex 1512, Moldex 1712, Moldex EZ-22, Preceito 65-3395, Prestige Ameritech RP88020, Sperian HC-NB095, Sperian HC-NB295F, USA Safety AD2N95A, and USA Safety AD4N95.	Ultraviolet germicidal irradiation.	Influenza H1N1 [®] A/ PR/8/34 (VR-1469; American Type Culture Collection, Manassas, VA)	Significant reductions in the viability of the influenza virus in both conditions of dirt were observed in the facial pieces of 12 of the 15 tested models and, in relation to the straps, in 7 of the 15 models. These data suggest that decontaminating and reusing the N95 mask with ultraviolet germicidal irradiation can be effective. However, there should be careful consideration on the mask model, type, and material.	Not evaluated.	Not evaluated.
Cadnum, et al. ⁽⁴¹⁾ /2020	To examine the effectiveness of ultraviolet-C light, and a high-level disinfection cabinet for the decontamination of FRMs' with N95 filters.	3M 1860S, Moldex 1517 and Kimberly- Clark 46727.	Ultraviolet-C light; high-level disinfection cabinet that generates aerosolized peracetic acid and hydrogen peroxide and dry heat at 70°C [¶] for 30 minutes.	Phi6 and MS2 [¶] bacteriophages and methicillin-resistant <i>Staphylococcus</i> <i>aureus</i>	Administration of ultraviolet-C light reduced contamination, but did not meet the criteria for decontamination in all places of the FRMs'. The high- level disinfection cabinet was effective in a long decontamination cycle of 31 minutes. Dry heat at 70°C [¶] for 30 minutes was not effective in decontaminating the bacteriophages.	No visible change was observed in any of the respirators after 3 or more treatment cycles with the decontamination cabinet of the ultraviolet-C room or with the ultraviolet-C light box.	Not evaluated.
Grossman, et al. ⁽⁴²⁾ / 2020	To present a process created for disinfecting FRMs' with N95 filters using hydrogen peroxide vapor.	Not applicable.	Vaporized hydrogen peroxide.	Not applicable.	Placing the Tyvek bag in a flat instead of in a standing position reduced the number of FRMs' that could be decontaminated during each cycle, but this change led to higher disinfection quality.	Some FRMs' subjected to one or more hydrogen peroxide vapor cycles successfully passed the quantitative fit test.	Not applicable.

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REPROCESSING							
Author/ Year	Objective	Type of mask	Reprocessing method	Types and sizes of the microorganisms tested	Efficacy of each type of reprocessing for decontamination of the FRMs	Effect of reprocessing on the tissue structure of the FRMs	Chemical risk
Xiang, Qifa, Gu ⁽⁴³⁾ /2020	To optimize the pasteurization temperature by dry heat for efficient decontamination of FRMs [*] .	Not specified.	Pasteurization by dry heat for one hour at 70°C [†] .	<i>Escherichia coli</i> , <i>Staphylococcus aureus</i> , <i>Pseudomonas aeruginosa</i> , <i>Klebsiella pneumoniae</i> , <i>Acinetobacter baumannii</i> , <i>Corynebacterium pseudodiphtheria</i> and <i>Candida albicans</i> , and H1N1 [§] as indicating virus.	Dry heat at 60°C [†] and 70°C [†] for 1 hour was able to successfully kill 6 species of respiratory bacterial and one fungal species, in addition to inactivating the H1N1 [§] indicating virus.	After being heated at 70°C [†] for 1, 2 and 3 hours, the N95 respirators and the surgical face masks did not present changes in their shape and components. The filtration efficiency of the FRMs [*] was 98%, 98% and 97% after being heated for 1, 2 and 3 hours, respectively. The filtration efficiency of surgical face masks was 97%, 97% and 96% for 1, 2 and 3 hours of heating, respectively.	Not applicable.
Perkins, et al. ⁽⁴⁴⁾ /2020	To describe the development of a process to select and implement the use of hydrogen peroxide vapor as a viable method for reprocessing FRMs [*] with N95 filters.	3M 1860 and 1870 N95s.	Hydrogen peroxide vapor.	Not applicable.	The instrument employed in the room was a Bioquell Clarus hydrogen vapor-generator using a 30% hydrogen peroxide solution. The hydrogen peroxide vapor generator has the following phases: Conditioning (10 min), Pre-gassing, Gasification (83 minutes) Gas cooling (36 minutes) and Aeration.	Not evaluated.	A PortaSens III hydrogen peroxide sensor is used to ensure that the hydrogen peroxide vapor in the room is below 1.0 parts per million before the staff enters the room.
Fischer, et al. ⁽⁴⁵⁾ /2020	To analyze four decontamination methods regarding their effectiveness to inactivate coronavirus-2 of the Severe Acute Respiratory Syndrome and the effect on filtration performance of the FRMs [*] .	Not specified.	Ultraviolet light, dry heat at 70°C [†] , 70% ethanol and hydrogen peroxide vapor.	SARS-CoV-2 [™] .	FRMs [*] can be decontaminated and reused up to three times using UV light and hydrogen peroxide vapor. They can be disinfected 1-2 times using dry heat. Treatment with hydrogen peroxide vapor had the best combination of fast inactivation for SARS-CoV-2 [™] and preserves the integrity of the FRMs [*] under the experimental conditions.	Quantitative fit testing showed that filtration performance of the FRMs [*] was not significantly reduced after a single decontamination instance of any of the four decontamination methods.	Not evaluated.
Schwartz, et al. ⁽⁴⁶⁾ /2020	To evaluate the potential applicability of hydrogen peroxide vapor for processing FRMs [*] with N95 filters.	3M (St. Paul, MN, United States) 1860 N95s.	Hydrogen peroxide vapor.	Not applicable.	There was no microbiological evaluation.	A quantitative fit test was performed to ensure their continued performance, and they were tested in 2 subjects with different face structures without fit or seal loss.	In approximately 4 hours, the hydrogen peroxide levels were reduced below the detection level (0 parts per million).

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REPROCESSING							
Author/ Year	Objective	Type of mask	Reprocessing method	Types and sizes of the microorganisms tested	Efficacy of each type of reprocessing for decontamination of the FRMs	Effect of reprocessing on the tissue structure of the FRMs	Chemical risk
Ozog ⁽⁴⁷⁾ / 2020	To verify the fit of the FRMs' after processing with ultraviolet germicidal irradiation.	3M N95 1860, 3M N95 9210, 3M N95 8210, N95 R/S Respirator from Cardinal Health USA, Moldex N95 2300N95 Respirator, Moldex N95 1511 Respirator, Moldex N95 1512 Respirator, 3M N95 9010 Respirator, N95A-S Respirator from Cardinal Health United States, GB2626-2206 KN95 Respirator.	Ultraviolet germicidal irradiation.	Not applicable.	There was no microbiological evaluation.	3M N95 1860 was the only model that passed 20 fit tests, five models did not go through any test, two models supported two tests and two models went only through a fit test. The FRMs must be physically examined before and after the decontamination cycles to verify degradation signs.	Not evaluated.
Boop, et. al. ⁽⁴⁸⁾ /2020	To examine the efficacy of autoclaving for reusing FRMs'.	Molded 3M 1860, folded 3M 1805, and 3M 1870/1870.	Autoclave.	Not applicable.	There was no microbiological evaluation.	Negligible changes were observed in the functionality and integrity of the 3M 1805 and 3M 1870/1870 FRMs' after three autoclave cycles. A slight elasticity loss in the rubber straps was observed with each autoclaving. In addition to that, the masks that went through through 5 processing instances failed the fit test, and masks such as 3M 1860 failed in the fit tests after only one autoclave cycle.	Not applicable.
Li, et al. ⁽⁴⁹⁾ /2020	To examine reprocessing with vapor and dry heat for reusing FRMs'.	3M 1860.	Vapor applied by means of an electric rice cooker and dry heat.	Methicillin-resistant <i>Staphylococcus aureus</i> and the MS2 ^{II} bacteriophage of the single-stranded RNA non-enveloped virus.	Vapor reprocessing resulted in a further 5 log ₁₀ reduction in the MS2 ^{II} bacteriophage and methicillin-resistant <i>S. aureus</i> , while dry heat at 100°C ^I for 15 minutes did not result in a reduction greater than 3 log ₁₀ of any organism.	There were no visible changes in any of the 3M 1860 masks after five decontamination cycles. The effect of reprocessing on the performance of the respirator was not examined.	Not applicable.
Carrillo, et al. ⁽⁵⁰⁾ /2020	To evaluate if decontamination by immediate-use vapor changes the structural efficacy and integrity of the FRMs'.	3M 1870 and M3 1870+ (3M, Saint Paul, MN).	Vapor sterilization employing an immediate-use autoclave.	Not applicable.	There were no microbiological tests.	The masks maintained their structural integrity and efficacy. For each subject, one fit test was performed before the autoclave cycle ready for use as a control element. The fit tests were performed again after three cycles. In all cases, the masks maintained their structural integrity and efficacy.	A chemical indicator and a biological indicator were used for each autoclave cycle, confirming that no biological or chemical contamination is found in the masks.

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REPROCESSING							
Author/ Year	Objective	Type of mask	Reprocessing method	Types and sizes of the microorganisms tested	Efficacy of each type of reprocessing for decontamination of the FRMs	Effect of reprocessing on the tissue structure of the FRMs	Chemical risk
Lao, et al. ⁽⁵¹⁾ /2020	To investigate several decontamination schemes commonly used in 95% particular filtration efficiency.	3M 8210 (NIOSH N95), 4C Air, Inc. (GB2626 KN95), ESound (GB2626 KN95) and Onnuripian (KFDA KF94).	Heat treatment, vapor treatment, alcohol treatment, treatment with chlorine solution, ultraviolet germicidal irradiation.	Not applicable.	There were no microbiological tests.	Ethanol- and chlorine-based solutions drastically degraded filtration efficiency to unacceptable levels. Ethanol: 56.33%; chlorine- based solution: 73.11%. Dry heat: 96.67%; boiling water cup: 95.16%; ultraviolet germicidal irradiation: 95.50%. Filtration efficiency was retained >95% after 20 cycles of thermal treatment, even in a humid environment.	Not performed.

*Face Respirator Mask; *Filtering Facepiece Respirator; *Surgical Respirators; *Influenza A, subtype H1N1; *MS2 Bacteriophage; *Degrees Celsius; **Severe Acute Respiratory Syndrome Disease; **N95 respirator; **Centers for Disease Control and Prevention

Figure 4 - Description of the studies regarding authors, objectives, type of mask, reprocessing method, type and size of the microorganisms, efficacy of each type of reprocessing, effect of reprocessing on the structure of the masks and chemical risk. Ribeirão Preto, SP, Brazil, 2020

The descriptions of the studies regarding authors, objectives, type of mask, size and type of the microorganisms, effect of reuse on the structure of

the masks and recommendation regarding reuse are presented in Figure 5.

REUSE						
Author/Year	Objective	Type of mask	Type and size of the microorganism tested	Effect of reuse on the structure of the FRMs*	Recommendation regarding reuse	
Sakaguchi, et. al. ⁽⁵³⁾ / 2010	To determine whether influenza A (H1N1 [§]), cultivated in laboratory, maintains its infectiousness on the surfaces of personal protective equipment and clothes used in health care institutions.	Rubber glove; mask with N95 filter; surgical mask; apron made of Tyvek; coated wooden table and stainless steel table.	Influenza A virus (0.5 ml).	Not applicable.	The influenza A virus maintained its infectiousness on the surfaces of the surgical mask and the N95 particle respirator for at least 8 hours. Infectiousness of the influenza virus was maintained for 8 hours on the surface of all the materials, except for the rubber glove, whose infectiousness was maintained for 24 hours.	
Duarte, et al. ⁽⁵²⁾ /2010	To quantify the damage imposed on PFF-2 ^{††} respirators during use time and to estimate its validity period in the clinical practice.	PFF-2 Masks [¶] (3M).	Not applicable.	Personal identification marks were found in all the FRMs* on the first day of use. From the fifth day on, all the masks were soiled and 80% had folds.	The validity period of the PFF-2 [†] type FRMs*, although it is not convenient to reuse them, should be limited to five days.	

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REUSE					
Author/Year	Objective	Type of mask	Type and size of the microorganism tested	Effect of reuse on the structure of the FRMs*	Recommendation regarding reuse
Roberge, et al. ⁽⁶⁴⁾ /2012	To evaluate the degradation of lashing devices of three FRM* models subjected to tension of five 15-minute wear periods interspersed with 15-minute periods of no wear.	3M 9210, Moldex 2301 and 3M 1860S N95s. Not applicable.	Not applicable.	Progressive decline in the loads generated on the three FRM* models that were tested over several simulated placements during 2.5 hours. The greatest reduction in the loads occurred within the first 15 minutes. The mean reductions in the loads of the simulated initial placement (zero minute) until the end of the fifth simulated 15-minute placement were 23.5%, 6.4% and 17.9%, respectively, for models 3M 9210, Moldex 2301 and 3M 1860S for the bottom side and 29.1%, 12.5% and 19.3% for the top side.	Not applicable.
Fisher, et al. ⁽⁶⁶⁾ /2012	To verify reaerosolization of bacteriophage particles from FRMs* after cough simulation.	N95 (Gerson 1730).	MS2 ^{II} bacteriophage as a substitute for airborne pathogenic viruses. The concentration of MS2 ^{II} applied was 10 ⁴ or 10 ⁵ plaque-forming units/cm ² .	A small percentage of viable bacteriophages was reaerosolized from the N95 masks by the reverse air flow.	The risks due to reaerosolization associated with prolonged use can be considered insignificant, although the risk assessments must be updated as new respiratory viruses emerge and better assessment data on exposure at work become available.
Bergman, et al. ⁽⁶⁵⁾ /2012	To investigate the impact of several gains in the fit of the facepiece of 6 models of the FRMs* using a group of 10 experiment test subjects by model.	N95 (Moldex 2200); 3M 8000; 3M 8210 and 3 Kimberly surgical N95s. Clark PFR95-270; 3M 1860 and 3M 1870.	Not applicable.	Several gonnings and degonnings exerted an impact on fit for the N95 models evaluated. Consecutive fits caused damages such as breaking the headband.	Five consecutive gonnings can be performed before the FRM* fit failures fall consistently below 100. This value is obtained by means of the concentration ratio of particles in the atmosphere divided by the concentration of particles in the mask.
Brady, et al. ⁽⁶⁷⁾ /2017	To characterize transfer of the MS2 ^{II} bacteriophage and fluoresceine and the FRMs* and the user's hands during three simulated use settings.	N95 Mask	MS2 ^{II} bacteriophage.	Handling masks contaminated with droplets resulted in higher levels of virus transfer to the hands of the professionals, with a statistical difference when compared to droplet nuclei, for the three types of mask.	The conclusions of this paper support the CDC** recommendations that allow reusing the N95 mask and its prolonged use in pandemic situations. A suitable technique for removing the N95 is an essential step to avoid contamination.

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REUSE					
Author/Year	Objective	Type of mask	Type and size of the microorganism tested	Effect of reuse on the structure of the FRMs*	Recommendation regarding reuse
Suen, et al. ⁽⁵⁸⁾ /2020	To evaluate FRM [*] fit before and after the Nursing procedures. The physical properties of these FRMs [*] were also examined.	3M N95 FFR [†] and nanofiber N95 FFR [†] .	Not applicable.	The nanofiber FRM [*] showed significantly better usability than the 3M FRM [*] . None of the respirators was able to provide consistent protection for the user, as detected by the face seal leak after performing Nursing procedures.	It is necessary to further improve the prototype's design in order to increase compliance and ensure respiratory protection for the users.
Sakaguchi, et al. ⁽⁵³⁾ /2010	To determine whether influenza A (H1N1 [§]), cultivated in laboratory, maintains its infectiousness on the surfaces of personal protective equipment and clothes used in health care institutions.	Rubber glove; mask with N95 filter; surgical mask; apron made of Tyvek; coated wooden table and stainless steel table.	Influenza A virus (0.5 ml).	Not applicable.	The hemagglutination titre of the influenza A virus was not reduced in any of the materials tested, even after 24 hours. Infectiousness of the influenza virus was maintained for 8 hours on the surface of all the materials, except for the rubber glove, whose infectiousness was maintained for 24 hours.

Face Respirator Mask; [†]Filtering Facepiece Respirator; [§]Influenza A, subtype H1N1; ^{||}MS2 Bacteriophage; ^{}N95 respirator; ^{**}Centers for Disease Control and Prevention

Figure 5 - Description of the studies regarding authors, objectives, type of mask, size and type of the microorganisms, effect of reuse on the structure of the masks and recommendation regarding reuse. Ribeirão Preto, SP, Brazil, 2020

Discussion

This study showed the complexity for the effective reprocessing and reuse of the N95 FRMs.

A successful decontamination method must inactivate the virus, not impair performance of the filter, not affect fit of the FRMs, not cause irritation to the user due to residual chemicals, and be easily performed in a timely manner⁽⁵⁶⁾.

Regarding reprocessing of the N95 FRMs and equivalent, we noticed that many methods were used for this purpose: ultraviolet germicidal irradiation was used in 14 studies^(27-28,30-31,33-35,37,39-41,45,47,51). Among them, ultraviolet light varied from 254 to 302 nanometers, and the doses ranged from 1 to 950 J/cm². The exposure time varied from one to 266 minutes. The authors identified⁽⁴¹⁾ that ultraviolet light administered as a cycle lasting one minute and 30 minutes reduced contamination, but did not meet the decontamination criteria for all places in the FRMs. Other authors showed that the FRMs can be decontaminated and reused up to three times employing ultraviolet light⁽⁴⁵⁾. Significant reductions (≥ 3 log) were observed in the viability of the influenza virus in 12 of 15 models tested and in relation to the straps of 7 of 15 models⁽⁴⁰⁾. The authors suggest that decontamination

of the N95 mask using ultraviolet can be effective, but it depends on the model, type and material of the FRMs. They also found that ultraviolet light was the only method that did not cause observable physical changes in the FRMs⁽²²⁾. However, only one model passed 20 fit tests and five models did not go through the test⁽⁴⁷⁾.

Thus, the use of ultraviolet light is still controversial in terms of decontamination and effectiveness of the FRMs.

As for the use of hydrogen peroxide, we identified eight studies^(27-28,30,41-42,44-46). The authors suggest that this method is promising in relation to FRM decontamination, although concerns remain about the residuals left after decontamination⁽²⁷⁾. However, a research study showed that, in four hours, the hydrogen peroxide levels were reduced below the detection level (0 parts *per* million)⁽⁴⁶⁾. The FRMs can be decontaminated and reused up to three times using hydrogen peroxide vapor⁽⁴⁵⁾. The decontamination effectiveness of the FRMs was demonstrated with a 31-minute long cycle⁽⁴¹⁾. In addition to that, in the treatment with gaseous hydrogen peroxide, the mean penetration levels were $>5\%$ for four of the six FRM models tested⁽²⁸⁾.

Although promising in relation to the destruction of microorganisms, this method can compromise filtration efficiency of the FRMs.

Regarding the use of vapor methods, four studies used decontamination with autoclave^(38-39,48,50). The exposure time varied from 15 to 60 minutes and the temperature from 115 to 121°C. In only one of the studies, immediate-use vapor decontamination was employed⁽⁵⁰⁾. It was observed that particle retention was reduced after each autoclave cycle, although the minimum requirements were maintained in the fit test for up to three autoclaving processes⁽⁴⁸⁾. In addition to that, a slight elasticity loss was observed in the rubber straps with each autoclave treatment. The masks that went through five processing procedures failed the fit test and presented observable folds⁽³⁸⁾. It is also noteworthy that some studies used temperatures below 121°C to sterilize the FRMs, being that, in the sterilizing phase, the prescribed temperature for the cycle would be 121 or 134°C, depending on the exposure time⁽⁵⁹⁾. It is emphasized that this method caused structural damage that can compromise the effectiveness of the FRMs.

Other studies also used vapor as a resource for decontaminating FRMs. Three of them used a vapor rice cooker^(38-39,49), six used microwave-generated vapor^(27-28,31,33-35) and one used vapor from a boiling water cup⁽⁵¹⁾. It is emphasized that these methods presented satisfactory results with respect to decontamination of microorganisms; however, they can cause structural damage to the FRMs. In addition to that, these reprocessing methods are not regulated for use in health services.

Regarding dry heat, five studies employed this method^(41,43,45,49,51). Temperatures varied from 60 to 100°C and time, from 15 minutes to three hours. Dry heat at 60°C and 70°C for one hour were able to successfully destroy the microorganisms tested and the FRM filtration efficiency was 98%, 98% and 97% after being heated for one, two and three hours, respectively⁽⁴³⁾. Dry heat at 70°C for 30 minutes was not effective in decontaminating bacteriophages⁽⁴¹⁾. A number of researchers showed that, at 70°C, dry heat can be used one or two times without impairing filtration of the FRMs⁽⁴⁵⁾, confirming other findings that evidenced filtration efficiency of 96.67% (± 0.65) after using dry heat⁽⁵¹⁾.

For effective sterilization of the materials, the oven must be kept closed continuously for 60 minutes with the temperature at 170°C, or for 120 minutes at 160°C. None of the studies used these parameters. Thus, it is not possible to talk about sterilizing the FRMs⁽⁶⁰⁾. Therefore, in relation to this method, there are doubts about the real effectiveness of this process in decontaminating the FRMs.

Regarding the use of chemical methods, eight studies were developed. Six used sodium hypochlorite^(27,30,36,38-40,51), four^(38-39,45,51) tested ethanol and one study used mixed oxidants. Different concentrations and volumes were used, but the odor of chlorine-based solutions remained after decontamination of the FRMs; in addition to that, bleach corroded the metal parts of the FRMs. This result was expected, considering that chlorine is an oxidizing agent.

Regarding filtration efficiency, it was shown that the ethanol- and chlorine-based solutions drastically degraded filtration efficiency to unacceptable levels, 56.33% (± 3.03) with ethanol and 73.11% (± 7.32) with the chlorine-based solution⁽⁵¹⁾, confirming other findings which showed that decontamination reduced filter quality after using 70% ethanol⁽³⁸⁾. Ethanol is an intermediate level disinfectant agent and acts on lipid viruses like SARS-CoV-2; however, its action depends on friction, which can explain degradation of the filtration efficiency. It is noteworthy that, in the design of the studies evaluating the chemical methods for decontaminating the FRMs, previous knowledge about the reprocessing methods were not taken into account. It is presumed that exposure of a filter as the one found in the FRMs can be altered when using decontamination liquid products, like ethanol and chlorine.

When analyzing the methods for decontaminating the FRMs, we did not find sufficient evidence to support their reprocessing. We also point out that, in Brazil, any article to be reprocessed must have a validation protocol according to Collegiate Board Resolution RDC 2606 of August 11th, 2006, which indicates cleaning, rinsing, drying, packaging, disinfection/sterilization, labeling and conditioning reprocessing phases⁽⁶¹⁾.

In the case of the FRMs, cleaning and rinsing were not performed in the studies analyzed, probably due to the risk of damaging the filter. We also emphasize that, for an article to be subjectable to reprocessing, it must maintain its characteristics, and its efficiency and physical characteristics must be assessed. The reprocessing protocol must also be prepared for each brand and in each of the health institutions, considering the different conditions of the equipment used for the cleaning/disinfection/sterilization procedures.

Another factor to be discussed is the major difficulty in defining decontamination of N95 masks, as determining the microbial load in the different clinical settings and activities is a limiting factor.

Regarding FRM reuse, from the total of studies identified, only seven (21.8%) addressed this topic. A research study⁽⁵⁷⁾ showed the transfer of microorganisms from the FRMs to the users' hands while handling and reusing them.

The health professional must not come into contact with the outer surface of the FRMs, for being considered contaminated. In addition to that, to avoid contamination, it is recommended to pay special attention to the adequate sequence and technique for mask removal after use, holding it by the straps placed on the back of the head⁽¹⁴⁾.

To reuse the FRM, the health professional must inspect it regarding its integrity, including the straps and nose clip that may present changes in their structure which affect fit and seal quality. In addition, the fit test must be performed immediately after placing the FRM to verify proper seal on the user's face so as to prevent air leakage. To this end, in general, this test is performed by placing both hands on the surface of the mask. The inspection, placement and removal of the mask after use involve its handling, increasing the chance for self-contamination.

The influenza A virus maintained its ineffectiveness on the surfaces of the surgical mask and of the FRM for at least eight hours⁽⁵³⁾. Thus, to prevent contamination, it is recommended to pay special attention to the adequate sequence and technique for removing the mask after use⁽¹⁴⁾.

Hand hygiene before and after PPE gowning and degowning and during the assistance provided to limit contamination of the health care environments deserves to be highlighted. In relation to SARS-CoV-2, a study showed that survival time on the human skin is approximately nine hours and increases the risk of viral transmission to other skin surfaces. On the other hand, SARS-CoV-2 was completely inactivated within 15 seconds of exposure to 80% (w/w) ethanol⁽⁶²⁾.

In the same sense, a study on the infectiousness of the influenza virus in the same PPE identified that it remained active on the surface of the FRMs for at least 8 hours, showing that PPE disposal to prevent cross-infection is an important practice. The researchers point out that reuse of the PPE can be responsible for cross-transmission of the influenza virus and, therefore, it is recommended to discard the mask when it becomes soiled with blood and respiratory secretions, immediately after use⁽⁵⁷⁾, and frequent replacement of the PPE for each patient as a preventive measure⁽⁵³⁾.

Another aspect related to the prolonged use of the FRMs refers to the risk of airborne transmission of particles containing virus, that is, whether they might act as a potential source of exposure risks due to reaerosolization. A research study showed that only a small percentage ($\leq 0.21\%$) of viable virus was reaerosolized from the tested FRMs by the reverse air flow generated by simulated cough. The viruses applied as aerosols were much more susceptible to reaerosolization than those contaminated with droplets. Thus, the authors

point out that the potential threat of reaerosolization, associated with prolonged use of the N95 mask, of most of the respiratory viruses seems insignificant and unlikely to health professionals and patients and that there is a need for studies as new respiratory pathogens emerge⁽⁵⁶⁾.

In relation to the research studies that analyzed the potential for contamination by pathogens of the FRMs and their transmission by contact and possibility for reaerosolization, all the studies were conducted in laboratories and, up to date, none of them studied the permanence and ineffectiveness of SARS-CoV-2.

Another concern with reusing N95 masks refers to the damage that multiple placements and removals can cause in their components (such as head straps, strap accessories, adjustable nose tips, etc.), which can adversely affect fit in the user's face and a proper seal over time⁽⁵⁵⁾.

Proper sealing of the FRMs on the user's face is fundamental for them to maintain adequate protection and comfort. One study showed a progressive decline in the loads generated in the top and bottom straps of the three tested FRM models analyzed over several placement and removal simulations. The largest reduction in the loads occurred within the first 15 minutes of stress, regardless of the mask model, and the magnitude of the load decline depended on the mask model for the upper and lower straps⁽⁵⁴⁾.

A research study showed that multiple placements and removals of the FRMs exert an impact on fit in six types of masks analyzed and was associated with the mask model. The data showed that five consecutive placements can be carried out before there is any failure ($FF < 100$)⁽⁵⁵⁾.

A study assessed the damage imposed on filter masks over time and estimated their validity period in the clinical practice, showing that, from the fifth day on, all masks were soiled and that folds were observed in more than 80%⁽⁵²⁾. Internal stains and folds were more common after 12-hour shifts than after 6-hour shifts. It was also identified that 16.17% of the masks were lost on the fifth day and 38.93% after 30 days of use, showing that use of the FRMs must be exclusive for a 12-working-hour shift at the most or, if reuse is really necessary, that the five-day validity period must be respected.

Given the limitation of the evidence found, more research studies are needed to establish the reuse time for the FRMs, especially in real work environments.

Ideally, FRMs should be discarded after each encounter with the patient and after aerosol-generating procedures, when damaged or deformed, when they no longer form an effective seal on the face, when they get wet or visibly soiled, when breathing becomes difficult, as well as when they become contaminated with blood, respiratory or nasal secretions, or other body fluids⁽¹⁴⁾.

For reusing the FRMs, the need for health care institutions to provide a suitable place for storage stands out, preventing their contamination.

Another aspect identified in this research refers to the usability of the FRMs, which is important because discomfort during use can affect compliance. Thus, a study evaluating the physical properties and usability of different FRM brands identified that those produced with nanofiber showed better usability than other materials in terms of facial warmth, breathability, facial pressure, speech intelligibility, itching, difficulty in maintaining the mask in place and comfort level. The nanofiber FRMs were also thinner and lighter and presented slightly higher bacterial filtration efficiency than the other masks evaluated⁽⁵⁸⁾.

The studies analyzed allow some recommendations to be listed, such as: 1) the need to train the health professionals working in the care of patients with infectious diseases, 2) the proper technique for placement and removal of the FRMs, as they can be fomites with potential for transmission of pathogens through contact, 3) prevention measures, such as the standard precautions with an emphasis on hand hygiene and measures to limit contamination of health care environments, in order to prevent cross-transmission of microorganisms between health professionals and patients, and 4) reuse is not indicated due to the risk of self-contamination and inadequate sealing.

Thus, as new respiratory pathogens emerge (at increased levels and/or of unknown virulence), there is a need for studies that focus on the possibility for reaerosolization. Future studies assessing the risks of prolonged use for the N95 mask should consider factors such as microbial load, stability of the organism in the environment, performance of the existing engineering controls, and exposure duration.

Finally, there is also a need for studies focused on the improvement of mask designs that favor usability of the FRMs.

We emphasize that more research studies are needed to obtain evidence, especially in real work environments for reusing and reprocessing FRMs, whether or not recommended.

The evidence from this review is indeed timely to the pandemic time of COVID-19 that the world is facing. Reflecting and applying knowledge about reuse and reprocessing of FRMs can contribute to and enrich the health authorities' decisions. Safety in the health professionals' work is fundamental against a high-transmissibility pathogen capability like SARS-CoV-2. Adherence to the precautions, especially hand hygiene, correct use of PPE, whether during gowning or degowning, should be strictly followed.

When considering the contributions of this study, some limitations should be listed, as the fact that the studies do not use the FRMs employed in the clinical practice, that none of the studies has carried out the necessary steps for reprocessing validation, as well as the fact that none of studies has used masks contaminated with SARS-CoV-2 virus in the health services. We also point out that, although we have assessed the level of evidence of the articles, we did not assess the methodological quality of the studies included in the review.

Conclusion

No evidence was found to support safe reprocessing of FRMs. The chemical methods studied should not be used, as they compromise mask integrity. Hydrogen peroxide vapor was listed as an effective method for decontaminating masks and causing less physical damage to them. However, we emphasize that no study conducted all the necessary steps for reprocessing validation. Reuse is contraindicated; however, health institutions perform this practice when they face situations of FRM shortage. A number of studies point out that adequate gowning and hand hygiene before and after removing the mask, as well as proper storage, can prevent mask contamination. In addition to that, mask integrity can be preserved for up to five reuse instances.

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