Title
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Journal
JAMA Otolaryngology - Head & Neck Surgery, 146(8)

ISSN
2168-6181

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Publication Date
2020-08-01

DOI
10.1001/jamaoto.2020.1423

Peer reviewed

HHS Public Access
Author manuscript
JAMA Otolaryngol Head Neck Surg. Author manuscript; available in PMC 2021 August 01.

Published in final edited form as:
JAMA Otolaryngol Head Neck Surg. 2020 August 01; 146(8): 734–740. doi:10.1001/jamaoto.2020.1423.

Decontamination Methods for Reuse of Filtering Facepiece Respirators

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Abstract

IMPORTANCE—The novel coronavirus disease 2019 (COVID-19) has proven to be highly infectious, putting health care professionals around the world at increased risk. Furthermore, there are widespread shortages of necessary personal protective equipment (PPE) for these individuals. Filtering facepiece respirators, such as the N95 respirator, intended for single use, can be reused in times of need. We explore the evidence for decontamination or sterilization of N95 respirators for health care systems seeking to conserve PPE while maintaining the health of their workforce.

OBSERVATIONS—The filtration properties and fit of N95 respirators must be preserved to function adequately over multiple uses. Studies have shown that chemical sterilization using soap and water, alcohols, and bleach render the respirator nonfunctional. Decontamination with

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Author Contributions: Author X had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
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Acquisition, analysis, or interpretation of data: Su-Velez, Maxim, St. John, Holliday.
Drafting of the manuscript: Su-Velez, Maxim, St. John.
Critical revision of the manuscript for important intellectual content: All authors.
Administrative, technical, or material support:
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Conflict of Interest Disclosures: None reported.

microwave heat and high dry heat also result in degradation of respirator material. UV light, steam, low-dry heat, and commercial sterilization methods with ethylene oxide or vaporized hydrogen peroxide appear to be viable options for successful decontamination. Furthermore, since the surface viability of the novel coronavirus is presumed to be 72 hours, rotating N95 respirator use and allowing time decontamination of the respirators is also a reasonable option. We describe a protocol and best practice recommendations for redoffing decontaminated N95 and rotating N95 respirator use.

CONCLUSIONS AND RELEVANCE—COVID-19 presents a high risk for health care professionals, particularly otolaryngologists, owing to the nature of viral transmission, including possible airborne transmission and high viral load in the upper respiratory tract. Proper PPE is effective when used correctly, but in times of scarce resources, institutions may turn to alternative methods of preserving and reusing filtering facepiece respirators. Based on studies conducted on the decontamination of N95 respirators after prior outbreaks, there are several options for institutions to consider for both immediate and large-scale implementation.

With each passing day, the novel coronavirus disease 2019 (COVID-19) pandemic escalates around the world. First identified in Wuhan, China, the disease is caused by a novel coronavirus: severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2).[1] Globally, health care professionals have been infected at high rates (63% of all cases in Wuhan as of February 11, 2020, were health care professionals; in Italy, 20% of health care professionals responding to the pandemic were reported to be infected) and are also dying of COVID-19.[1–5] These high rates are likely due to transmission of the virus through droplet, contact, and even airborne modalities, similar to the 2002–2003 SARS pandemic,[6] as well as by asymptomatic individuals. A study by Zou et al[7] has shown similar viral loads present in both asymptomatic and symptomatic patients, with the highest viral load being identified in the nasal cavity. Subsequently, it is not surprising that otolaryngologists have been identified as a high-risk group among health care professionals, given their level of exposure to the upper aerodigestive tract.[8–10]

The risk of infection for health care professionals is compounded by shortages of personal protective equipment (PPE), including filtering facepiece respirators (FFRs), in particular, N95 respirators.[2,11] Early studies report that adequate PPE and hand hygiene provide good protection from infection, especially in cases of high-risk procedures in which SARS-CoV-2 can be aerosolized.[12,13] The N95 respirators were widely used in previous SARS and influenza outbreaks to prevent both droplet and airborne transmission.[6,14] At UCLA Health, the use of N95 respirators along with a gown and eye protection or face shield is required for any invasive otolaryngologic procedure involving mucosal surfaces, in line with recent guidelines based on international experience.[8] In the US, the supply of necessary PPE has been unable to keep up with the rapid increase in the number of patients with COVID-19 owing to the disruption of the global supply chain.[2,15] The Centers for Disease Control and Prevention (CDC) has estimated that more than 90 million respirators would be required for health care professionals alone in a pandemic lasting 42 days.[16] As of March 2020, the US Department of Health and Human Services estimated that 3.5 billion N95 respirators would be needed in a severe event, but only 35 million were available.[17] Previously, the CDC set guidance for extending the use of single-use PPE in times of high demand and more recently released new guidelines on decontamination methods for N95 respirators.[15,18,19] We present a review of available options for decontamination and reuse of N95 respirators in the interest of conserving this PPE resource.

Data Sources and Selection

We conducted a literature review on methods for decontamination of N95 filtering facepiece respirators using the PubMed database for articles published in English using the following search terms: *COVID-19*, *SARS-CoV-2*, and *coronavirus* in conjunction with *PPE* or *N95*. Separate searches were conducted using the Medical Subject Headings for *respiratory protective devices* and *disinfection*. Articles were reviewed and selected for relevance on the topic. Article references were also reviewed to identify other relevant literature. All articles were published between 2009 and 2020; we completed our search on April 25, 2020.

Owing to the urgency of the ongoing pandemic, the evidence base is new and evolving rapidly. For this reason, in the interest of timeliness and to provide a thorough overview of available practices for consideration, we have also included data from several non–peer-reviewed sources, media reports, and personal communications. This article is not intended as a systematic review, nor do we advocate or advise on specific practices for PPE use or decontamination. We suggest continued adherence to official institutional policies and procedures.

Discussion

Filtering facepiece respirators are usually single-use, disposable masks designed to reduce exposure to airborne particles and are used in a variety of work settings beyond health care. Different models and filtration efficiencies of FFRs are approved by the National Institute for Occupational Safety and Health.[20,21] The designation N95 denotes a respirator that is able to capture at least 95% of oil-free airborne particles with a median diameter of 300 nm (0.3 μm). The N99 respirators are 99% efficient, for comparison, although N95 respirators are the most commonly available in the health care setting.[20,22] With oversight by the National Institute for Occupational Safety and Health, there are numerous manufacturers of FFRs (eg, 3M, Kimberly Clark, Gerson, and Moldex), and each makes N95 respirators with different shapes, sizing, and materials.[14,21] The mechanism of filtration in FFRs, including most N95 respirators, is a combination of filtration by size through multiple layers of microfiber materials, as well as with a layer of electrostatically charged material.[20,22,23]

In addition to the integrity and electrostatic charge of the filter material, mask fit is crucial for adequate protection. Any gaps between the wearer's face and the seal of the respirator allows for unfiltered entry of any contaminants.[24] Facial hair can interfere with this fit, and eye protection should be donned after the mask.

Lessons From Past Pandemics

After the SARS pandemic in 2003 and the H1N1 influenza outbreak in 2009, both the CDC and the Institute of Medicine published recommendations on the possibility of needing to reuse PPE in the event of a shortage. N95 respirators were used widely by health care professionals during these previous outbreaks, prompting concerns regarding supply at that time and for future epidemics. The CDC has guidance on both extended use, defined as wearing the same N95 respirator continuously for multiple patient encounters, as well as reuse, where the respirator is removed and donned again for multiple patient encounters. As the N95 respirator is not manufactured for reuse, any gross contamination of the respirator or any structural breakdown that compromises the mask fit or filtration is a clear contraindication for reuse or extended use.[18,24]

Bergman et al[24] studied the outcome of repeated use of N95 respirators and reported that filtration performance, straps, and other adjustable parts (nosepiece) apparently were not compromised for up to 5 separate donning and doffing events. The Institute of Medicine also proposed using a second surgical mask as a barrier over the N95 respirator as protection from contamination, which has been found to be well tolerated by health care professionals.[21,25] However, the major risk of N95 respirator reuse is the possibility of contact transmission through health care professionals touching the N95 respirator. Human coronaviruses can survive for hours at a time, even on surfaces such as fabric and gloves, rendering PPE as an additional method of infection transmission.[25,26] As a result, decontamination would be a necessary component in situations of extending N95 respirator use.

SARS-CoV-2 Virus

Human coronaviruses are RNA viruses that have a lipid envelope, and typically are considered more fragile compared with viruses without an envelope, as this lipid envelope can be disrupted with desiccation, heat, and various disinfectants (eg, ethanol and bleach). In coronaviruses, the envelope also contains viral proteins that are necessary for binding to and entering host cells to establish infection.[27,28] Despite their enveloped nature, human coronaviruses can persist for a long time in the environment, and their survival and infectivity can be prolonged in humidity or with the aid of organic materials (eg, proteins or droplet secretions).[27] Coronaviruses are about 125 nm in diameter.[28] The coronavirus SARS-CoV-1, which caused the 2003 SARS pandemic, is the human coronavirus most closely related to SARS-CoV-2.[29]

The transmission of respiratory infectious disease is usually defined as either droplet transmission generated by activities such as sneezing, coughing, or talking at close range, or airborne transmission via smaller particles called droplet nuclei, which are larger than individual virus particles, that can be suspended in air and cause infection at greater distances. The World Health Organization defines droplet transmission as particles greater than 5000 nm (5 μm), and airborne transmission is through particles less than or equal to that size.[29–31] Typically, regular surgical masks are considered adequate protection against droplets, and N95 respirators are needed for protection against airborne transmission. In the case of SARS-CoV-1 and now SARS-CoV-2, the available data suggest mostly droplet and contact transmission, although concerning evidence of airborne transmission has been seen.[29] The World Health Organization currently recommends droplet and contact precautions for PPE against SARS-CoV-2 but specifies that procedures that are likely to generate aerosols from the respiratory tract may create a risk of airborne particle transmission.[31]

The routes of transmission for SARS-CoV-2, including from the environment, remain poorly understood. A non–peer-reviewed study reported that evidence of airborne SARS-CoV-2 RNA was detected in various hospital areas as well as public areas in China.[32] Early evidence from van Doremalen et al[29] indicated that SARS-CoV-2 viral particles could still infect living cells after persisting in airborne aerosols for up to 3 hours, as well as up to 72 hours on stainless steel and plastic. On cardboard, a porous surface, the virus was detected for up to 24 hours. Another recent study reported SARS-CoV-2 survival on wood and cloth for 2 days and up to 7 days on steel or plastic. These authors also apparently found detectable virus after 7 days on a surgical mask.[33] Other studies looking at SARS-CoV-1 or other human coronaviruses, such as Middle East respiratory syndrome coronavirus, have reported differing surface survival times, ranging from 2 to 6 days on dry nonporous surfaces, such as plastic, and 3 days on other materials, such as fabric and paper.[34–37] This variance in results is likely owing to differences in experimental methods, although survival time of these viruses consistently decreases with decreasing virus concentration.[34,36] With this information in mind, N95 respirators should be required for any aerosol-generating procedure or close contact with patients who have confirmed COVID-19. Methods for appropriate decontamination are needed to mitigate the limited supply of respirators and the risk of infection from the virus on used PPE.

N95 Decontamination Methods

To date, several techniques have emerged with the goal of decontaminating N95 respirators for reuse. These techniques include preservation of the N95 respirator (decontamination by time) or resterilization via methods such as chemical processing (bleach, alcohol, and soap and water), UV germicidal irradiation (UVGI), vaporized hydrogen peroxide, or application of heat (dry oven or steam sterilization). None of these techniques are perfect in terms of balancing adequate viral decontamination with preserving mask fit and function, however, as N95 respirators are not designed for reuse. Proper hand hygiene, handling of used PPE, and donning and doffing techniques still need to be used with decontaminated PPE to minimize risk of infection.

Preserving an N95 respirator over time for reuse is simple, requires minimal resources, and can be done by individual health care professionals.[15] The basis of this technique is the reported surface viability of SARS-CoV-2 and similar coronaviruses of about 72 hours on porous surfaces, such as cloth, paper, and cardboard (similar to respirator material).[29,33,36] Although some reports suggest that the virus can survive up to 7 days or longer, the survival time depends on the viral load.[33,34,36] Only N95 respirators without gross viral exposure and worn under a face shield or other surgical mask to provide additional protection should be considered for decontamination and reuse.[18] After using PPE in the work setting, a health care professional can doff the N95 respirator into a clean, date-marked paper bag, which allows for drying and is stored in a designated area. After at least 72 hours (or longer if possible: the CDC recommends 5 days), the health care professional may reuse the respirator with careful PPE donning and doffing technique, since most previously exposed virus should no longer be viable.[19] The health care professional will need to use additional N95 respirators during the drying and storage period; however, this method allows for prolonged use of a limited supply of N95 respirators when used in rotation (ie, 3 respirators used every 3 days, or 5 respirators used every 5 days). Many institutions, including ours, have adopted this method and are also incorporating techniques in line with the Institute of Medicine recommendation of wearing a second mask[16] to protect the N95 respirator from gross contamination, including face shields to cover the outer surface and allow for reuse. In Box 1, we present a protocol for safe donning and doffing of decontaminated N95 respirators, based on CDC and National Institute for Occupational Safety and Health recommendations.[18,19]

Sterilization of N95 respirators with chemical agents known to be effective against other coronaviruses (bleach, alcohol, or soap and water)[34] has major shortcomings, as bleach treatment leaves behind a residual toxic odor, while alcohols and soap and water baths degrade filtration efficiency significantly.[38] N95 respirators contain an electrostatically charged filtration layer; thus, any chemical or physical method that degrades the charge will compromise the filtration ability, potentially allowing increased particle passage.[20,22]

Others have examined the use of UVGI for N95 respirator decontamination. To simulate real-world conditions, Mills et al[14] tested 15 different N95 respirator models contaminated with the H1N1 influenza virus and then soiled with artificial saliva or skin oil. Despite the addition of soiling agents to mimic organic material, UVGI treatments significantly reduced influenza viability in 12 of the 15 models tested, but the mask straps were not decontaminated at equal rates. High-dose UVGI (up to 950 J/cm^2) applied to 4 types of N95 respirators did not significantly increase penetration of the mask filtration, but higher UV doses physically degraded respirator materials.[39] The authors of this latter study did not test UVGI dosing effectiveness on pathogens, nor did they test the outcome of repeated UVGI decontamination. Recently, Fischer et al[40] (article not peer reviewed), also tested UVGI with adequate viral inactivation and mask performance over 3 rounds of decontamination, but noted that UV treatment required more time than other methods.

Viscusi et al[23] compared several decontamination methods: 55-minute treatment with vaporized hydrogen peroxide (VHP) (commercially available), 5-hour processing with ethylene oxide (commercially available), 30-minute UVGI treatment, 2 minutes of 1100W microwave oven radiation, and bleach (deemed ineffective due to residual odor as described above). The microwave heating resulted in melting of respirator material in some of the respirator models tested, rendering them unwearable. The remaining methods did not result in substantial changes to filtration ability or airflow resistance; however; ethylene oxide was less favorable owing to the length of time required. In the case of VHP, masks containing cellulose-based products, such as cotton, could potentially interfere with the sterilization cycle. Salter et al[41] investigated whether various chemical decontamination methods left harmful residuals on respirators, and while ethylene oxide left traces of a contaminant, VHP had no detectable residuals. The presence of cellulose materials can cause the sterilization cycle to abort due to higher absorption of the hydrogen peroxide. Based on these results, UVGI and VHP appeared to be the most promising modalities for decontamination, keeping in mind the importance of UV dosage and timing as well as the limitations of VHP with different mask brands and materials.

Another study demonstrated that UVGI, 15 minutes at 1.8 J/cm^2; microwave-generated steam; and oven-generated steam all appeared to effectively decontaminate N95 respirators soiled with H5N1 influenza virus in droplet form without any change in filtration.[20] Fisher et al[21] also suggested successful decontamination of N95 respirators without compromising filtration function using commercially available microwave steam bags, although in this study a bacteriophage was used as a proxy for a true pathogenic virus. In addition to steam applied with boiling water vapor for 10 minutes, preliminary findings of a study (not peer reviewed) using dry oven heating at 70 °C for 30 minutes suggested effective decontamination of *Escherichia coli* bacteria and preserved filtration efficiency.[42]

In summary, UV light, steam heating, dry heat, and vaporized hydrogen peroxide sterilization all show potential for enabling effective and safe reuse of N95 respirators, although challenges of scale and implementation remain. The Table presents these data for ease of comparison. For health care facilities that may not have the resources needed to process N95 respirators with the above-described methods, preservation of respirators (time decontamination) remains an option. Both UV and VHP methods have been implemented in several institutions. As of April 2020, the US Food and Drug Administration has issued several emergency use authorizations for the application of commercial VHP sterilization to N95 respirators; all of these authorizations stipulate that VHP is not compatible with respirators containing cellulose.[44,45] In our institution, we have already been using the technique of time decontamination for N95 respirator reuse while investigating and recently implementing other methods, such as UVGI. However, owing to the heterogeneity of manufacturers and materials used in N95 respirators, as well as heterogeneity among study parameters, the results of these studies cannot be generalized to all types of N95 respirators in all situations. In addition, none of these studies on N95 respirator decontamination (save for one, which is not yet peer reviewed)[40] have, at time of writing, suggested adequate reduction of infectivity for SARS-CoV-2. These methods must be used with caution and in conjunction with proper donning and doffing technique. In Box 2, we present our protocol and best practices for N95 respirator preservation and reuse, based on available data regarding virus survival as well as CDC recommendations.

Centered on the UVGI results in the literature, the University of Nebraska has suggested a protocol for the use of UVGI at a maximum of 0.3 J/cm^2 to decontaminate and reuse N95 respirators in the COVID-19 pandemic (not peer reviewed).[46] Duke University has recently adopted VHP for decontamination (not peer reviewed).[43] Our institution has also instituted a UVGI decontamination protocol for large-scale reprocessing of N95 respirators. We hope the current concerns regarding PPE shortage can be addressed from a supply-chain level soon, but in the meantime ongoing work is needed to clarify the safety of these decontamination protocols.

Conclusions and Implications for Practice

As this COVID-19 pandemic develops and new knowledge comes to light, the protection of front-line health care professionals with appropriate PPE remains paramount. In times of crisis, however, the supply of necessary PPE is often not enough to meet the demand. We sought to review the most up-to-date literature at the time of writing on the decontamination of N95 respirators with the goal of extending a limited supply while maximizing health care professional safety. Health care professionals in endemic regions should consult their institutions to determine the optimal decontamination method for their unique circumstances.

SARS-CoV-2 is already known to be present with high viral loads in the nasal cavity and upper aerodigestive tract, and most otolaryngologic procedures, such as laryngoscopy, nasal endoscopy, and tracheostomy, should be considered high-risk, aerosol-generating procedures.[8–10,47] We hope that our otolaryngology colleagues will keep this in mind and use the necessary PPE to keep themselves and their patients healthy during this unprecedented time.

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Box 1.

Recommended Protocol for Donning and Doffing N95 Respirators Treated for Decontamination

1. Perform hand hygiene before donning N95 respirator
   - Use soap and water or alcohol-based hand sanitizer
2. Inspect the N95 for any evidence of physical damage
   - Look for broken straps, tears in the material, loosened nosepiece, etc
3. Don N95 respirator and check fit
   - Refer to institution's or respirator manufacturer's guidelines for fit testing and specific instructions
   - N95 respirator should always be worn with eye protection
4. Keep the N95 respirator clean; use additional barriers to prevent contamination
   - Use surgical mask or face-shield over the N95 respirator to prevent soiling
   - Always wear eye protection
   - Wear N95 respirator as long as possible; avoid doffing
5. Perform hand hygiene before doffing
   - Use soap and water or alcohol-based hand sanitizer
6. Doff mask into a clean container per institution's decontamination protocol
   - Mark with name, date, or other designated identifying information before depositing in designated collection area
   - Consider containers that allow for evaporation of any moisture
   - Avoid touching outside of the mask; use straps when handling
7. Perform hand hygiene
   - N95 respirator is used and may be contaminated
8. Decontamination process
   - Per institutional protocol
9. Before donning a used N95 respirator, inspect the respirator carefully again to ensure no damage
   - Consider respirator as potentially still contaminated; avoid touching inside of respirator, use straps when handling
   - Wear gloves (nonsterile) to don a used N95 respirator

- Discard any respirator that is obviously damaged or hard to breathe through
- Check respirator seal before removing gloves

10. Perform hand hygiene after donning used respirator

11. Avoid touching or adjusting N95 respirator throughout session of use

- Hand hygiene should be performed any time the N95 respirator is touched or adjusted
- Immediately discard any respirator that becomes grossly contaminated with blood, respiratory secretions, or other bodily fluids from patients
- The maximum recommended number of days of N95 respirator reuse is 5

Box 2.

Recommended Protocol for Preservation and Reuse of N95 Respirators

1. Perform hand hygiene before donning N95 respirator
    - Use soap and water or alcohol-based hand sanitizer
2. Inspect the N95 f respirator or any evidence of physical damage
    - Look for broken straps, tears in the material, loosened nosepiece, etc
3. Don N95 respirator and check fit
    - Refer to the institution's or respirator manufacturer's guidelines for fit testing and specific instructions
    - N95 respirator should always be worn with eye protection
4. Keep the N95 respirator clean; use additional barriers to prevent contamination
    - Use surgical mask or face-shield over the N95 respirator to prevent soiling it
    - Always wear eye protection
5. Perform hand hygiene before doffing
    - Wear N95 respirator as long as possible; avoid doffing
6. Doff mask into a clean paper bag clearly marked with the date
    - Preload paper bag into a plastic bag for ease of transport to health care professional's designated storage space
    - Paper bag allows for evaporation of any moisture
    - Avoid touching outside of mask; use straps when handling
7. Perform hand hygiene
    - N95 respirator is used and may be contaminated
8. Store bag in designated storage space
    - Use a locker, container in vehicle trunk, etc
    - Do not store other materials in this storage space that may directly contact paper bags
    - To prevent cross-contamination, only 1 N95 respirator should be stored in each bag
    - Label with name if necessary to avoid cross-contamination
9. Set aside bag with N95 respirator for at least3d (72 h) or up to 7 d

- After this amount of time, the severe acute respiratory syndrome coronavirus 2 virus has reduced infectivity after at least 72 h on porous surfaces

10. Before donning a used N95 respirator, inspect the respirator carefully again to ensure no damage

- Wear gloves (nonsterile) to don a used N95 respirator. Avoid touching the inside of the respirator
- Discard any respirator that is obviously damaged or hard to breathe through
- Check respirator seal before removing gloves

11. Perform hand hygiene after donning used respirator

- Used respirator is assumed to potentially still harbor some infectious material

12. Avoid touching or adjusting N95 respirator throughout session of use

- Hand hygiene should be performed any time the N95 respirator is touched or adjusted
- Immediately discard any respirator that becomes grossly contaminated with blood, respiratory secretions, or other bodily fluids from patients

13. Stockpile of used N95 respirators can be rotated approximately every 72 h or longer (ie, 3 per 72-hour cycle)

- The maximum recommended number of days of N95 respirator reuse is 5

Table.

Summary of Decontamination Methods for N95 Respirators

Technique	Protocol	Duration	Advantages	Disadvantages	Effect on filtration	Evidence
Time decontamination	Doff used N95 respirator into clean paper bag, store in designated space until reuse	At least 72 h, longer if possible (5–7 d ideal)	Simple, low-cost, easiest to implement	Unproven, requires daily extended use, requires adequate supply for rotation	Minimal, secondary to reuse	Not validated[a] but based on studies by van Doremalen et al,[29] 2020; Kampf et al,[34] 2020; Chin et al,[33] 2020; Otter et al,[36] 2015; endorsed by CDC[19]
Chemical decontamination						
Bleach[b]	Submerge N95 respirator mask in 0.6% bleach solution, rinse with deionized water, dry overnight	Treat 30 min then dry 16-h	Toxic to coronaviruses, readily available, low cost	Residual toxic, unpleasant odor	Aerosol penetration met NIOSH certification criteria	Peer-reviewed: Viscusi et al,[23] 2009; Kampf et al,[34] 2020
Alcohols[b]	Submerge N95 respirator in solution of 70% isopropyl alcohol, dry	Soak 20 min, then dry 72 h	Toxic to coronaviruses, readily available, low cost	Rendered respirator filter ineffective	Filtration efficiency significantly degraded	Peer reviewed: Viscusi et al,[38] 2007; Kampf et al,[34] 2020
Soap and water[b]	Soak N95 respirator in Ivory bar soap, 1 g/L, shaved from bar and diluted in tap water, dry	Soak 20 min, then dry 72 h	Readily available, low cost	Rendered respirator filter ineffective	Filtration efficiency significantly degraded	Peer reviewed: Viscusi et al,[38] 2007
Vaporized hydrogen peroxide	STERRAD 100S: H_2O_2 gas plasma sterilizer, single 55-min standard cycle	55 min	Commercially available, fast turnaround	Cellulose-based product (ie, cotton in certain brands) may interfere with sterilization	Aerosol penetration met NIOSH certification criteria	Peer-reviewed: Viscusi et al,[23] 2009; Not peer reviewed: Duke protocol,[43] 2020; Fischer et al,[40] 2020
Ethylene oxide[b]	Steri-Vac 5XL: single warm cycle (55 °C) and 100% ethylene oxide gas, followed by aeration	Ethylene oxide 1 h, then 4-h aeration	Commercially available	Lengthy protocol may limit overall capacity; residual chemicals present	Aerosol penetration met NIOSH certification criteria	Peer-reviewed: Viscusi et al,[23] 2009; Salter et al,[41] 2010
Heat decontamination						
Microwave steam	1100–1250 W–Microwave; individual N95 respirator placed on box filled with 50 mL water, or commercially available steam bag (Medela) with 60 mL water	Microwave 1.5–2 min at full power, then drying time (60 min)	Fast turnaround, materials commercially available	Requires individual mask sterilization; may be difficult to scale up	Filtration efficiency remains >95%	Peer reviewed: Fisher et al,[21] 2011; Lore et al,[20] 2012
Microwave oven heat	1100-W microwave at full power; individual N95 respirator placed on a paper towel over revolving glass plate	2 min total (1 min per side of mask)	Commercially available, fast turnaround	Mask material melted after treatment	Unable to test filtration owing to melted components	Peer reviewed: Viscusi et al,[23] 2009
Dry oven heat	Heat N95 respirator at 70–160 °C in oven for 30 min	30-min treatment	>99% effective against *Escherichia coli*, relatively fast	Temperatures >100 C may cause mask to melt	Filtration efficiency remains >95% at 70C, degraded at 160C	Peer reviewed: Viscusi et al, 38 2007; Non–peer reviewed: Price and Chu,[42] 2020; Fischer et al,[40] 2020

Technique	Protocol	Duration	Advantages	Disadvantages	Effect on filtration	Evidence
Hot water vapor/ moist heat	Treat N95 respirator with hot water vapor from boiling water, or moist heat at 65 °C	10–20 min treatment	>99% effective against *E coli*, fast treatment, low cost	Protocol not well described, not proven against viruses	Filtration efficiency remains high	Peer reviewed: Lore et al,[20] 2012 Non–peer reviewed: Price and Chu,[42] 2020
UV light decontamination						
UVGI	Protocols vary; UV light applied to 1 or both sides of N95 respirator; UVGI studied at exposures ranging from 2 to 950 J/cm^2	1- to 30- min exposure	Multiple studies suggesting effectiveness; protocol for clinical use already pioneered	Variability in protocols; mask contour affects UV dose; parts of mask (straps) may take longer to treat; high dose UV may degrade mask	Aerosol penetration met NIOSH certification criteria	Peer reviewed: Mills et al,[14] 2018; Lindsley et al,[39] 2015, Viscusi et al,[23] 2009 Non–peer reviewed: Nebraska protocol,[43] 2020; Fischer et al,[40] 2020

Abbreviations: NIOSH, National Institute for Occupational Safety and Health; UVGI, UV germicidal irradiation.

[a] The studies are peer reviewed on likely survival time of virus on surfaces; however, the technique of using time as a decontamination method has not been tested or validated.

[b] These decontamination methods are not recommended for consideration owing to the risk of toxic residual chemicals or degradation in respirator function.