ORIGINAL ARTICLE

Household Materials for Homemade Masks: How Effective Are They?

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ABSTRACT

Introduction: With the fear of uncertain behaviours and mechanisms of the coronavirus in the rapidly evolving COVID-19 pandemic, people are required to cover their mouth and nose to prevent the spread of the virus. This has become a challenge as most countries struggle with the dwindling stocks of face masks. However, the Centers for Disease Control and Prevention suggested the use of cloth masks as a substitute. In an effort to find suitable materials that serve this purpose and ensure sufficient protection afforded, the masks need to be tested. **Methods:** In this study, the penetration and breathing resistance of 13 easily obtained household materials potentially used by the public as face masks, were randomly selected and tested by using TSI Model 8130 Automated Filter Tester, while the thickness was measured by S-Cal EVO Proximity caliper. **Results:** The level of thickness ranged between 0.25 mm (satin) and 4.83 mm (diaper). Double-layer denim material showed the lowest percentage of penetration (Median, IQR: 27.50%, 27.05-28.80) while the greatest was single-layer lycra (Median, IQR: 90.60%, 80.80-92.10). Single-layer chiffon fabric showed the best breathing resistance (Median, IQR in mmH_2O: 1.30, 0.90, 1.45) while the worst was diaper (Median, IQR in mmH_2O: 87.20, 86.95, 87.25). **Conclusion:** Double-layer dried wet tissue, single-layer tissue paper and double-layer non-woven fabric can be considered to be used as face masks due to their efficiency based on penetration and breathing resistance factors.

Keywords: Household materials, fabric, face mask, COVID-19

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INTRODUCTION

COVID-19 pandemic is a rapidly evolving phenomenon that presents serious challenges. Its spread works by the epidemiological triad of the agent (virulence and pathogenicity of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2 virus itself), the host (individual with susceptibility) and the environment (extrinsic factors that can influence exposure, such as the use of face masks) (1). Although the emphasis for protection using respiratory protective devices is on the high-risk frontliners, particularly healthcare workers, the public is also concerned about the protection afforded by the masks they wear. The use of cloth face coverings with disposable masks for double protection is recommended by Centers for Disease Control and Prevention (CDC) where it is hard to maintain other social distancing measures as long as they fulfill the requirements of having multiple layers, snug fit, allows for breathing without restriction and washable (2). However, the use is restricted for the public only, and not for healthcare workers and other medical first responders.

China is the world's largest producer of facemasks, accounting for half of the worldwide output. Even if full production is attained, 20 million facemasks per day do not appear to be sufficient to fulfill the demands of the world population. The findings by Wu et al. (2020) suggested that facemask shortage would occur regardless of the implementation of a universal facemask wearing policy, particularly for N95 face masks (3). Owing to the shortage, various solutions have been proposed including extended use and decontamination. The public has even opted for sewing their own face masks, and improvising the masks (Do-It-Yourself) using household materials, such as T-shirts, tissue papers or cotton towels, believed to be effective enough for daily use. In some parts of the world like the United States (4) and London (5), the use of scarves is becoming more common among the people when in public. Renowned sports brands (6) and fashion designers (7) also came up with their very own stylish versions of face masks, claiming to serve the same purpose. However, the extent of protection afforded by the respiratory protection devices remains vague. Materials available at home may be unworthy as they are not able to provide the desired protection, considering that they are not designed for protecting the respiratory system and the filtering performance against the particle size is still unclear.

WHO has updated that COVID-19 can be spread either between people who are within 1 metre (short range) or farther than 1 metre (long-range) due to the suspension of aerosols in the air, especially in indoor settings that are poorly ventilated and/or crowded. A person can be infected when droplets of aerosols containing the virus are inhaled or in contact with the eyes, nose or mouth (8). Recently, airborne transmission is one of the transmission modes of SARS-CoV-2 besides droplet transmission, contact transmission, and fecal-oral transmission (8-9). Typically, viruses (~20 nm) released during breathing, coughing, and talking are attached to mucous, making them slightly larger than their original sizes (10). The smaller the size of droplets produced from the nose and mouth of the patients, the longer they can linger in the air and travel long distances. Researchers have studied infectious disease transmission by various diameter sizes ranging from <1000 nm to >1000 nm (11).

The fate and danger of droplets probably containing viruses after exhalation strongly depends on their size. In seconds, tiny droplets smaller than several tens of mm evaporate (12), leaving droplet nuclei, depending on the amount of dissolved material, at 30-50 percent of their initial diameter. Smaller particles can reach deeper respiratory system regions as smaller diameter of droplet nuclei (less than 10 mm) can be inhaled and remain airborne over extended periods of time (13). Meanwhile, large particles sediment (diameter greater than 100 mm) quickly and deposit on a surface before they evaporate (12). In order to prevent COVID-19 transmission, in addition to thorough hand hygiene and physical distancing, wearing of face masks is advised.

Nowadays, fabric masks also have pouches for putting tissues, handkerchiefs, or extra layers of activated carbon inserts as additional protection, yet have not been tested. A previous study showed that improvised fabric materials (cotton, bath towel, handkerchief) recorded varying levels of protection when tested with large (2000 nm) aerosols of *Bacillus globigii* (14). Another study showed a trend of decreased effectiveness with smaller size particles was observed, suggesting lower protection against particles of <410nm (15).

It is crucial to get a better understanding on the filtering performance and breathing resistance of various types of cloth materials against the most penetrating particle size (0.3 μm). Therefore, this study aims at testing the effectiveness of various types of household materials as an alternative for face masks for public use.

METHODS AND MATERIALS

Selection of fabric materials

In this study, thirteen types of materials from eight major household items were randomly selected to be tested as alternative materials for face masks. They are single-layer and double-layers tissue paper, dried wet tissue, denim, kitchen towel, plain non-woven craft bag fabric, chiffon scarf, lycra scarf, satin scarf, silk shirt, 100% cotton t-shirt, 100% polyester t-shirt, 100% micro dry t-shirt and diaper which totaled up to 25 samples altogether. These household material samples were obtained from personal collections, while some were either purchased from hypermarkets and online shopping platforms ranging from as low as RM1 to RM 35 per piece. All samples were randomly selected based on the commonness and obtainability of the materials at home and the potential to be used as an alternative for covering nose and mouth. It should be noted that none of the other fabric materials was designed to be used as filtering media and the composition for the household fabric was not available.

Thickness testing

Thickness was measured using a digital S-Cal EVO Proximity caliper (Sylvac, Switzerland), in accordance with IEC 60529 standard (16), with 20 μm accuracy and 0.01 mm resolution. Materials were placed in between the jaws of the instrument and the flat surface of the mask was measured at three random points.

Penetration Testing

Aerosol penetration test method (polydisperse) conducted was in accordance with the standard methods as detailed in MS2323:2010 (17), similar to EN149:2001+A1:2009. The TSI Model 8130 Automated Filter Tester (AFT) (TSI, Inc., St. Paul, MN) was used to measure filter aerosol penetration and breathing resistance. The TSI 8130 delivers a solid polydisperse sodium chloride (NaCl) aerosol which meets the particle size standards for

EN149:2001+A1:2009 and size distribution criteria set forth in 42 CFR 84 Subpart K, Section 84.181.(g) for NIOSH certification (CFR, 1995). The TSI Model 8130 AFT produces a particle concentration of 12 - 20 mg/m^3 and generates an initial instantaneous filter penetration result. The NaCl aerosol must have a count median diameter (CMD) of 0.075 ± 0.020 micrometer and a geometric standard deviation (GSD) not exceeding 1.86. The ratio of particle concentration downstream to upstream was used to calculate for the percentage penetration. All samples were tested in triplicates for reproducibility of the results.

$$\text{Peneration (\%)} = \frac{\text{NaCl after filter}}{\text{NaCl before filter}} \times 100$$

Breathing Resistance Testing

The reading of resistance was also obtained from TSI Model 8130 Automated Filter Tester (AFT) (TSI, Inc., St. Paul, MN). The resistance was determined by a highly accurate electronic pressure transducer, where pressure transducer and photometer readings are taken between every test to determine the new pressure offset and photometer background values. The reading was recorded in millimeter of water (mmH_2O) units. Intermediate system checks were conducted prior to each testing for quality control and assurance. This included the media tests to ensure the particle sizes are within range, pressure plate tests to determine the flow and acceptable pressure drop, as well as gravimetric tests to measure the aerosol mass concentrations. The tests were only resumed once all the system checks met the specifications.

Less thick materials, with lower penetration and breathing resistance values of less than 24.5 mmH_2O (17) were concluded as effective to be used as an alternative materials for face masks.

Statistical Analysis

Data were analysed using the IBM SPSS Statistics 25. Median and interquartile range (IQR) were calculated for each of the materials. Mann-Whitney U Test was conducted to determine the differences between the same types of materials on penetration and resistance. Significant difference was reported when alpha was less than 0.05 ($p< 0.05$).

RESULTS

Materials Thickness

Common household materials and their thickness are presented in Table I. The level of thickness ranges from 0.25 mm (satin) to the highest of 4.83 mm (diaper). The most comfort material (in terms of thickness) was single-layer satin with a median IQR of 0.25 (0.23-0.28) mm, followed by single-layer dried wet tissue with a median IQR thickness of 0.29 (0.28-0.29) mm, double-layer satin (median IQR; 0.33, 0.30-0.35), single-layer silk (median IQR, 0.40, 0.32-0.43), double-layer silk (median IQR; 0.40, 0.38-0.47), single-layer lycra (median, IQR; 0.40, 0.35-0.75), single-layer chiffon (median, IQR; 0.45, 0.34-0.46) and single-layer tissue paper (median, IQR; 0.44, 0.38-0.47). Apart from that, all materials have a median thickness of more than 0.50 mm.

Penetration

A wide range of resistance and penetration values were obtained for all the materials. Table II shows the types and characteristics of the household material samples selected in the polydisperse aerosol penetration tests (filtering performance and breathing resistance). Overall, in Fig.1 different household materials showed variability of penetration. The lowest penetration was observed in double-layer denim materials with a median IQR percentage of 27.50% (27.05-28.80), followed by diaper with a median (IQR) penetration of 32.10% (31.25-32.65), and double-layer tissue paper (median IQR; 41.30%, 27.90-43.20). Single-layer denim, dried wet tissue, single-layer tissue paper, non-woven fabric, double-layer kitchen towel, and single-layer satin were among materials with penetration ranging from 52 to 69%. Other materials showed significantly greater penetration (>70%), with the greatest percentage of penetration observed among single-layer lycra material (Median: 90.60%: IQR of 80.80-92.10). Significant difference was observed between single and double-

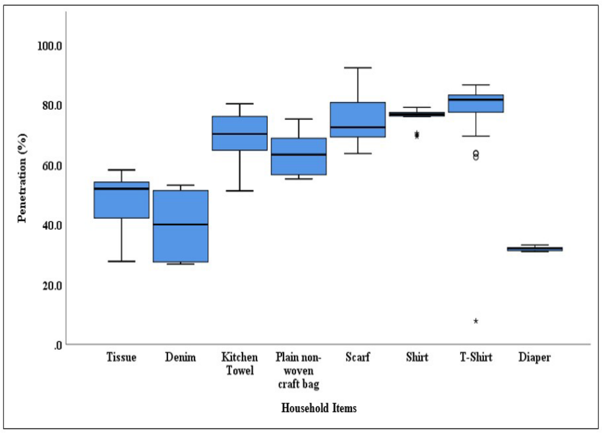

Fig 1: Penetration levels for eight major household items tested for polydisperse aerosols penetration. Percentage penetration for eight major household items consisting of tissue, denim, kitchen towel, plain non-woven craft bag, scarf, shirt, T-shirt and diaper were tested for polydisperse aerosols penetration tests. Household materials from denim, diaper and tissues recorded median values of less than 60% which contributed to safety from hazardous airborne particles.

layers among most of the materials ($p<0.05$) except for cotton fabric. Therefore, the number of layerings had a significant impact on the penetration of particles on most materials.

Breathing Resistance

With regards to ease of breathing, single-layer chiffon fabric showed the best breathing resistance median (IQR) of 1.30 (0.90, 1.45) mmH_2O, while the worst was diaper (median, IQR: 87.20 (86.95, 87.25) mmH_2O. About 16% (4 out of 25) of these tested materials were observed to have breathing resistance of more than the required standard of 24.5 mmH_2O (17). These materials are double-layer tissue papers, single and double-layer denim and diaper (Table II). Summarising these results by the eight types of household categories as depicted in Fig. 2, denim and diaper were the most uncomfortable in terms of breathability. Breathing resistance and thickness had a statistically significant linear relationship

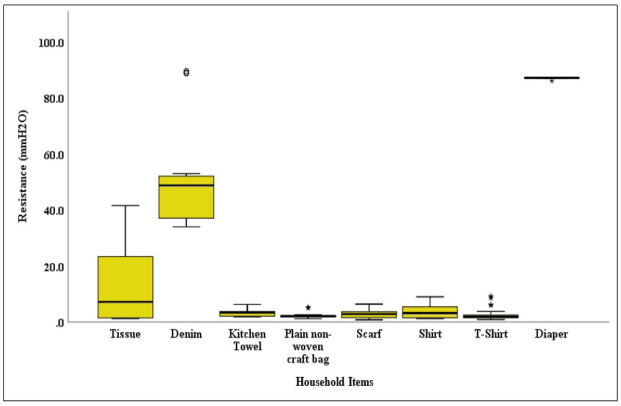

Fig 2: Breathing resistance (mm water) measured for eight major household items. Breathing resistance (mm water) measured for eight major household items consist of tissue, denim, kitchen towel, plain non-woven craft bag, scarf, shirt, T-shirt and diaper. Household materials from denim and diaper recorded breathing resistance values higher than others (greater than 80 mmH_2O) which contributed to the lack of safety for breathing penetration to humans.

($p<0.001$, Spearman $\rho= 0.50$), suggesting that the thicker the material, the greater the breathing resistance, which means that the wearer will experience breathing difficulties.

DISCUSSION

Table I shows the thickness of numerous materials tested for polydisperse aerosols penetration test. It is shown that all of the materials gave a higher median value of thickness (IQR) for double-layer materials compared to single-layer materials according to their type. The performance of face masks in terms of penetration is improved with the increasing number of layers. For instance, single-layer denim, tissue paper, dried wet tissue, non-woven material, kitchen towel, lycra and 100% cotton showed lower penetration compared to the same materials in double layers (Table II).

These findings are in agreement with Konda et al. (2020) where the number of mask layers increased the performance of face masks (18). Huang et al. (2013) also highlighted increasing penetration of particles through filters with decreasing thickness of filter (19).

However, the structure of materials may have also influenced the results since satin, chiffon, silk, 100% micro dry and 100% polyester showed vice versa. For example, satin, chiffon, silk, 100% micro dry and 100% polyester in single layer showed better penetration compared to the same materials in double layers, respectively (Table II). Structure of materials has been reported to influence the performance of face masks, in which different compositions of material provided different filtration efficiency (18). This may also explain

Table I. Common household materials and their thickness

Household Material	Picture	Thickness (mm) Median (IQR)
Tissue		
Tissue paper, single-layer		0.44 (0.38,0.47)
Tissue paper, double-layer		0.88 (0.83,0.95)
Dried Wet Tissue, single-layer		0.29 (0.28,0.29)
Dried Wet Tissue, double-layer		0.51 (0.50,0.51)
Denim		
Denim, single-layer		1.90 (1.32,2.46)
Denim, double-layer		2.65 (1.57,2.88)
Kitchen Towel		
Kitchen towel, single-layer		1.98 (1.83,3.42)
Kitchen towel, double-layer		2.11 (2.02,3.62)
Plain non-woven craft bag		
Non-woven, single-layer		0.53 (0.42,0.67)
Non-woven, double-layer		0.89 (0.74,0.89)
Shirt		
Silk, single-layer		0.40 (0.32,0.43)
Silk, double-layer		0.40 (0.38,0.47)

CONTINUE

Table I. Common household materials and their thickness (cont.)

Household Material	Picture	Thickness (mm) Median (IQR)
Scarf		
Chiffon, single-layer		0.43 (0.34,0.46)
Chiffon, double-layer		0.52 (0.48,0.54)
Lycra, single-layer		0.40 (0.35,0.75)
Lycra, double-layer		0.81 (0.70,0.87)
Satin, single-layer		0.25 (0.23,0.28)
Satin, double-layer		0.33 (0.30,0.35)
T-Shirt		
100% Cotton, single-layer		0.82 (0.25,1.19)
100% Cotton, double-layer		0.98 (0.45,1.27)
100% Polyester, single-layer		0.52 (0.26,0.63)
100% Polyester, double-layer		0.63 (0.57,0.74)
100% micro dry, single-layer		0.66 (0.61,0.69)
100% micro dry, double-layer		0.81 (0.79,0.84)
Diaper		
Diaper, single-layer		4.83 (4.83,4.84)

the better penetration of single-layer materials compared to double-layer materials. Although the penetration of single-layer tissue paper was reasonably good, it is not in the top five materials due to the high breathing resistance (25.30 mmH_2O), which was slightly greater than the maximum inhalation resistance which is 24.5 mmH_2O, as set by the Malaysian Standard MS2323:2010 (17).

Among others, single-layer lycra showed the worst penetration with a percentage of penetration 90.60%. It is therefore deemed unsuitable to be used since face masks with the greatest penetration signifies potential penetration of aerosol into the bronchi (20). According to He et al., (2013), filter penetration is one of the factors that contribute to the effectiveness of masks (21).

Meanwhile, the performance of face masks in terms of breathing resistance improves with the decreasing number of layers. From this study, all of the tested

Table II Common household materials tested for filtering performance and breathing resistance

Household Material	Penetration (%) Median (IQR)	Resistance (mmH_2O) Median (IQR)
Tissue		
Tissue paper, single-layer	52.30 (41.50,53.00)**	13.80 (12.60,22.80)**
Tissue paper, double-layer	41.30 (27.90,43.20)	25.30 (24.00,41.20)
Dried Wet Tissue, single-layer	57.40 (56.80,57.80)**	1.30 (1.20,1.40)**
Dried Wet Tissue, double-layer	51.90 (51.40,52.55)	1.60 (1.55,1.80)
Denim		
Denim, single-layer	51.30 (50.55,53.05)**	37.10 (35.20,48.00)
Denim, double-layer	27.50 (27.05,28.80)	52.10 (48.75,88.90)
Kitchen Towel		
Kitchen towel, single-layer	76.10 (74.85,79.60)**	2.10 (1.95,3.60)**
Kitchen towel, double-layer	64.80 (52.10,65.60)	3.70 (3.15,6.20)
Plain non-woven craft bag		
Non-woven, single-layer	68.80 (61.00,74.45)**	1.90 (1.25,2.30)
Non-woven, double-layer	56.60 (55.65,65.50)	2.10 (1.90,5.05)
Scarf		
Chiffon, single-layer	70.90 (69.45,72.35)**	1.30 (0.90,1.45)
Chiffon, double-layer	76.30 (72.50,80.15)	1.30 (1.20,2.00)
Lycra, single-layer	90.60 (80.80,92.10)**	3.20 (2.80,3.45)**
Lycra, double-layer	72.20 (67.50,85.95)	6.00 (5.35,6.25)
Satin, single-layer	64.40 (64.10,66.05)**	2.80 (2.75,2.95)**
Satin, double-layer	74.60 (69.60,75.85)	3.70 (3.60,3.85)
Shirt		
Silk, single-layer	76.20 (70.25,77.05)**	1.50 (1.35,5.35)
Silk, double-layer	76.90 (76.65,78.45)	3.50 (3.10,8.65)

CONTINUE

Table II Common household materials tested for filtering performance and breathing resistance (cont.)

Household Material	Penetration (%) Median (IQR)	Resistance (mmH_2O) Median (IQR)
T-Shirt		
100% Cotton, single-layer	79.40 (77.60,86.20)	2.50 (0.90,3.70)
100% Cotton, double-layer	76.60 (63.75,81.55)	6.20 (1.15,8.75)
100% Polyester, single-layer	72.20 (69.70,79.25)**	1.80 (1.30,1.95)
100% Polyester, double-layer	83.70 (82.60,84.60)	1.60 (1.20,2.10)
100% micro dry, single-layer	82.30 (81.05,85.10)**	2.00 (1.85,2.15)**
100% micro dry, double-layer	82.40 (81.55,83.60)	2.50 (2.00,2.65)
Diaper	32.10 (31.25,32.65)	87.20 (86.95,87.25)

** Significant difference was observed between the same categories of fabric ($p<0.05$); Mann-Whitney U tests

materials indicated increased performance of breathing with decreasing number of layers except for double-layer 100% polyester fabric. However, its resistance performance was slightly similar compared to the same material in single-layer which were 1.60 mmH_2O and 1.80 mmH_2O respectively (Table II).

The breathing resistance for single and double-layer denim (37.10 mmH_2O and 52.10 mmH_2O respectively) and diaper (87.2 mmH_2O) exceeded the maximum resistance guidelines by the Department of Standards Malaysia (17). Since people in the surrounding areas will be effectively protected when wearing the mask with sufficient flow resistance (22), the poor breathing resistance value of denim material makes it ineffective to be used as a face mask although it has been categorized as the best material in terms of penetration. Although denim (single and double-layer) and diaper showed the worst breathing resistance value which was 87.2 mmH_2O, increasing the number of material layers could cause difficulty in breathing due to the drop of pressure (23).

Thus, by considering these three main factors: thickness, penetration and breathing resistance, the most effective materials that can be used for face masks are dried wet tissue, tissue paper, double-layer non-woven fabric, dried wet tissue and satin. Among these materials, dried wet tissue (single and double-layer) are the best to be used for face masks according to penetration and resistance factors. Hence, it is an ideal household material to be used as a homemade cloth mask. This finding shows that the efficiency of materials is not enhanced with increasing number of layers (dried wet tissue). Although not as good as N95 and surgical masks, these household homemade materials are capable of blocking aerosols regarding their performance in aerosol penetration and breathing resistance and are able to contribute to the booming use of DIY facemasks in reducing the rate of infections, provided if they are worn in combination with surgical face masks as the outside layer.

CONCLUSION

While it is critical to provide solutions to the shortage of supplies, it is equally, if not more, important to avoid false sense of security. Household material for homemade masks studied did not indicate satisfactory results for the penetration and breathing resistance at par with surgical face masks. However, some of the materials studied such as double-layer dried wet tissue, single-layer tissue paper and double-layer non-woven fabric, dried wet tissue and satin can be considered to be used as face masks due to their efficiency based on penetration and breathing resistance factors. With regards to the double masking practice encouraged by WHO, it is important to understand that the use of 3-ply disposable mask and cloth mask is meant to provide a better fit to tackle problems associated with the characteristics of aerosols. Surgical masks are not designed to prevent aerosols from entering through the sides of the masks, thus are unsuitable for healthcare workers for COVID-19 situations. This test covers penetration of particles and breathability of the materials, regardless of droplets or aerosol, which implies that fit testing is recommended where snug fit is of concern. Nonetheless, this study provides insights on low-cost options for making face masks to be worn for double masking.

ACKNOWLEDGEMENTS

We would like to thank the management of NIOSH Malaysia for providing the facilities for the test. Special thanks to the team members of the Dust Mask Lab and Consultation Management Centre of NIOSH Malaysia for the cooperation throughout the study.

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