STUDY OF LAYERING ORDER ON FILTRATION ABILITY OF SURGICAL FACE MASKS

Hongqing Shen, Ph.D., 202 Caraway Road, Apt. 1-D, Reisterstown, MD 21136, Hongqing.shen@gmail.com

Karen K. Leonas, Ph.D., Department of Textiles, Merchandising and Interiors, University of Georgia, Athens, GA 30605, kleonas@fcs.uga.edu

ABSTRACT

Health care workers can be exposed to biological aerosols capable of transmitting disease during normal daily activities. Attention is placed on reducing the potential of airborne exposure through the use of surgical face masks. Although nonwoven manufactures have shown much interest in the layering order of the surgical face masks, there are no published papers about the effect of layering order on the filtration ability of surgical face masks. In evaluating the effect of layering order on filtration ability of surgical face masks, Laser Scanning Confocal Microscopy (LSCM) cross sectional examination technique was used to determine particle capture. The transmission of small particles through the cross section of the surgical face mask was examined using LSCM. In each of three face masks examined, the filtration layer stopped the penetration of small particles through face masks no matter whether the filtration is the second layer of a three-layer face mask or the second layer of a four-layer face mask or the third layer of a four-layer face mask. Although layering order varied in this study, the filtration layer always stopped the penetration of the small particles. Therefore, layering order did not affect the filtration ability of the surgical face mask greatly.

Keywords: Filtration, Nonwovens, Surgical Face Mask, Layering Order

INTRODUCTION

Health care workers, involved in treating and caring for injured or sick individuals, can be exposed to biological aerosols capable of transmitting disease. These diseases can pose significant risks to life and health. Since engineering controls can not eliminate all possible exposures, attention is placed on reducing the potential of airborne exposure through the use of medical face masks. [1]

Although there are a variety of surgical face mask styles currently in the market, the layered face mask is one of the most common types. Within the available layered face masks, there are a variety of different layering orders. Some of the masks have three layers, and the filtration layer, the layer with the high packing density, is between the outside cover layer and the inner shell layer. Others have four layers and the position of filtration layer changes in the layer arrangement of the four-ply face mask. The filtration layer may be behind the outside cover layer or proceed the inner shell layer. Although nonwoven manufactures have shown much interest [2] in the layering order, there are no published
papers about the effect of layering order on the filtration ability of surgical face masks. In the paper presented here, the effect of layering order on the filtration ability of face masks was studied. The results of this study can provide significant information for health care workers and medical product manufacturers.

MATERIALS AND METHODS

Nonwoven Fabrics

The primary objective of this paper is to study the impact of layering order on the filtration ability of surgical face masks. Therefore, other variables such as the type and the weight of nonwoven fabrics were fixed in this study. Four typical nonwoven fabrics used for surgical face masks were obtained, including three polypropylene spunbonded nonwoven fabrics and one polypropylene meltblown nonwoven fabric. The meltblown nonwoven fabric was used for the filtration layer and its weight was about 20 g/m². Three spunbonded nonwoven fabrics were used for the other three layers. The weights for the cover layer, support layer and shell layer were approximately 20 g/m², 26 g/m² and 18 g/m² respectively.

Order Nonwoven Fabric Layers to Simulate Face Masks

The following three most commonly used layering orders were used to determine the effect of layering order on the filtration ability of surgical face masks:

1) Three-layer face mask and a layer arrangement of cover fabric, filtration fabric and shell fabric from outside to inside (Face mask 1),

2) Four-layer face mask and a layer arrangement of cover fabric, filtration fabric, support fabric and shell fabric from outside to inside (Face mask 2),

3) Four-layer face mask and a layer arrangement of cover fabric, support fabric, filtration fabric and shell fabric from outside to inside (Face mask 3).

According to these three levels of layering order, the cover fabric layer, filtration layer, support layer and shell layer were arranged to simulate different face masks. Three different simulated face masks were formed. For each of the three face masks, a minimum of 3 specimens was formed for the evaluation of filtration ability.

Evaluation of Filtration

Evaluation of filtration was composed of two steps: (1) exposure of the face mask to challenge aerosol containing small particles, and (2) LSCM cross sectional examination. First, the face masks were exposed to a challenge aerosol composed of synthetic blood and small latex particles. Then a LSCM cross sectional examination technique was used to determine particle capture.

Exposure of the face mask

The face masks were exposed to a challenge aerosol by modifying Standard Test Method ASTM F2101-01, Standard Test Method for Evaluating the Bacterial Filtration Efficiency (BFE) of Medical Face Mask Materials, Using a Biological Aerosol of Staphylococcus aureus [1]. Prior to the exposure, the simulated face masks were conditioned for a minimum of 4 hours in conditions of 21 ± 5°C and a relative humidity of 85 ± 5%. To study the filtration ability of face masks against small particles, a challenge liquid containing small particles rather than a S. aureus suspension was used to generate the aerosol. This challenge liquid was composed of latex microspheres and synthetic blood. Synthetic blood is a mixture of a red dye/surfactant, thickening agent, and distilled water having a surface tension and viscosity representative of blood and some other body fluids, and the color of blood. [3] The spheres are fluoresbhir™ carboxylate microspheres (Polysciences, Inc.) the average size of which is 1.0 micron, and they are round in shape. These physical properties are similar to that of bacteria S. aureus, and spheres were used in previous studies [4,5] to simulate S. aureus. The concentration of the solution was 2.5 X 10⁻⁴. The face masks were exposed to the challenge aerosol for 2 minutes.
**LSCM cross sectional examinations**

After the exposure of the face mask to the challenge aerosol, the face mask specimen was examined with a Leica TCS SP2 Spectral Confocal Microscope to locate the small particles present on/in the structure of the face mask. To study the effect of layering order on the filtration ability of face masks, the transmission of small particles through the entire face mask was necessary. Therefore, a technique involving LSCM cross sectional examination was used. LSCM has several advantages over the conventional fluorescent microscopy, they are:

1. Contrast and resolution are improved since out of focus information is greatly reduced,
2. LSCM can use a variety of excitation illuminations and change the scan pattern,
3. Non-destructive examination of surface topography can be done using LSCM.

The LSCM cross sectional examination on the face mask was composed of the following steps (Figure 1, a-e): 1) The face mask was cut into one square inch specimen that contains the exposed area, (Figure 1-a) 2) The specimen was immediately frozen by liquid nitrogen, (Figure 1-b) 3) The specimen was mounted and kept in the liquid nitrogen, (Figure 1-c) 4) A cross section of the specimen was cut when it was still in the frozen status, (Figure 1-d) 5) The cross section was observed using LSCM. (Figure 1-e)

For each face mask, three specimens were examined and for each specimen, five different locations of the cross sections of the face masks were examined using LSCM.

![Procedure for the cross sectional observation technique](image)

**Figure 1** Procedure for the cross sectional observation technique; (a) cut specimen, (b) freeze specimen, (c) mount and preserve specimen, (d) prepare a cross section, and (e) observation

**RESULTS AND DISCUSSION**

The entire face mask of each of three simulated face masks were examined to evaluate the filtration ability. LSCM cross sectional examination was used to study the filtration ability of entire face masks. To locate the latex microspheres on/in the structure of nonwoven fabrics, a variety of combinations LSCM parameters were evaluated to determine those that produced the most effective images for this study. Table 1 showed the parameters actually used in this study. To locate the small particles on/in nonwoven fabrics, two
detectors were used to identify different components by selective signal detection. Therefore, there were three images obtained by LSCM for each specimen. The left image was obtained by PMT one that was optimized to show the fabric. The middle image was obtained by PMT two that was optimized to show the small particles. The right image was the merged image that combined the left and the right images to show the distribution of small particles on the fabric.

The liquid used to generate the challenge aerosol was first examined by the LSCM with the parameters in Table 1 and the results are shown in Figure 2. In these color micrographs, the microspheres were represented by red. When these three images are evaluated, it was apparent that nothing was identified by detector one while latex microspheres were clearly identified by detector two and the merged image was the same as the image obtained by detector two. This was expected as only the liquid that contains small particles was examined.

The cross sections of three simulated face masks were also examined by the LSCM with the same parameters and the results were shown in Figure 3-5. In these color micrographs, the fabrics were represented by shades of gray. The left images in Figures 3, 4 and 5 clearly showed the layer structures of the simulated face masks. Each of the face masks has a relatively flat layered structure and pockets of air are found between each layer. Face mask 1 has three layers and face masks 2 and 3 have four layers. When all these images were evaluated, it was apparent that the layer structure of fabrics was clearly identified by detector one while nothing was identified by detector two and the merged images were the same with the images obtained by detector one. This was expected as only control face masks were examined.

### Table 1 Parameters of LSCM

<table>
<thead>
<tr>
<th>Source</th>
<th>Ar/He Ne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excitation Wavelength (nm)</td>
<td>100% 476</td>
</tr>
<tr>
<td>Emission Wavelength of PM 1 (nm)</td>
<td>478-493</td>
</tr>
<tr>
<td>Emission Wavelength of PM 2 (nm)</td>
<td>499-576</td>
</tr>
<tr>
<td>Dichroic Mirror</td>
<td>TD 488/543/633</td>
</tr>
<tr>
<td>Beam Expander</td>
<td>Beam Exp 3</td>
</tr>
<tr>
<td>Pinhole (micron)</td>
<td>459.26</td>
</tr>
<tr>
<td>Zoom</td>
<td>1</td>
</tr>
<tr>
<td>Image Dimension (mm*mm)</td>
<td>1.50*1.50</td>
</tr>
<tr>
<td>Voxel Size (micron*micron)</td>
<td>2.93*2.93</td>
</tr>
<tr>
<td>High NA Objective Lens</td>
<td>20×</td>
</tr>
<tr>
<td>Scan Mode</td>
<td>xy</td>
</tr>
<tr>
<td>Speed (HZ)</td>
<td>400</td>
</tr>
<tr>
<td>Format</td>
<td>512*512</td>
</tr>
<tr>
<td>Gain PMT 1 (V)</td>
<td>503</td>
</tr>
<tr>
<td>Gain PMT 2 (V)</td>
<td>799</td>
</tr>
</tbody>
</table>
Figure 2 LSCM image of challenge liquid which was composed of synthetic blood and microspheres; (a) image obtained by PMT one, (b) image obtained by PMT two, and (c) merged image.

Figure 3 LSCM image of cross section of face mask 1; (a) image obtained by PMT one, (b) image obtained by PMT two, and (c) merged image.
Figure 4 LSCM image of cross section of face mask 2; (a) image obtained by PMT one, (b) image obtained by PMT two, and (c) merged image

Figure 5 LSCM image of cross section of face mask 3; (a) image obtained by PMT one, (b) image obtained by PMT two, and (c) merged image

To study the effect of layering order on the filtration ability of the entire face mask, the transmission of small particles through the face mask as a whole was as necessary. LSCM cross sectional examination was used to study the impact of layering order on filtration ability. All three simulated face masks were exposed to the challenge aerosol using the modified Standard Test Method ASTM F2101-01.

Results were presented in Figures 6 - 8. In these color micrographs, the microspheres were represented by red and the fabrics were represented by shades of gray in color.

Figures 6, 7 and 8 show the cross sections of three face masks after exposure to the challenge aerosol using the modified ASTM F 2101. Figure 6 shows the face mask with layering order layer one and
shows that for face mask 1, small particles have penetrated through the first layer, the cover layer. Although small particles had penetrated into the second layer, the filtration layer, they had not penetrated through this layer and had not reached the third layer, the shell layer. Therefore, the filtration layer stopped the penetration of small particles.

Figure 7 shows the face mask with layering order layer two and shows that for face mask 2, small particles have penetrated through the first layer, the cover layer. Although small particles had penetrated into the second layer, the filtration layer, they had not penetrated through this layer and had not reached the third layer, the support layer or the fourth layer, the shell layer. Therefore, the filtration layer stopped the penetration of small particles.

Figure 8 shows the face mask with layering order layer three and shows that for face mask 3, small particles have penetrated through the first layer, the cover layer, and the second layer, the support layer. Although small particles had penetrated into the third layer, the filtration layer, they had not penetrated through this layer and had not reached the fourth layer, the shell layer. Therefore, the filtration layer stopped the penetration of small particles.

In each of three face masks examined, the filtration layer stopped the penetration of small particles through face masks no matter whether the filtration was the second layer of a three-layer face mask or the second layer of a four-layer face mask or the third layer of a four-layer face mask. In summary, although its location changed in the three layering orders, the filtration layer always stopped the penetration of small particles.

Figure 6 LSCM cross sectional image of face mask 1 exposed to challenge aerosol using modified ASTM F 2101; (a) image obtained by PMT one, (b) image obtained by PMT two, and (c) merged image
Figure 7 LSCM cross sectional image of face mask 2 exposed to challenge aerosol using modified ASTM F 2101; (a) image obtained by PMT one, (b) image obtained by PMT two, and (c) merged image

CONCLUSIONS

The primary objective of this paper is to study the effect of layering order on filtration ability of surgical face masks. Four typical nonwoven fabrics used for surgical face masks were selected as a cover fabric, a filtration fabric, a support fabric and a shell fabric. Then the nonwoven fabrics were ordered to simulate face masks with three different layering orders. To study the effect of layering order on the filtration ability of the entire face mask, LSCM cross sectional examination was performed to evaluate the
cross sections of the face masks and the penetration of small particles through the face masks. The results showed that the filtration layer halted the penetration of small particles through face masks no matter whether the filtration was the second layer of a three-layer face mask or the second layer of a four-layer face mask or the third layer of a four-layer face mask. Although its location changed in the three layering orders, the filtration layer always stopped the penetration of the small particles. Therefore, the layering order did not affect filtration ability of the surgical face mask greatly.

ACKNOWLEDGEMENTS

We would like to express our deep appreciation to AATCC Student Research Award Review Board and AES Southern Regional Project S-1002 for providing funding for this project.

REFERENCES