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Research paper

Re-use of health masks after autoclaving

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A B S T R A C T
With the rapid global spread of the new coronavirus and risk of pneumonia from COVID-19 infection, wearing a mask has become an essential defense for all frontline doctors, nurses, and healthcare professionals. Plus, the rise in demand for masks from the general public means the worldwide supply of masks is insufficient, which has led to an increase in the reuse of disposable masks. Therefore, this study compared the impact of autoclaving (steaming) and 70% ethyl alcohol treatment for decontaminating masks, as both methods can easily be used at home. The autoclaved masks showed a better filtration efficiency than the 70% ethyl alcohol-treated masks. A further investigation of 8 used KF 94 masks (filtration efficiency > 94%) also showed that autoclaving for decontamination was limited to two times. Moreover, a kitchen towel mask, a popular homemade alternative, did not show sufficient filtration efficiency.

1. Introduction

The recent coronavirus (COVID-19) pandemic is causing severe health issues all over the world, with the general public clearly aware of the contagious nature of COVID-19 and the need for protection. Although the route of infection of this virus has been identified as a spray infection forming aerosol via the respiratory system (van Doremalen et al., 2020), the aerosol nature of this virus has not yet been clarified. Moreover, despite such limited information, many health officials and governments recommend using personal protective equipment, such as respirators or masks, in the case of unknown risks in an indoor or outdoor environment. Yet, some governments have announced that the public may not need respiratory protection, such as masks, and instead masks should first be given to healthcare professionals in contact with COVID-infected patients and to infected patients to avoid further spread in healthcare facilities. In Asia, masks are already widely used by the general public as protection from fine particle exposure, especially in China and South Korea. Therefore, when these countries were hit first by the coronavirus epidemic, the general population immediately took to wearing masks as protection from potential virus exposure, in contrast to what happened in Europe and North America. While the benefits of wearing a mask have already been well-studied for protecting workers from potential particle exposure in a dusty workplace, the benefits of wearing masks against infective agents such as virus particles have not yet been clearly established. However, densely populated South Korea experienced lower levels of community infection than many less densely populated countries (Worldometer, n.d.). Most coronavirus infections in South Korea stemmed from a nursing home and religious group where many people were gathered together without mask protection. Most people wear masks for protection in the workplace or outdoors. Yet, there is a current lack of masks for the public and health professionals due to the unusually high demand related to the coronavirus outbreak. In the case of South Korea, each member of the public can buy two masks per week with proper identification, and there is a ban on exporting masks internationally until the domestic demand has been satisfied. Indeed, several research colleagues testing the decontamination of masks for reuse have experienced difficulty obtaining enough sample masks for their study. Notwithstanding, this study procured a sufficient number of masks to investigate the re-use of disposable masks after an appropriate decontamination procedure. The results confirm the possibility of reusing decontaminated masks, allowing the provision of sufficient numbers of masks to health professionals and patients.

2. Materials and methods

2.1. Selection of masks

Korean MFDS (Ministry of Food and Drug Safety) certified KF 94 masks were selected for the filter testing. MFDS mask certification is similar to NIOSH mask certification (NIOSH (National Institute of Occupational Safety and Health), 2019). KF 94 requires a higher than
94% particle filtration efficiency, ranging from 0.02 to 2 µm with an average diameter of 0.6 µm. The KF 94 standard is equivalent to FFP2 (European Union), KN95 (China), and DS/DL2 (Japan). KF94 masks are made of non-woven melt-blown fabrics commonly used as filtration, sorbents, hygiene products, and apparel and are electrostatically charged to increase the capture of particles (McCulloch, 1999; Sarbatly et al., 2016; Wehmann and McCulloch, 2012). Five randomly selected masks, which had all been used for one full day, were first tested for their filtration efficiency and then autoclaved for re-use. The autoclaved masks were used again for one full day and their filtration efficiency then tested after a second cycle of autoclaving.

### 2.2. Mask decontamination treatment

The used KF94 masks were either treated with 70% ethyl alcohol or autoclaving. The used masks were completely sprayed until wet with 70% ethyl alcohol and then dried overnight in an oven or autoclaved at 121°C with 15 atmospheric pressure for 15 min and then dried overnight in an oven.

#### 2.3. Filter performance test

The filter performance test was the same as described by Mohraz et al. (2019, 2020). An atomizer (4810, HCTm Co., Ltd., Korea) was used to generate the KCl (0.1%) test aerosol, ranging from 10 to 1000 nm diameter with an average diameter of 100 nm, which is similar in size to the coronavirus 120 nm (Fehr and Perlman, 2015). A particle-free airflow from a drycleaned air supply system, consisting of an oil trap, diffusion dryer, and HEPA (high-efficiency particulate air) filter, was supplied to the atomizer. The atomized particles were passed through the diffusion dryer for humidity removal and then delivered to the duct system where the particle-laden air was diluted with ultra-low penetration air (ULPA)-filtered make-up air. The make-up airstream was filtered using a ULPA filter to ensure that only KCl particles were present in the air stream. The test masks were located in a filter holder within an airtight test rig to determine their filtration efficiency against KCl particles. Two identical centerline isokinetic sampling probes were used to obtain representative readings of particle concentrations from the inlet and outlet sides of the material specimen test section. The number concentration and size distribution of inlet and outlet particles for each filter sample test were measured using a scanning nanoparticle spectrometer (SNPS, HCT Co., Ltd., Korea) connected to a condensation particle counter (CPC, model 3022A, TSI Inc., Shoreview, MN, USA). The sheath flow and particle-laden airflow used in the SNPS and CPC were 15 and 1.5 L min⁻¹, respectively. The representative size distribution of the KCl test particles was measured by SNPS and OPC. The masks were tested under face velocities of 2, 5, and 10 cm s⁻¹. The pressure drops across the test filter media sample during the filtration test were measured using a differential pressure gauge (Model CP 110, Kimo Co, France). The experimental setup for evaluating the performance of the nanofiber filter media is shown in Supplement 1. The fractional particle filtration efficiency was calculated using the following equation.

\[
\text{Filtration efficiency} (%) = \left( C_1 - C_2 \right) \times 100\% / C_1
\]

where C1, before filtration; C2, after filtration.

#### 2.4. Statistical analysis

The statistical analysis was conducted by Sigmaplot Version 11 using ANOVA multiple comparisons of Dunnett T3 to compare the sequential mask treatments. The levels of significance were set at \( P < 0.05 \).

| Treatment                  | Filtration Average particle size (± SD) (nm) | DP (Pa) |
|----------------------------|---------------------------------------------|--------|
| Mask used once             | Before 95.56 ± 6.42                         | 59.50 ± 13.36 |
| (Table 2)                  | After 85.75 ± 24.35                         | 76.75 ± 19.17 |
| Mask used once & autoclaved| Before 94.91 ± 6.99                         | 54.38 ± 11.62 |
| Autoclaved (Table 3)       | After 107.65 ± 13.60                        | 77.75 ± 18.71 |
| Autoclaved & used again     | Before 101.03 ± 2.86                        | 70.75 ± 22.63 |
| Autoclaved a second time    | After 109.62 ± 18.24                        | 92.25 ± 24.78 |
| 3 layers of kitchen towel   | Before 119.10 ± 16.66                       | 85.63 ± 30.93 |
| 4 layers of kitchen towel   | After 100.71 ± 3.42                         | 99.33 ± 10.60 |
|                            | After 113.00 ± 3.14                         | 196.33 ± 44.88 |
|                            | After 117.53 ± 2.51                         | 210.33 ± 1.53 |

SD, standard deviation; DP (Pa), differential pressure in Pa.

### 3. Results and conclusion

#### 3.1. Initial screening test

The atomized KCl solution consisted of particles with an average diameter ranging from 95 to 101 nm according to SNPS (Table 1). Particle size distributions measured by SNPS and OPC were shown in Supplement 2. An initial test on a dental mask without treatment showed a filtration efficiency of 81.56%. For the KF 94 mask, autoclaving reduced the filtration efficiency from 93.76 to 85.03%, while 70% of ethyl alcohol reduced the filtration efficiency to 76.98%. Another mask filtration experiment using K 94 mask A also showed similar results, where autoclaving reduced the filtration efficiency from 99.46 to 98.64%, while 70% ethyl alcohol reduced the filtration efficiency to 90.73%. Consequently, since 70% ethyl alcohol significantly reduced the filtration efficiency, only autoclaving was used for decontamination in all further tests (Table 2).

#### 3.2. Mask filtration test after autoclaving

Eight masks that had been used once showed a filtration efficiency of 96.65 ± 3.25% (Table 3). After autoclaving these same masks, the filtration efficiency stayed at 92.08 ± 5.47% (Table 4), representing no significant difference with after one use. Similarly, when the autoclaved masks were re-used, the filtration efficiency remained at 94.54 ± 3.80%, also representing no significant difference with after one use and after autoclaving once, respectively (Table 5). However, when autoclaving the masks a second time, the filtration efficiency decreased to 81.69 ± 17.28% (Table 6), although still no significant difference with the results in Tables 2, 3, and 4. Since the current testing was applied to re-used masks, there was some pressure build-up due to accumulated particle capture in the masks (Table 1).

#### 3.3. Filtration efficiency of kitchen towel masks

Three-layer and 4-layer kitchen towel masks showed lower filtration efficiencies at 52.81 ± 8.23% and 63.55 ± 2.20%, respectively (Tables 7–8).

#### 3.4. Particle size distribution and differential pressure

As shown in Table 1 the particle size ranged from 95 to 101 nm. The mask filter pressure before the filter test was under or near 70 Pa, as required by the KF 94 mask pressure standard (below 70 Pa) prescribed by MFDS (2019). Moreover, as the kitchen towel masks showed a pressure higher than 100 Pa before and after filter testing, this could create breathing problems.
Filtration efficiency of masks after 70% alcohol and autoclaving.

| Mask               | Treatment | Filtration | SNPS (×10^6 particles) | CMD (nm) | GSD | DP (Pa) | Vacuum pump (LPM) | Filter mass (mg/m^3) | Filtration efficiency (%)^a |
|--------------------|-----------|------------|------------------------|----------|-----|---------|-------------------|----------------------|----------------------------|
| Dental mask        | No        | Before     | 3.80E+06               | 93.70    | 2.16| 38      | 29.12             | 3.65                 | 81.56                      |
|                    |           | After      | 6.23E+05               | 104.21   | 2.18| 45      | 28.90             | 0.67                 | 93.76                      |
| KF 94 mask A       | No        | Before     | 3.77E+06               | 96.58    | 2.17| 62      | 28.76             | 3.75                 | 76.98                      |
|                    |           | After      | 2.14E+05               | 99.32    | 2.18| 77      | 28.31             | 0.23                 | 99.46                      |
| Autoclave          | Before    | 4.02E+06   | 96.52                  | 2.18     | 66  | 28.50   | 4.38              | 85.03                |
|                    | After     | 1.22E+05   | 97.26                  | 2.06    | 82  | 28.19   | 0.66              | 98.84                |
| 70% alcohol        | Before    | 3.21E+06   | 99.56                  | 2.18    | 29.10| 3.35    | 97.38             | 0.81                 | 97.38                      |
|                    | After     | 4.04E+05   | 136.73                 | 2.17    | 28.70| 4.18    | 94.6              | 99.46                |
| KF 94 mask B       | No        | Before     | 3.48E+06               | 96.94    | 2.17| 69      | 29.54             | 4.18                 | 94.6                      |
|                    |           | After      | 1.95E+04               | 62.26    | 1.73| 87      | 28.67             | 0.02                 | 94.6                      |
| Autoclave          | Before    | 4.01E+06   | 95.81                  | 2.18    | 74.81| 4.16    | 98.64             | 0.06                 | 98.64                      |
|                    | After     | 7.52E+04   | 89.10                  | 1.89    | 81.81| 4.06    | 98.64             | 0.06                 | 98.64                      |
| 70% alcohol        | Before    | 4.15E+06   | 95.96                  | 2.19    | 75   | 28.57   | 4.39              | 90.73                |
|                    | After     | 2.53E+05   | 130.14                 | 2.18    | 92.38| 0.41    | 96.65 ± 3.25      | 98.64                |

SNPS, scanning nanoparticle spectrometer; CMD, count median diameter; GSD, geometric standard deviation; DP, differential pressure; LPM, liters per minute.

^a (Before filter mass – after filter mass) / Before filter mass × 100.

### 4. Discussion

Several research groups have already investigated mask decontamination. For example, NIOSH-certified N95 filtering facepiece respirators (FFRs) have been decontaminated using 5 methods; UV irradiation, ethylene oxide, vaporized hydrogen peroxide, microwave oven irradiation, and bleaching. When testing the filtration efficiency and airflow resistance, microwave oven irradiation was found to melt the samples of two FFR models, while UV irradiation, ethylene oxide, and vaporized hydrogen peroxide showed the most promising results. The smell of bleach remained noticeable, even after overnight drying, and low levels of chlorine gas were found to off-gas from bleach-decontaminated FFRs when rehydrated with deionized water (Viscusi et al., 2009).

Another on-going study at Stanford University, currently limited in supplies due to COVID-19, has tested three disinfection methods; hot air (75 °C, 30 min), UV irradiation (254 nm, 30 W, 30 min), and steam (10 min). Their results suggest that hot air applied over 20 cycles did not degrade the filtration efficiency (> 95%), UV treatment over 10 cycles did not degrade the filtration efficiency (> 95%), and steam treatment requires caution, as the filtration efficiency can be maintained (> 95%) within 3 cycles, yet the efficiency degrades to ~85% after 5 cycles and drops to ~80% after 10 cycles (Liao et al., 2020). Other decontamination studies also tested a rice cooker (149–164 °C for 3 min, without adding water), autoclave (121 °C for 16 min), ethanol (70% ethanol, 10 min submersion), isopropanol (100% isopropanol, 10 min submersion), and bleach (5% sodium hypochlorite solution, 10 min submersion). As a result, the physical decontamination methods (rice cooker and autoclave) were found to be less destructive to the filter than the chemical methods that eliminated the electrostatic charges on the filters (Lin et al., 2017).

The current study results also showed some consistency with other studies. Chemical treatment, such as 70% alcohol, isopropanol, and bleach, eliminates the electrostatic charges on the filter. Microwave oven treatment can destroy masks unless using a well standardized power level. UV irradiation can be effective at a wavelength of 254 nm for 30 min. Steam (hot water vapor) and autoclaving give consistently good filtration results without affecting the electrostatic capturing capacity, although for autoclaving there is a limit to the number of times, and in the current study this limit was twice. Pressure build-up after autoclaving was also a concern in the current study as the testing was conducted on used masks, unlike other studies, as repeated use can cause pressure build-up due to particle capture.

Overall, the present study shows that, in the case of mask shortage, decontamination via autoclaving or steaming allows the re-use of masks up to two times for protection against COVID-19 infection in healthcare facilities or at home.

### 5. Conclusions

The current filtration efficiency test results showed that health

| Treatment | Number | Filtration | SNPS (×10^6 particles) | CMD (nm) | GSD | DP (Pa) | Vacuum pump (LPM) | Filter mass (mg/m^3) | Filtration efficiency (%)^a |
|-----------|--------|------------|------------------------|----------|-----|---------|-------------------|----------------------|----------------------------|
| No        | 1      | Before     | 2.76                   | 94.11    | 2.22| 52      | 29.57             | 3.10                 | 97.41                      |
|           |        | After      | 0.11                   | 72.86    | 2.00| 68      | 28.99             | 0.08                 | 97.41                      |
|           | 2      | Before     | 2.78                   | 97.54    | 2.19| 52      | 29.89             | 3.07                 | 97.38                      |
|           |        | After      | 0.15                   | 78.07    | 2.06| 65      | 28.93             | 0.08                 | 97.38                      |
|           | 3      | Before     | 4.55                   | 99.46    | 2.24| 52      | 28.74             | 6.87                 | 98.33                      |
|           |        | After      | 0.04                   | 92.89    | 2.25| 71      | 28.71             | 0.11                 | 98.33                      |
|           | 4      | Before     | 1.44                   | 88.37    | 2.22| 53      | 29.12             | 1.90                 | 97.11                      |
|           |        | After      | 0.25                   | 81.92    | 2.10| 65      | 28.72             | 0.16                 | 97.11                      |
|           | 5      | Before     | 1.47                   | 85.54    | 2.22| 55      | 28.88             | 1.85                 | 97.57                      |
|           |        | After      | 0.04                   | 72.83    | 2.01| 68      | 28.47             | 0.04                 | 97.57                      |
|           | 6      | Before     | 2.97                   | 93.53    | 2.57| 52      | 28.13             | 4.08                 | 99.30                      |
|           |        | After      | 0.02                   | 68.19    | 1.97| 72      | 27.58             | 0.03                 | 99.30                      |
|           | 7      | Before     | 5.20                   | 103.65   | 2.25| 91      | 26.95             | 9.78                 | 100.00                     |
|           |        | After      | 0.03                   | 76.16    | 1.86| 122     | 26.56             | 0.00                 | 100.00                     |
|           | 8      | Before     | 4.49                   | 102.28   | 2.26| 64      | 27.53             | 7.95                 | 91.52                      |
|           |        | After      | 0.23                   | 143.12   | 2.19| 83      | 27.47             | 0.67                 | 91.52                      |

SNPS, scanning nanoparticle spectrometer; CMD, count median diameter; GSD, geometric standard deviation; DP, differential pressure; LPM, liters per minute.

^a (Before filter mass – after filter mass) / Before filter mass × 100.
Table 4
Filtration efficiency of used masks after autoclaving once (used once/autoclaved once).

| Treatment Number | Filtration SNPS \(\times 10^6\) particles | CMD (nm) | GSD | DP (Pa) | Vacuum pump (LPM) | Filter mass (mg/m³) | Filtration efficiency (%) \(^a\) | Filtration efficiency (%) average ± SD |
|------------------|---------------------------------|--------|-----|--------|-------------------|-------------------|----------------|----------------------------------|
| Autoclave 1      | Before 1 | 1.36 | 91.40 | 2.21 | 52 | 29.18 | 1.84 | 86.97 | 92.08 ± 5.47 |
|                  | After 1  | 0.38 | 113.34| 2.24 | 63 | 28.25 | 0.24 | 88.89 |
|                  | Before 2 | 1.47 | 91.70 | 2.20 | 53 | 28.53 | 1.90 | 88.98 |
|                  | After 2  | 0.10 | 114.02| 2.26 | 67 | 27.80 | 0.21 | 86.98 |
|                  | Before 3 | 3.64 | 90.68 | 2.17 | 69 | 28.11 | 3.65 | 86.98 |
|                  | After 3  | 0.33 | 112.08| 2.22 | 101| 27.58 | 0.48 | 96.48 |
|                  | Before 4 | 1.75 | 83.76 | 2.19 | 48 | 27.82 | 1.97 | 96.48 |
|                  | After 4  | 0.08 | 100.85| 2.17 | 73 | 27.38 | 0.07 | 96.48 |
|                  | Before 5 | 2.84 | 94.37 | 2.24 | 63 | 28.25 | 0.24 | 96.48 |
|                  | After 5  | 0.27 | 102.90| 2.26 | 48 | 28.9 | 0.28 | 96.48 |
|                  | Before 6 | 4.82 | 103.42| 2.27 | 58 | 27.73 | 8.48 | 96.48 |
|                  | After 6  | 0.10 | 100.51| 2.10 | 97 | 27.11 | 0.12 | 96.48 |

SNPS, scanning nanoparticle spectrometer; CMD, count median diameter; GSD, geometric standard deviation; DP, differential pressure; LPM, liter per minute.

\(^a\) (Before filter mass − after filter mass) / Before filter mass \(\times 100\).

Table 5
Filtration efficiency of masks used after autoclaving once (used once/autoclaved once/used again).

| Treatment Number | Filtration SNPS \(\times 10^6\) particles | CMD (nm) | GSD | DP (Pa) | Vacuum pump (LPM) | Filter mass (mg/m³) | Filtration efficiency (%) \(^a\) | Filtration efficiency (%) average ± SD |
|------------------|---------------------------------|--------|-----|--------|-------------------|-------------------|----------------|----------------------------------|
| No               | Before 1 | 4.29 | 101.62| 2.22 | 110 | 28.14 | 6.04 | 98.51 | 94.54 ± 3.80 |
|                  | After 1  | 0.07 | 116.59| 2.06 | 138 | 27.38 | 0.09 | 100.00 |
|                  | Before 2 | 5.45 | 104.69| 2.22 | 72  | 28.37 | 6.60 | 100.00 |
|                  | After 2  | 0.03 | 74.03 | 1.84 | 96  | 28.04 | 0.00 | 100.00 |
|                  | Before 3 | 5.27 | 96.14 | 2.20 | 71  | 28.04 | 6.31 | 94.31 |
|                  | After 3  | 0.25 | 92.91 | 2.10 | 84  | 27.58 | 0.36 | 94.31 |
|                  | Before 4 | 4.68 | 101.36| 2.23 | 66  | 27.55 | 4.85 | 93.07 |
|                  | After 4  | 0.20 | 121.75| 2.13 | 88  | 27.00 | 0.47 | 93.07 |
|                  | Before 5 | 4.06 | 98.36 | 2.22 | 90  | 28.14 | 6.09 | 87.73 |
|                  | After 5  | 0.29 | 132.55| 2.14 | 111| 27.67 | 0.75 | 87.73 |
|                  | Before 6 | 4.14 | 99.68 | 2.26 | 32  | 28.46 | 6.93 | 92.48 |
|                  | After 6  | 0.19 | 117.20| 2.18 | 82 | 27.71 | 0.34 | 92.48 |

SNPS, scanning nanoparticle spectrometer; CMD, count median diameter; GSD, geometric standard deviation; DP, differential pressure; LPM, liters per minute.

\(^a\) (Before filter mass − after filter mass) / Before filter mass \(\times 100\).

Table 6
Filtration efficiency of masks after autoclaving twice (used once/autoclaved once/used again/autoclaved again).

| Treatment Number | Filtration SNPS \(\times 10^6\) particles | CMD (nm) | GSD | DP (Pa) | Vacuum pump (LPM) | Filter mass (mg/m³) | Filtration efficiency (%) \(^a\) | Filtration efficiency (%) average ± SD |
|------------------|---------------------------------|--------|-----|--------|-------------------|-------------------|----------------|----------------------------------|
| Autoclave 1      | Before 1 | 4.75 | 96.38 | 2.20 | 50 | 28.10 | 5.47 | 70.48 | 81.69 ± 17.28 |
|                  | After 1  | 1.30 | 121.62| 2.16 | 60 | 27.46 | 1.62 | 65.71 |
|                  | Before 2 | 4.46 | 99.83 | 2.21 | 44 | 28.15 | 5.45 | 65.71 |
|                  | After 2  | 1.12 | 133.05| 2.19 | 52 | 28.09 | 1.87 | 65.71 |
|                  | Before 3 | 5.33 | 101.69| 2.22 | 97 | 26.88 | 7.35 | 99.53 |
|                  | After 3  | 0.09 | 119.08| 2.10 | 124| 26.82 | 0.03 | 99.53 |
|                  | Before 4 | 4.48 | 100.83| 2.23 | 44 | 28.07 | 6.35 | 64.61 |
|                  | After 4  | 1.03 | 139.20| 2.20 | 55 | 28.01 | 2.25 | 64.61 |
|                  | Before 5 | 4.22 | 96.68 | 2.22 | 67 | 28.27 | 6.23 | 62.07 |
|                  | After 5  | 1.02 | 135.18| 2.15 | 86 | 27.87 | 2.36 | 62.07 |
|                  | Before 6 | 5.70 | 80.74 | 2.26 | 81 | 28.44 | 8.03 | 97.66 |
|                  | After 6  | 0.24 | 93.05 | 2.11 | 101| 27.78 | 0.19 | 97.66 |
|                  | Before 7 | 3.22 | 91.31 | 2.22 | 108| 27.39 | 4.10 | 98.61 |
|                  | After 7  | 0.06 | 110.76| 2.09 | 132| 26.87 | 0.06 | 98.61 |
|                  | Before 8 | 2.89 | 92.81 | 2.25 | 60 | 28.19 | 3.75 | 94.85 |
|                  | After 8  | 0.12 | 100.89| 2.18 | 75 | 27.57 | 0.19 | 94.85 |

SNPS, scanning nanoparticle spectrometer; CMD, count median diameter; GSD, geometric standard deviation; DP, differential pressure; LPM, liters per minute.

\(^a\) (Before filter mass − after filter mass) / Before filter mass \(\times 100\).
**Table 7**

Filtration efficiency of kitchen towel (3 layers).

| Treatment | Number | Filtration | SNPS ($\times 10^6$ particles) | CMD (nm) | GSD | DP (Pa) | Vacuum pump (LPM) | Filter mass (mg/m³) | Filtration efficiency (%) | Filtration efficiency (%) average ± SD |
|-----------|--------|------------|--------------------------------|---------|------|---------|--------------------|----------------------|--------------------------|-----------------------------------|
| No        | 1      | Before     | 5.78                           | 104.27  | 2.22 | 109     | 27.72              | 8.49                 | 60.24                   | 52.81 ± 8.23                |
|           |        | After      | 0.07                           | 116.59  | 2.06 | 248     | 24.48              | 3.38                 |                         |                                   |
|           | 2      | Before     | 3.96                           | 100.41  | 2.22 | 101     | 28.19              | 5.42                 | 43.97                   |                                   |
|           |        | After      | 1.86                           | 110.75  | 2.15 | 167     | 26.70              | 3.03                 |                         |                                   |
|           | 3      | Before     | 4.64                           | 97.45   | 2.21 | 88      | 28.66              | 7.41                 | 54.20                   |                                   |
|           |        | After      | 2.07                           | 111.66  | 2.12 | 174     | 26.23              | 3.39                 |                         |                                   |

SNPS, scanning nanoparticle spectrometer; CMD, count median diameter; GSD, geometric standard deviation; DP, differential pressure; LPM, liters per minute.  
* (Before filter mass – after filter mass) / Before filter mass × 100.

**Table 8**

Filtration efficiency of kitchen towel (4 layers).

| Treatment | Number | Filtration | SNPS ($\times 10^6$ particles) | CMD (nm) | GSD | DP (Pa) | Vacuum pump (LPM) | Filter mass (mg/m³) | Filtration efficiency (%) | Filtration efficiency (%) average ± SD |
|-----------|--------|------------|--------------------------------|---------|------|---------|--------------------|----------------------|--------------------------|-----------------------------------|
| No        | 1      | Before     | 5.77                           | 104.31  | 2.24 | 133     | 27.34              | 8.06                 | 61.04                   | 63.55 ± 2.20                |
|           |        | After      | 2.06                           | 120.40  | 2.11 | 210     | 26.14              | 3.14                 |                         |                                   |
|           | 2      | Before     | 5.84                           | 101.29  | 2.21 | 122     | 26.57              | 9.18                 | 64.49                   |                                   |
|           |        | After      | 1.84                           | 115.75  | 2.10 | 212     | 26.46              | 3.26                 |                         |                                   |
|           | 3      | Before     | 5.88                           | 105.25  | 2.20 | 123     | 26.84              | 9.24                 | 65.14                   |                                   |
|           |        | After      | 1.81                           | 116.43  | 2.09 | 209     | 25.37              | 3.22                 |                         |                                   |

SMPS, scanning mobility particle sizer; CMD, count median diameter; GSD, geometric standard deviation; DP, Differential pressure; LPM, liters per minute.  
* (Before filter mass – after filter mass) / Before filter mass × 100.

Masks can be re-used after autoclaving up to two times without any significant decrease in the filtration efficiency. However, autoclaving more than two times may reduce the filtration efficiency. Decontaminating masks using 70% ethyl alcohol was shown to reduce masks, should not be used for respiratory protection unless there are no other available protective measures.

**Table 8**

Filtration efficiency of kitchen towel (4 layers).

| Treatment | Number | Filtration | SNPS ($\times 10^6$ particles) | CMD (nm) | GSD | DP (Pa) | Vacuum pump (LPM) | Filter mass (mg/m³) | Filtration efficiency (%) | Filtration efficiency (%) average ± SD |
|-----------|--------|------------|--------------------------------|---------|------|---------|--------------------|----------------------|--------------------------|-----------------------------------|
| No        | 1      | Before     | 5.77                           | 104.31  | 2.24 | 133     | 27.34              | 8.06                 | 61.04                   | 63.55 ± 2.20                |
|           |        | After      | 2.06                           | 120.40  | 2.11 | 210     | 26.14              | 3.14                 |                         |                                   |
|           | 2      | Before     | 5.84                           | 101.29  | 2.21 | 122     | 26.57              | 9.18                 | 64.49                   |                                   |
|           |        | After      | 1.84                           | 115.75  | 2.10 | 212     | 26.46              | 3.26                 |                         |                                   |
|           | 3      | Before     | 5.88                           | 105.25  | 2.20 | 123     | 26.84              | 9.24                 | 65.14                   |                                   |
|           |        | After      | 1.81                           | 116.43  | 2.09 | 209     | 25.37              | 3.22                 |                         |                                   |

SMPS, scanning mobility particle sizer; CMD, count median diameter; GSD, geometric standard deviation; DP, Differential pressure; LPM, liters per minute.  
* (Before filter mass – after filter mass) / Before filter mass × 100.

The authors declare that they have no competing interests.

**Appendix A. Supplementary data**

Supplementary data to this article can be found online at https://doi.org/10.1016/j.impact.2020.100231.

**References**

van Doremalen, N., Bushmaker, T., Morris, D.H., Holbrook, M.G., Gamble, A., Williamson, B.N., Tamin, A., Harcourt, J.L., Thornburg, N.J., Gerber, S.L., Lloyd-Smith, J.O., de Wit, E., Munster, V.J., 2020. Aerosol and surface stability of SARS-CoV-2 as compared with SARS-CoV-1. N. Engl. J. Med. https://doi.org/10.1056/NEJMc2004973. 2020 Mar 17. (Epub ahead of print).

Fehr, A.R., Perlman, S., 2015. An overview of their replication and pathogenesis; section 2 genomic organization. In: Maier, H.J., Bickerton, E., Britton, P. (Eds.), Methods in Molecular Biology. 1282. Springer, 978-1-4939-2438-7, pp. 1–23. https://doi.org/10.1007/978-1-4939-2438-7_2. (PMC 3469385. PMID 25728466).

Liao, L., Xiao, W., Yu, X., Wang, H., Zhao, M., Wang, Q., Chu, S., Cui, Y., 2020. Can N95 Facial Masks Be Used After Disinfection? And for How Many Times? Report From The Collaboration of Stanford University and 4C Air, Inc. March 25, 2020.

Lin, T.H., Chen, C.C., Huang, S.H., Kuo, C.W., Lai, C.Y., Lin, W.Y., 2017. Filter quality of electret masks in filtering 14.6 ± 594 nm aerosol particles: effects of five decontamination methods. PLoS One 12 (10), e0186217. https://doi.org/10.1371/journal.pone.0186217.

Mc Culloch, J.G., 1999. The history of the development of melt blowing technology. Int. Nonwovens J. 3 (1). https://doi.org/10.1177/1558925099OS-800123.

MFDS (Ministry of Food and Drug Safety), 2019. Guideline for Health Mask Standard. National Insitute of Food and Drug Safety Evaluation, Republic of Korea.

Mohraz, M.H., Golbaaei, F., Yu, I.J., Mansounia, A.S., Zadeh, S., Dehgan, S.F., 2019. Preparation and optimization of multifunctional electrospun polyurethane/chitosan nanofibers for air pollution control applications. Int. J. Environ. Sci. Technol. 16 (2), 681–694.

Mohraz, M.H., Yu, I.J., Beiollahi, A., Dehgan, S.F., Shin, J.H., Golbaaei, F., 2020. Assessment of the potential release of nanomaterials from electrospun nano fibers by electro decontamination. Nanoimpact. 19. https://doi.org/10.1016/j.impact.2020.100223.

NIOSH (National Institute of Occupational Safety and Health), 2019. Determination of Particulate Filter Efficiency Level for N95 Series Filters Against Solid Particulates for Non-powered, Air-purifying Respirators Standard Testing Procedure (STP) (Procedure No. TEB-APR-STP-0059). National Institute for Occupational Safety and Health, National Personal Protective Technology Laboratory, Pittsburgh, PA Available at. https://www.cdc.gov/niosh/npptl/stps/apresp.html.

Sarbatly, R., Krishnaiah, D., Kamin, Z., 2016. A review of polymer nano bres by elec trospinning and their application in oil-water separation for cleaning up marine oil spills. Mar. Pollut. Bull. 106 (1–2), 8–16. https://doi.org/10.1016/j.marpolbul.2016.
Viscusi, D.J., Bergman, M.S., Eimer, B.C., Shaffer, R.E., 2009. Evaluation of five decontamination methods for filtering facepiece respirators. Ann. Occup. Hyg. 53 (8), 815–827.

Wehmann, M., McCulloch, W.J.G., 2012. Melt blowing technology. In: Karger-Kocsis, J. (Ed.), Polypropylene, pp. 415–420. https://doi.org/10.1007/978-94-011-4221-6_58. Worldometer https://www.worldometers.info/coronavirus, Accessed date: 4 March 2020.