Decontamination of face masks with steam for mask reuse in fighting the pandemic COVID-19: Experimental supports

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Funding information
Shandong Key Research and Development Program in China, Grant/Award Number: 2019GNC106074; Shandong Team-training Program for Talents of Superior Disciplines at Colleges in China, Grant/Award Number: 1119029; National Key R&D Program for the 13th Five-Year Plan of China, Grant/Award Numbers: 2016YFD050110404, 2016YFD0500707-7

Abstract
The coronavirus disease 2019 pandemic caused by the novel coronavirus SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) has claimed many lives worldwide. Wearing medical masks (MMs) or N95 masks (N95Ms) can slow the virus spread and reduce the infection risk. Reuse of these masks can minimize waste, protect the environment, and help solve the current imminent shortage of masks. Disinfection of used masks is needed for their reuse with safety, but improper decontamination can damage the blocking structure of masks. In this study, we demonstrated using the avian coronavirus of infectious bronchitis virus to mimic SARS-CoV-2 that MMs and N95Ms retained their blocking efficacy even after being steamed on boiling water for 2 hours. We also demonstrated that three brands of MMs blocked over 99% viruses in aerosols. The avian coronavirus was completely inactivated after being steamed for 5 minutes. Altogether, this study suggested that MMs are adequate for use on most social occasions and both MMs and N95Ms can be reused for a few days with steam decontamination between use.

KEYWORDS
coronavirus, COVID-19, decontamination, mask, reuse

1 | INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic caused by the novel coronavirus SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) has spread to most countries in the world and has claimed over 160,000 lives. Wearing medical masks (MMs) or N95 respirators can slow virus spread and reduce infection risk. The N95 respirators are termed in this report N95 masks (N95Ms). Although these masks are intended for single-use only and should be carefully worn and disposed as recommended by manufacturers, nonemergency reuse of them has been practiced for decades even in developed countries for reducing unnecessary waste. Currently, reuse of these masks is highly needed due to an imminent shortage of supply.
decontamination effect and influence of the mask’s blocking efficacy of this measure were examined.

2 | MATERIALS AND METHODS

The vaccine strain of avian infectious bronchitis virus H120 was used to mimic SARS-CoV-2 as they are both coronaviruses. The virus was from Qingdao Ruijie Biotechnology Company in Qingdao, China, and propagated using 10-day-old embryonated eggs. Virus quantification was performed using a real-time TaqMan reverse transcription-polymerase chain reaction (RT-PCR) assay reported previously.\(^1\) Four brands of MMs (MMa, MMb, MMc, MMd) and two brands of N95Ms (N95Ma, N95Mb) produced in China were tested. Their brand names were not showed herein to avoid conflict of interest. These masks were put into intact plastic bags and steamed on boiling tap water in a kitchen pot for certain time.

The blocking efficacy was detected using the device reported previously (Figure 1).\(^2\) In brief, the top parts of 60-mL syringes were removed, and then they were wrapped with the tested masks except for the control tubes. A facial cleaning sponge (8-mm thick) made of hydrophilic polyvinyl alcohol was set inside the syringe in advance behind the wrapped mask for collecting the virus passing through the masks. Three or four syringes were then aligned and bound seamlessly together to generate paired data. These syringes were connected with a seamless plastic bag, which collected the aerosols containing the virus produced with a nebulizer. The aerosols have a median diameter of 3.9 μm, and 65% of the aerosols have diameters less than 5.0 μm, as given in the specifications of the nebulizer.

The allantoic fluid containing the coronavirus was diluted 1:10 using phosphate-buffered saline (PBS). The fluid was added into the nebulizer for producing the aerosols containing the virus. The air containing the aerosols was inhaled into and out of the syringes 100 times through the synchronous piston movement of the syringes (approximately 40 mL air was inhaled per piston movement), to mimic human breath. Then the masks were unwrapped, and the sponge inside the syringe was taken out, soaked in a small plastic bag containing 2 mL PBS, and pressed ten times. RNA from 0.2 mL of the PBS was extracted for the detection of the amount of the virus using the TaqMan RT-PCR.

Each detection in this study was conducted using different individual items four times. The data difference was statistically analyzed using the paired t test (tails: 2; type: 1).

3 | RESULTS

3.1 | Blocking efficacy of masks before steaming

As given in Table 1, over 99% of the viruses were blocked by MMa, MMc, MMd, N95Ma, and N95Mb before steaming. MMb blocked approximately 98% of the virus, and its Ct values were significantly lower than those of the other masks (\(P < .01\)).

3.2 | Blocking efficacy of steamed masks

To examine whether the blocking efficacy of the masks declined significantly due to steam decontamination, the masks were steamed on boiling water. Some MMa, MMd, and N95Me had been used for 7 days before steam treatment and the remaining brands had not been used before the steam treatment (Table 1). As given in Table 1,
| Masks     | Steamed time, min | C\(_i\) increase (X ± SD) | Percentage blocked (95\% CI) |
|-----------|------------------|---------------------------|-----------------------------|
| MMa       | 0                | 11.071 ± 0.714            | 99.954 (99.934-99.972)      |
| MMa       | 20               | 10.820 ± 1.159            | 99.945 (99.876-99.975)      |
| MMa       | 60               | 9.992 ± 1.654             | 99.902 (99.691-99.969)      |
| MMa\(^a\) | 120              | 9.626 ± 0.871             | 99.873 (99.768-99.931)      |
| MMb       | 0                | 5.838 ± 0.593             | 98.251 (97.362-98.841)      |
| MMb       | 120              | 4.785 ± 0.571             | 96.373 (94.612-97.558)      |
| MMc       | 0                | 9.486 ± 0.070             | 99.860 (99.854-99.867)      |
| MMc       | 120              | 8.531 ± 0.764             | 99.730 (99.541-99.841)      |
| MMd       | 0                | 9.070 ± 1.305             | 99.814 (99.540-99.925)      |
| MMd\(^a\) | 120              | 8.970 ± 1.019             | 99.801 (99.596-99.902)      |
| N95Me     | 0                | 12.363 ± 0.318            | 99.981 (99.976-99.985)      |
| N95Me     | 20               | 11.370 ± 1.311            | 99.962 (99.906-99.985)      |
| N95Me\(^a\) | 60              | 12.308 ± 0.577            | 99.980 (99.971-99.987)      |
| N95Mf     | 0                | 12.404 ± 1.253            | 99.982 (99.956-99.992)      |
| N95Mf     | 120              | 11.417 ± 1.633            | 99.963 (99.887-99.988)      |

\(^a\)These masks had been used for 7 days before the hot steam treatment.

all the C\(_i\) values of the six brands of masks, used or unused, were of no significant difference after they were steamed for 20, 60, or 120 minutes (P > .05). Accordingly, their blocking efficacy changed little due to the hot steam.

### 3.3 Decontamination efficacy of the steaming measure

The allantoic fluid containing the avian coronavirus was added into five 1.5 mL Eppendorf tubes (0.2 mL for each tube). Four of these five tubes were closed and steamed on boiling water for 5 minutes, and the remaining tube was kept at room temperature. Then, the allantoic fluid in the four steamed tubes was 10-fold diluted using PBS. This was followed with inoculation of embryonated eggs using the diluted allantoic fluid (0.1 mL fluid per egg, 3 eggs per tube). Then, the allantoic fluid in the tube kept at room temperature was diluted and used to inoculate three embryonated eggs in the same manner. After incubation for 3 days, the embryonated eggs inoculated with the fluid from steamed tubes were all negative in the real-time TaqMan RT-PCR assay, and the embryonated eggs inoculated with the fluid from the tube kept at room temperature were all positive in the real-time TaqMan RT-PCR assay. These pieces of data suggested that the avian coronaviruses were completely inactivated through 5-minute steaming on boiling water.

### 4 DISCUSSION

This study suggested that all the tested MMs and N95Ms had excellent efficacy in blocking the coronavirus, although MMb showed a little less blocking efficacy. The MMb and the MM used in our previous study were of the same origin.\(^3\) Their blocking data in this study (approximately 98%) was higher than that in our previous study (approximately 96%), likely because the data herein was compared with the control without any blocking material before the virus-collecting sponge, and the data in our previous study was compared with the control having a layer of leaky cloth. All the four MMs were made of melt-blown polypropylene, but the weight of nonwoven cloth in MMb (2.115 ± 0.012 g/piece) was significantly lower than that in the three others (from 2.499 ± 0.008 g/piece to 2.619 ± 0.014 g/piece) with P < .01. MMb was thus thinner than the three others, and this likely accounts for the lower blocking efficacy of MMb. Collectively, these pieces of data demonstrated that MMs are adequate for use on most social occasions, and too thin MMs could be of less blocking efficacy.

In the background of the current pandemic, viruses are better than bacteria or physical particles for use in examining the blocking efficacy of masks. In our previous study, we used an avian influenza virus to mimic SARS-CoV-2 because they are both enveloped and pleomorphic spherical viruses with a similar size.\(^3\) In this study, the avian coronavirus was presumed to better mimic SARS-CoV-2 than the avian influenza virus.

Various measures including washing, boiling, baking, sunlight exposure, hairdryer blowing, autoclave, alcohol treatment, active chlorine treatment, ozone treatment, ethylene oxide treatment, gamma irradiation, or ultraviolet irradiation have been recommended to decontaminate masks for reuse.\(^5\)–\(^10\) Some of them can damage the blocking structure of MMs or N95Ms through physical or chemical action, and some of them may inactivate pathogens incompletely, and some of them are unsuitable for ordinary people because they require specific instruments or materials.\(^5\)–\(^10\)

The masks tested in this study are all made of at least three nonwoven fabric layers of melt-blown polypropylene. Decontamination of the masks should not damage the filtering structure of the masks. In this study, mask decontamination with steam on boiling water is without abrasive physical or chemical action. This can account for its excellent performance in maintaining the masks’ blocking efficacy.
We wore some of the steamed masks, and we felt they were as breathable in airflow as new masks, and the unpleasant smell of some used masks declined after the steam. This measure has other advantages including safety, not requiring special agents or devices, and rapid inactivation of most microbes potentially attached to the surface of masks. The steamed masks were dry because they were kept in plastic bags during the steaming process and can be used directly thereby. We presume, if available, that it is better to put the masks in stainless steel boxes than plastic bags for steam treatment.

It is worth noting that wearing masks cannot replace the important roles of social distancing and hand hygiene, and the donning and doffing of masks should be done correctly. Otherwise, their blocking efficacy might decline greatly and the infection risk might greatly increase. If a doffed mask is reused, it should be doffed without touching its surface, and the doffed mask should be put directly into a plastic bag or stainless steel box for steam and avoiding contamination of the surface of other items. Then, the hands should be washed immediately.

As most microbes potentially attached to the masks can be decontaminated within minutes through steaming on boiling water and the blocking efficacy of MMs and N95Ms declines little even after they have been steamed for 2 hours, we presume that MMs and N95Ms can be used for up to 7 to 10 days if they are kept clean and fitted and have not been damaged by other factors. Therefore, this study is valuable for solving the great shortage of masks in many countries for fighting the COVID-19 pandemic. It can also minimize unnecessary waste and protect the environment against discarding reusable masks.

ACKNOWLEDGMENTS
We thank Meng Yang and Randong Li for their helpful advice and assistance. This study was funded by the National Key R&D Program for the 13th Five-Year Plan of China (2016YFD050110404 and 2016YFD0500707-7); the Shandong Key Research and Development Program in China (2019GNC106074); the Shandong Team-training Program for Talents of Superior Disciplines at Colleges in China (1119029). The funders do not have any role in the design, conduct, and reportage of this study. This study was conducted in the College of Veterinary Medicine, Qingdao Agricultural University.

CONFLICT OF INTERESTS
The authors declare there are no conflict of interests.

AUTHOR CONTRIBUTIONS
Design: JMC, QXM, and HS; Experiment: JMC, QXM, CMZ, HLZ, GML, and RMY; Data analysis: JMC, QXM, and HS; Funding: HS; Manuscript writing: JMC and HS.

DATA AVAILABILITY STATEMENT
The derived data supporting the findings of this study are available within the article, and the raw data supporting the findings of this study are available from the corresponding author JC on request.

ETHICS STATEMENT
The study does not involve the participation of animals and humans other than the authors.

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How to cite this article: Ma Q-X, Shan H, Zhang C-M, et al. Decontamination of face masks with steam for mask reuse in fighting the pandemic COVID-19: Experimental supports. J Med Virol. 2020;92:1971-1974. https://doi.org/10.1002/jmv.25921