ABSTRACT

Background: Due to coronavirus disease 2019 (COVID-19), world-wide face mask use is increasing exponentially. These face masks are difficult to recycle, and their accumulation contributes to enormous environmental threats. In this study, we hypothesize that the face mask can be reused as long as it retains its original structure, which will slow the environmental impacts.

Materials and Methods: We selected common disposable surgical masks for this study and classified test conditions based on wear time and reuse method. After wearing the mask for 10 hours, we let it dry naturally in the shade for 14 hours. The specimens were measured by scanning electron microscope and capillary flow porometer.

Results: The pore structure of the mask did not change when worn 4 times for 10 hours each time, and there was no significant pore structure change when impregnated with ethyl alcohol (purity 95%), treated with UV or steam, or run through a washing machine.

Conclusion: The pore structure of the surgical mask was not changed significantly after 40 hours of use. Surgical mask pore structure did not change significantly after treatment with ethyl alcohol, UV light, steam, or a washing machine.

Keywords: Face mask; Reuse mask; Pore structure; Capillary flow porometer; COVID-19

INTRODUCTION

Human history is divided into the Stone Age, Bronze Age, and Iron Age according to the human tools used. With plastic considered an important material in the present, some call this the 'Plastic Age' [1, 2].

Globally, plastics usage is increasing exponentially [3]. According to a Greenpeace 2019 report, Korea's annual disposable product use per person was 9.2 kg for plastic bags, 1.45 kg for polyethylene terephthalate bottles, and 0.9 kg for plastic cups [4].

As plastic usage increases, much of the waste is flowing into the soil and sea [2, 5]. Plastic waste decomposes into micro-plastics, and marine animals can mistake them for food. This causes them damage or death and can accumulate through the food chain and can even threaten human health [2, 5].
Miranda and de Carvalho-Souza [5] reported a very high micro-plastic intake rate in king mackerel (Scomberomorus cavalla) and Brazilian sharpnose sharks (Rhizoprionodon lalandii) captured on Brazil’s east coast. Various studies have reported that humans are eating fish that have consumed microplastic [5-7].

At the end of 2019, an unknown virus causing pneumonia was discovered in Wuhan, China. It was reported to the World Health Organization (WHO) and named coronavirus disease 2019 (COVID-19). The virus rapidly spread worldwide, causing millions of infections and deaths. In March 2020, WHO declared a pandemic, the highest epidemic alert phase risk level [8].

Current studies agree that person-to-person COVID-19 transmission mainly occurs through respiratory droplets, and wearing a mask can effectively prevent infection spread [9-12]. As a result, worldwide disposable face mask use has increased dramatically, coinciding with an increase in discarded products [13].

Oceans Asia reports that improperly discarded masks are being pushed to Soko Island, an uninhabited island in Hong Kong [14]. Also, it is estimated that up to 20 million disposable masks have been discarded per day in Korea during the COVID-19 pandemic, according to Korean Federation for Environmental Movement (KFEM) [15]. The mask waste decomposes into microplastics and accumulates in marine life, which then can threaten human health. Therefore, mask waste should be well managed to protect the environment and human health [14-17].

Since disposable face masks are difficult to recycle, it is necessary to extend their service life as much as possible as long as they retain functionality [18]. In addition, a method to sterilize masks is important since mask shortages could occur in emergency situations such as a pandemic or war.

COVID-19 is one of the first global disasters in modern civilized society [19, 20]. Therefore, most face mask life and reuse research is relatively recently.

Viscusi et al. [21] investigated filter aerosol penetration and filter airflow resistance decontamination methods for reusing Filtering Facepiece Respirators (FFRs). Results suggest that Ultraviolet Germicidal Irradiation (UVGI), Ethylene Oxide (EtO), and Vaporized Hydrogen Peroxide (VHP) are the most promising decontamination methods and chemicals.

Lindsley et al. [22] investigated UVGI treatment impacts on an N95 mask filter including particle penetration, flow resistance, and bursting strengths of the individual respirator coupon layers and the breakage strength of the respirator straps. Results showed that UVGI did not significantly affect the mask filter’s physical properties and suggested that it can be disinfected and reused.

de Man et al. [23] reported that steam sterilizing a mask at 121°C in a laminate bag did not affect the mask’s function and suggested that this method may be useful for reuse if the mask is rapidly insufficient.

Ma et al. [18] reported that medical masks (three brands) and N95 masks blocked more than 99% of viruses even after being placed in boiling water for 2 hours. These results suggest that medical masks and N95 masks can be reused after steam treatment.
Face masks in Korea are certified by the National Institute of Food and Drug Safety Evaluation (NIFDS) and are divided into two types, KF94 and KF80, according to dust collection efficiency [24]. Although KF94 or higher masks were recommended in the early days of virus outbreak, the NIFDS recently reported that cotton masks are also useful when other mask supplies are insufficient [25]. Davies et al. [26] reported that homemade masks can be considered as a last resort to block respiratory droplets and are better than not wearing a mask. Verma et al. [27] reported that stitched masks made of quilting cotton could effectively obstruct respiratory jets. Surgical face masks were originally developed for use during surgery to protect patients by filtering respiratory droplets discharge from healthcare providers’ mouths and noses [28]. These masks can also be used to block respiratory droplets transmission in everyday life [20, 29].

We clarify that this study does not provide a way to reuse masks for healthcare workers or those exposed to infection. However, we aimed to find the answer to the following questions.

Should we insist on wearing a mask only once even if the supply is temporarily interrupted due to war or another pandemic situation?

Is it correct for those with limited exposed to an infectious environment to throw away the mask after using it once in daily life?

If pore size of a reused surgical mask is smaller than that of a cotton mask without particle collection function, it can offer protection for the environment.

In this study, we evaluated disposable surgical mask pore structure with respect to period of use as well as how the structure responds to several reuse cleaning methods.

**MATERIALS AND METHODS**

We selected common disposable surgical masks for this study. As shown in Table 1 and Table 2, we classified test conditions based on wear time and reuse method. After wearing the mask for 10 hours, we let it dry naturally in the shade for 14 hours. In addition, a common cotton mask (cotton: 70% and polyester 30%) was prepared to compare it with a reused surgical mask.

We cut the mask into 2-cm-diameter pieces to measure pore size (Fig. 1). We measured 5 pieces per mask.

| Table 1. Mask wear time |
|-------------------------|
| **Sample** | Sample 1 | Sample 2 | Sample 3 | Sample 4 | Sample 5 | Sample 6 |
| **Wear time** | Control | 10 | 20 | 30 | 40 | Cotton mask |
| *Time unit: hour.* |

| Table 2. Mask reuse preparation methods |
|----------------------------------------|
| **Method for reuse** | **Treatment time** |
| Sample A Ethyl alcohol (purity 95%) impregnation | 0.2 |
| Sample B UV treatment using a household UV sterilizer | 0.2 |
| Sample C Steam treatment | 0.2 |
| Sample D Washing machine treatment | 1 |
| *Time unit: hour; UV: ultraviolet.* |
1. Morphology analysis using a Scanning Electron Microscope (SEM)
For each test condition, we cut the mask into 5 × 5 mm pieces and coated them with gold using an ion sputter-coater (SCM, Emcrafts, Kwang-ju, Korea). Samples were analyzed using SEM (Genesis-1000, Emcrafts, Kwang-ju, Korea) in high vacuum mode (7.5 × 10⁻⁵ torr).

2. Pore size analysis using a capillary flow porometer
Pore size measurements using a fluid on a porous solid material can be conducted by two methods, Mercury Intrusion Porosimetry (MIP) and Capillary Flow Porometry (CFP) [30]. In this study, we followed the CFP technique using a capillary flow porometer (model: CFP-1200 AEL, Porous Material Inc, Ithaca, New York, USA). This method is based on ASTM F316-03 [31] and ASTM D6767-20 [32]. It analyzes pores directly involved in filtration by selectively measuring only the constricted pore parts (Fig. 2), which is why it is suitable for evaluating pore structure of mask.

The CFP method is a ‘dry up/wet up’ process as shown in Fig. 3. In the ‘dry up’ step, pressurized air is applied vertically to a dry sample to obtain a pressure and flow graph. Next, the sample is immersed in Galwick solution with low surface tension (15.9 dynes/cm) and low volatility so the voids fill with the solution. Gradual vertical pressure extrudes the Galwick solution; pressure and flow over the course of this process are measured and graphed. The pressure at which the Galwick solution first escapes the pores is called the bubble point, the maximum pore size is obtained by Equation. 1. The mean flow pore size is determined using a ‘half dry curve,’ which is an imaginary line drawn at a 1/2 slope of the ‘dry curve.’ The mean

![Figure 1. Sample locations of a surgical mask (A) and cotton mask (B) for pore size measurements.](https://icjournal.org)

![Figure 2. Pores measured using a capillary flow porometer.](https://icjournal.org)
Flow pore pressure is obtained using Equation 1, which describes the pressure at the point where the ‘half dry curve’ and the ‘wet curve’ meet:

\[ D = \frac{C \tau}{p} \]

where \( D \) = limiting diameter, \( \tau \) = surface tension, \( p \) = pressure, and \( C \) = constant (\( C = 2,860 \) in Pa, 2.15 in cm Hg, and 0.415 in psi).

3. Statistical analysis
To verify pore size differences among test conditions, we used the one way ANOVA (Analysis of Variance) in IBM SPSS statistics v25 software (IBM Corp, Armonk, NY, USA).

RESULTS
1. SEM analysis
Figure 4 shows SEM images of the surgical mask at each condition. The pore structure of surgical mask is a melt blown filter structure, as shown previous studies [33, 34].

It was difficult to determine any structural changes based on usage time or reuse preparation method.

On the other hand, Fig. 4G shows a sparse pore structure of the cotton mask compared to the surgical mask.

2. Pore size analysis
The pore size of each measurement condition is shown in Fig. 5 and Fig. 6.

Results for usage time samples showed a maximum pore size of 21.033 ± 1.050 \( \mu \)m (± standard deviation) for sample 1, 21.613 ± 0.983 \( \mu \)m for sample 2, 21.519 ± 1.216 \( \mu \)m for sample 3, 21.545 \( \mu \)m for sample 4, and 21.587 \( \mu \)m for sample 5.
Changes in pore size of surgical mask by wear time and reuse method

± 1.679 μm for sample 4, and 21.442 ± 1.626 μm for sample 5. Mean pore sizes were 8.543 ± 0.154 μm for sample 1, 9.226 ± 0.677 μm for sample 2, 9.0946 ± 0.380 μm for sample 3, 8.606 ± 0.156 μm for sample 4, and 8.725 ± 0.416 μm for sample 5.

The ANOVA results of samples 1 to 5 showed a maximum pore size of $F = 0.118$, $P = 0.975$ and mean flow pore size of $F = 2.244$, $P = 0.101$. Because both the maximum pore size and mean flow pore size have a significant probability ($P > 0.05$), we supported the null hypothesis. This means that pore size changes over use time were not statistically significant.
On the other hand, the maximum pore size of the cotton mask was 110.343 ± 16.028 μm and mean pore size was 47.285 ± 3.358 μm, significantly larger than that of the surgical mask (maximum pore size F = 693.154, P < 0.001 and mean pore size F = 2,764.893, P < 0.001).

Pore size results for reuse preparation methods showed a maximum pore size of 30.365 ± 0.939 for sample A, 20.778 ± 2.152 μm for sample B, 21.175 ± 1.040 μm for sample C, and 21.391 ± 1.303 μm for sample D. Mean pore sizes were 8.853 ± 0.578 μm for sample A, 7.996 ± 0.573 μm for sample B, 8.532 ± 0.447 μm for sample C, and 9.303 ± 0.935 μm for sample D.

The ANOVA results yielded a maximum pore size of F = 0.332, P = 0.853 and mean flow pore size of F = 2.460, P = 0.079.

Because both the maximum pore size and mean flow pore size have a significant probability (P > 0.05), the change in pore size was not statistically significant.

**DISCUSSION**

The results of the study on the difference in pore structure according to usage time and reuse method of the surgical mask are as follows.

1. The pore structure of the surgical mask was not changed significantly after 40 hours of use.
2. Surgical mask pore structure did not change significantly after treatment with ethyl alcohol, UV light, steam, or a washing machine.
3. The pore size of the reused surgical mask was smaller than that of the cotton mask.

As a limitation of this study, we did not conduct collection efficiency experiments on the surgical masks. However, previous studies have reported that cotton masks without particle collection function can prevent saliva droplet transmission. With this in mind, although the reused surgical mask may not exhibit the performance of the original mask, a reused surgical mask with smaller pores will not have a lower performance of saliva droplet prevention than a cotton mask. In addition, there any mask slows viral transmission by flow resistance. Also, since wearing a mask reduces involuntary touching of the face, it is more likely to prevent infection than not wearing a mask.
This study will contribute to preserving resources and the environment while maintaining public health safety in everyday life.

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