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Filtration Efficiency of Different Material of Masks

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ABSTRACT

The effectiveness of medical masks in preventing respiratory infection was investigated by, filtration efficiency. The surgical mask showed the highest filtration efficiency with *B atrophaeus*. Also, its measured low-pressure drop showed it to be the most suitable material among those tested for use as a face mask. The pillowcase and the 100% cotton t-shirt were found to be the most suitable household materials for an improvised face mask. The slightly stretchy quality of the t-shirt made it the more preferable choice for a face mask as it was considered likely to provide a better fit. The PM10 (particulate matter) filtering efficiency of masks ranged from 63% to 84%. The poor filtering efficiency may have arisen from larger and open pores present in the masks. This study showed that the filtering efficiency of cloth face masks was relatively lower, and washing and drying practices deteriorated the efficiency. The findings of this study will be very helpful for increasing public awareness and help government agencies to make proper guidelines and policies for the use of face masks.

INTRODUCTION

A mask is a device covering the mouth, nose, and chin ensuring a barrier that limits the transmission of an infective agent between the people. A surgical mask was developed to contain and filter large droplets of microorganisms expelled from the mouth and nasopharynx of healthcare workers during surgery, thereby protecting the patient. These are generally available in two configurations, molded cup shape with an elastic cord around the head and non-molded which may be further available as a pleated or a flat paper shield with two ties or ear loops. Furthermore, pleats can be either two-ply or three ply[1]. The effectiveness of medical masks in preventing respiratory infection was investigated by testing bacterial leakage, filtration efficiency, respiratory resistance, and oxygen concentration of the enclosed space [2].

By now, you've probably heard that there is a shortage of N95 masks for health care professionals trying to deal with the COVID-19 coronavirus pandemic. Lack of such protection for health care workers can make it much more likely for them to get infected with the severe acute respiratory syndrome coronavirus 2 (SARS-CoV2)[3]. To prevent and control infectious respiratory diseases, the first line of defense should be to prevent exposures by using control measures, such as isolation, quarantine, or restricting or closing group gatherings, and/or using local exhaust ventilation. Along with it respiratory hygiene and personal hygiene are also important. Personal respiratory protection provides the last line of defense[4].

More effective surgical face masks which provide 85% or even 99% protection is required to prevent the spread of transmission diseases. The high degree of filtration efficiency is attained with a very fine filter layer of textile fibers covered on both sides with conventional non-woven bonded fabrics. The thickness of fiber is from <1 to 10 µm[5].

A respirator is a device designed to protect the wearer from inhaling hazardous atmospheres, including fumes, vapors, gases, and particulate matter such as dust and airborne microorganisms. Air-purifying respirators range from relatively inexpensive single-use, disposable face masks sometimes referred to as a dust mask to more robust reusable models with replaceable cartridges often called a gas mask.this are used by a wide range of industries use respirators including healthcare & pharmaceuticals, defense& public safety services (defense, firefighting& law enforcement), oil and gas industries, manufacturing (automotive, chemical, metal fabrication, food and beverage, woodworking, paper, and pulp), mining, construction, agriculture and forestry, cement production, power generation, shipbuilding, and the textile industry[6]. Some N95 respirators have also been cleared by the U.S. National Institute for Occupational Safety and Health (NIOSH) and U.S. Food and Drug Administration as surgical and are labeled "Surgical N95", "medical respirators," or "healthcare respirators," providing respiratory protection to the wearer as well[7,8].

The CDC recommends the use of respirators with at least N95 certification to protect the wearer from inhalation of infectious particles including Mycobacterium tuberculosis, avian influenza, severe acute respiratory syndrome (SARS), pandemic influenza, and Ebola[9].

MATERIALS AND METHODS

1. Testing the Filtration Efficiency

A range of common household materials was tested, together with the material from a surgical mask (Molnlycke Health Care Barrier face mask 4239, EN14683 class I), for comparison. Circular cut-outs of the tested materials were placed without tension in airtight casings, creating a ‘‘filter’’ in which the material provided the only barrier to the transport of the aerosol[10].

A Henderson apparatus allows the closed-circuit generation of microbial aerosols from a Collison nebulizer at controlled relative humidity. This instrument was used to deliver the challenge aerosol across each material at 30L/min using the method of Wilkes et al[11], which is about 3 to 6 times per minute the ventilation of a human at rest or doing light work but is less than 0.1 the flow of an average cough.

Downstream air was sampled simultaneously for 1minute into 10ml of phosphate buffer manucol antifoam using 2 all-glass impingers. One impinger sampled the microorganisms that had penetrated through the material filter, while the other sampled the control (no filter). The collecting fluid was removed from the impingers and assayed for microorganisms. This test was performed 9 times for each material. The filtration efficiency (FE) of the fabric was calculated using the following formula (CFU indicate colony-forming units):

FE = Upstream cfu - Downstream cfu *100/upstream cfu

The pressure drop across the fabric was measured using a manometer (P200UL, Digitron), with sensors placed on either side of the filter casing, while it was challenged with a clean aerosol at the same flow rate.

1.1 Microorganisms

Two microorganisms were used to simulate particle challenge: Bacillus atrophaeus is a rod-shaped spore-forming bacterium (0.95-1.25mm) known to survive the stresses caused by aerosolization[12]. The suspension was prepared from batches previously prepared by the Health Protection Agency, Centre for emergency preparedness and Response Production Division[13]. Each material was challenged with approximately 107 cfu B atrophaeus. Bacteriophage MS2 (MCIMB10108) is a nonenveloped single-stranded RNA coliphage, 23nm in diameter, known to survive the stresses of aerosolization[14]. Each material was challenged with approximately 109 plaque-forming units (pfu) of bacteriophage MS2.

The two test organisms can be compared in size to influenza virus, which is pleomorphic and ranges from 60 to 100nm; *Yersinia pestis,* which is 0.75mm; *B anthracis,* which is 1 to 1.3mm; *Francisellatularensis,* which is 0.2mm; and *mycobacterium tuberculosis,* which is 0.2 to 0.5mm(6) Bacteriophage MS2 and B atrophaeus were chosen as the test organisms to represent influenza virus. This decision was made not only because of the lower risks of associated infection but also because the work would be technically easier to carry out using an Advisory Committee on Dangerous Pathogens (ACDP) class 1 organism versus an ACDP class 2 organism influenza.

1.2 Results

Table No. 1: Filtration Efficiency and Pressure Drop Across Materials Tested with Aerosol of *Bacillus atrophaeus* and Bacteriophage MS2(30L/min)[a]

Material	*B atrophaeus*		*Bacteriophage MS2*		Pressure Drop Across Fabric	
	Mean % Filtration Efficiency	SD	Mean % Filtration Efficiency	SD	Mean % Filtration Efficiency	SD
100 % cotton T-shirt	69.42 (70.66)	10.53 (6.83)	50.58	16.81	4.29 (5.13)	0.07 (0.57)
Scarf	62.30	4.44	48.87	19.77	4.36	0.19
Tea towel	83.24 (96.71)	7.81(8.73)	72.46	22.60	7.23(12.10)	0.96(0.17)
Pillow case	61.28 (62.38)	4.91(8.73)	57.13	10.55	3.88(5.50)	0.03(0.26)
Antimicrobial pillowcase	65.62	7.64	68.90	7.44	6.11	0.35
Surgical mask	96.38	0.68	89.52	2.65	5.23	0.15
Vacuum cleaner bag	94.35	0.74	85.95	1.55	10.18	0.32
Cotton mix	74.60	11.17	70.24	0.08	6.18	0.48
Linen	60.00	11.18	61.67	2.41	4.50	0.19
silk	58.00	2.75	54.32	29.49	4.57	0.31

[a] Numbers in parentheses refer to the result from 2 layers of fabric.

All the materials tested showed some capability to block the microbial aerosol challenges. In general, the filtration efficiency for bacteriophage MS2 was 10% lower than for *B atrophaeus* (Table 1). The surgical mask had the highest filtration efficiency when challenged with bacteriophage MS2, followed by the vacuum cleaner bag, but the bag's stiffness and thickness created a high-pressure drop across the material, rendering it unsuitable for a face mask. Similarly, the tea towel, which is a strong fabric with a thick weave, showed relatively high filtration efficiency with both *B atrophaeus* and bacteriophage MS2, but a high-pressure drop was also measured.

The surgical mask (control) showed the highest filtration efficiency with *B atrophaeus*. Also, as expected, its measured low-pressure drop showed it to be the most suitable material among those tested for use as a face mask. The pillowcase and the 100% cotton t-shirt were found to be the most suitable household materials for an improvised face mask. The slightly stretchy quality of the t-shirt made it the more preferable choice for a face mask as it was considered likely to provide a better fit.

Although doubling the layers of fabric did significantly increase the pressure drop measured across all 3 materials (P,.01 using Wilcoxon signed-rank test), only the 2 layers of tea towel material demonstrated a significant increase in filtration efficiency that was marginally greater than that of the face mask.

In the questionnaire on mask use during a pandemic, 6 participants said they would wear a mask some of the time, 6 said they would never wear a mask, and 9 either did not know or were undecided. None of the participants said that they would wear a mask all of the time. With 1 exception, all participants reported that their face mask was comfortable. However, the length of time each participant kept their mask on during testing was minimal (15min), and with long-term wear, comfort might decrease.

2. Filtration efficiency of layered mask

Low-cost face masks made from different cloth materials are very common in developing countries. The cloth masks (CM) are usually double-layered with stretchable ear loops. It is common practice to use such masks for months after multiple washing and drying cycles. If a CM is used for a long time, the ear loops become stretched. The loop needs to be knotted to make the mask loop fit better on the face. It is not clear how washing and drying and stretching practices change the quality of a CM. The particulate matter (PM) filtering efficiency of a mask depends on multiple parameters, such as pore size, shape, clearance, and pore number density. It is important to understand the effect of these parameters on the filtering efficiency.

We characterized the surface of twenty different types of CMs using the optical image analysis method. The filtering efficiency of selected cloth face masks was measured using the particle counting method.

2.1 Methods

This was a prospective unblinded study of six healthy volunteers using combinations of one, two, three, or five surgical masks (Surgikos, Johnson & Johnson, Arlington, TX, USA). The Surgikos mask is a pleated rectangular three-ply mask with a bacterial filtration efficiency of 95% at 3 µm. All volunteers gave written informed consent[15].

2.2 Results

The pore size of masks ranged from 80 to 500 µm, which was much bigger than a particular matter having a diameter of 2.5 µm or less (PM2.5) and 10 µm or less (PM10) size. The PM10 filtering efficiency of four of the selected masks ranged from 63% to 84%. The poor filtering efficiency may have arisen from larger and open pores present in the masks. Interestingly, we found that efficiency dropped by 20% after the 4th washing and drying cycle. We observed a change in pore size and shape and a decrease in microfibers within the pores after washing. Stretching of the CM surface also altered the pore size and potentially decreased the filtering efficiency. As compared to CMs, the less frequently used surgical/paper masks had complicated networks of fibers and much smaller pores in multiple layers in comparison to CMs, and therefore had better filtering efficiency. This study showed that the filtering efficiency of cloth face masks was relatively lower, and washing and drying practices deteriorated the efficiency. We believe that the findings of this study will be very helpful for increasing public awareness and help government agencies to make proper guidelines and policies for the use of face mask[16].

Table 2[17]

Mask Type	Standards	Filtration Effectiveness		
Single-Use Face Mask 	**China:** YY/T0969	Open-Data Tests Smart Air SmartAirFilters.com 3.0 Microns: ≥95% 0.1 Microns: ✗		
Surgical Mask 	**China:** YY 0469	3.0 Microns: ≥95% 0.1 Microns: ≥30%		
	USA: ASTM F2100	Level 1	Level 2	Level 3
		3.0 Microns: ≥95% 0.1 Microns: ≥95%	3.0 Microns: ≥98% 0.1 Microns: ≥98%	3.0 Microns: ≥98% 0.1 Microns: ≥98%
	Europe: EN 14683	Type I	Type II	Type III
		3.0 Microns: ≥95% 0.1 Microns: ✗	3.0 Microns: ≥98% 0.1 Microns: ✗	3.0 Microns: ≥98% 0.1 Microns: ✗
Respirator Mask 	**USA:** NIOSH (42 CFR 84) **China:** GB2626	N95 / KN95	N99 / KN99	N100 / KN100
		0.3 Microns: ≥95%	0.3 Microns ≥99%	0.3 Microns ≥99.97%
	Europe: EN 149:2001	FFP1	FFP2	FFP3
		0.3 Microns: ≥80%	0.3 Microns: ≥94%	0.3 Microns: 99%

3.0 Microns: Bacteria Filtration Efficiency standard (BFE).
0.1 Microns: Particle Filtration Efficiency standard (PFE).
0.3 Microns: Used to represent the most-penetrating particle size (MPPS), which is the most difficult size particle to capture.
✗: No requirements.

DISCUSSION

A surgical mask is a loose-fitting, disposable device that creates a physical barrier between the mouth and nose of the wearer and potential contaminants in the immediate environment. If worn properly, a surgical mask is meant to help block large-particle droplets, splashes, sprays, or splatter that may contain viruses and bacteria. Surgical masks may also help reduce exposure from the wearer's saliva and respiratory secretions to others, especially during surgical procedures[18].

A surgical mask, by design, does not filter or block very small particles from the outside air that may be transmitted by coughs, sneezes, or certain medical procedures to the wearer. Surgical masks also do not provide complete protection from germs and other contaminants because of the loose fit between the surface of the face mask and the face. Collection efficiency of surgical mask filters can range from less than 10% to nearly 90% for different manufacturers' masks when measured using the test parameters for NIOSH certification. However, a study found that even for surgical masks with "good" filters, 80–100% of subjects failed an OSHA-accepted qualitative fit test, and a quantitative test showed 12–25% leakage[19].

Some N95 respirators have also been cleared by the U.S. National Institute for Occupational Safety and Health (NIOSH) and U.S. Food and Drug Administration as surgical and are labeled "Surgical N95", "medical respirators," or "healthcare respirators," providing respiratory protection to the wearer as well[20,21]. The CDC recommends the use of respirators with at least N95 certification to protect the wearer from inhalation of infectious particles including Mycobacterium tuberculosis, avian influenza, severe acute respiratory syndrome (SARS), pandemic influenza, and Ebola[22].

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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