Study of Electrostatic Field Responses of Locally Marketed Face Masks in the Philippines

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Abstract. The face mask is the first line of defense against infectious particulates and droplets that may cause illness. Currently in the Philippines, the wearing of face mask is compulsory whenever citizens leave their residences as mandated by the government to mitigate the spread of COVID-19. The wearing of face masks has become a new normal among Filipinos. This created market opportunities for different types which became commonly and immediately available for purchase. This study aimed to differentiate the effectiveness of locally available face masks in terms of electrostatic filtration capability. Twelve different types of face masks grouped into five categories – surgical, fabric, N95 variants, foam type, and novelty type – were evaluated. Electrostatic fields were measured from each face mask including pore sizes via scanning electron microscopy. Moreover, by utilizing the estimated charge and mass of the SARS-CoV-2 virion, the transmission rate was simulated using COMSOL Multiphysics®. It was observed that face masks with negatively charged materials combined with small pore sizes afforded less particle transmission. The results of this study are of timely significance in potentially laying out public awareness in the selection and utilization of face masks that can provide foremost shielding against viral transmission.

Keywords: face mask, triboelectricity

1. Introduction
In the Philippines, the continued rise of COVID-19 cases has prompted the Inter-Agency Task Force for the Management of Infectious Diseases to make it compulsory for citizens to wear face masks (along with face shields) whenever they leave their residential premises. The local government units are tasked to enforce, arrest, and fine citizens for violating this directive, making the wearing of face masks the new normal. This situation created market opportunities for various types. The N95 is still the benchmark for face masks in terms of filtering capabilities. However, due to its scarcity and cost, several options ranging from surgical, fabric, and novelty-types have sprung up in the local market to fill in the gap. The Philippine Food and Drug Administration (FDA), through its advisory No. 2020-1181 [1], listed medically approved face masks based on the assessment set by the US Centers for Disease Control
and Prevention. However, some of the popular face masks in the market are not included on the FDA list. Unfortunately, local buyers are attracted by aesthetic appearances and marketing promotions. Driven by this lack of awareness, the effectiveness of locally available face masks in terms of electrostatic filtration capability was investigated. Triboelectric charges are generated when two surface materials come in contact and separate from each other. The separated materials gain either positive or negative charges depending on their electron affinity in the triboelectric series. The electrostatic charges on the surface of these materials generate an electric field. The mechanism is illustrated in Figure 1. For negatively charged materials, positively charged particles are attracted and trapped in the fibers, whereas negatively charged particles are repelled. The human skin and the face mask create an interface suitable for generating triboelectricity which produces an electrostatic field. Electrostatic field plays an important role in filtering by repelling particulates such as enveloped viruses like SARS-CoV-2 which are positively charged and aerosolized in the air [2, 3, 4]. Meanwhile, any rouge viral particles can be filtered-out by smaller pore sizes.

Figure 1. An illustration showing negatively charged fibers that attract and trap positively charged particles and repel negatively charged particles.

This study presents an alternative method to characterize and classify locally marketed face masks based on filtration capabilities using electrostatic repulsion by simulating the COVID-19 virus (SARS-CoV-2) as a charged particle. The outcome of this study could provide baseline data as guide for local regulators in setting up an in-house testing facility for classifying and determining face mask efficacy.

2. Materials and Methods

2.1. Face mask types

Twelve different face masks were randomly bought from mall outlets and were grouped into five, namely: (a) surgical three-ply with melt-blown fabric in the middle layer; (b) fabric with cotton non-woven material; (c) N95 variants (N95, KP94 and KN95); (d) novelty type with metal infused material as outer layer, and non-woven fabric as inner material; and (e) stretchable foam-like material. For the legal protection of the manufacturers, brand names were withheld. The face mask conditions were brand new and unused when measurements were taken.

2.2. Measurement of triboelectric charge and SEM scanning

During the measurement of triboelectric voltage, each face mask was placed on top of a wooden table to simulate skin contact on the material. Each mask was frictionally rubbed three times in a unidirectional motion via the outer layer of the mask (facing outwards). The triboelectric voltage was measured using a 3M718 electrostatic field meter at 20mm from the material. The measurements were taken inside a clean laboratory with a temperature from 21 to 22°C, and a relative humidity from 57 to 65%. A JEOL model JSM IT500HR Schottky Field Emission Scanning Electron Microscope (FE SEM)
(JEOL, Tokyo, Japan) was used to magnify the filter and measure the pore sizes of each layer in the face mask. A small portion (4mm x 4mm) was cut from the lower right side of each face mask for this purpose and were mounted on an Al sample stub (12mm x 10mm) and secured by a double-sided conductive carbon tape (JEOL accessories with part no. 78004523). Each of these samples were Pt sputter coated using a JEOL model JEC-3000FC magnetron type sputter coater before being subjected to SEM. The pore sizes were measured using the built-in computational algorithm of the SEM software. The pore sizes were measured at three different locations in the sample and average values were calculated.

2.3. Bacterial filtration efficiency
To simulate particle challenge, the protocol by Davies et al. (2013) was followed [5]. A non-pathogenic type of strain of Escherichia coli (ATCC 25922) was used to simulate bacterial particle challenge due to ease of availability, rather than an actual virus, and to imitate whether biologically contaminated aerosol can be filtered out in varying degrees of effectivity. The test was performed three times for each material with the filtration efficiency (FE) calculated using Equation 1, where CFU stands for colony-forming units, while U and D connote upstream and downstream measurements, respectively.

$$FE = \frac{(U_{CFU} - D_{CFU}) \times 100}{U}$$

2.4. Electrostatic filtration simulation
COMSOL Multiphysics® was used to simulate the transmission of the virus particles through all the layers of the face masks. A small portion of each mask with dimensions of 1mm at each side were simulated with 1mm thickness. A 3-dimensional representation of the simulation is shown in Figure 2. The face mask rendered in this figure presented two layers with different average pore sizes located in B. All simulated COVID-19 viral particles were released from location A with an initial speed of 0.5 m/s to mimic sneezing. An accumulator or particle counter was simulated at C to measure the total number of rouge particles that went through the face mask layers in B. The calculation was based on data gathered from previous literature on COVID-19 [6, 7] with applied parameters listed in Table 1.

| COVID-19 Parameters                  | Estimated Values                  |
|-------------------------------------|-----------------------------------|
| Diameter                            | 60 to 120 nm                      |
| Mass                                | 400,000 kDa                       |
| Electrostatic charge (S-protein)    | 1.296 to 1.589 x 10¹⁹ C           |

A voltage difference was setup in the simulation by applying the triboelectric voltage measured in the laboratory. Furthermore, the particle trajectories and the electric fields around the face masks were also gathered. The electric field around the masks can also influence the movement of the simulated positively charged COVID-19 viral particles upon approaching the first layer of the mask.

3. Results and Discussion
3.1 Pore sizes and magnified images of each layer
Table 2 features structural SEM images of each face mask at 200x. The 3-ply surgical masks contain a melt-blown fabric at an average of 11µm pore size with brand ID having the smallest pore size at 5µm. The outer and inner layers have non-woven fabrics with an average of 50µm and 84µm, respectively. The non-woven cotton fabric material of brand KS is like a surgical 3-ply mask. Meanwhile, brand WT is the lone mask with foam-like material while the novelty type is composed of polyurethane infused with Cu as advertised by its marketer. Brand VD is similar to polyester materials used in clothing. Lastly, the N95 and its variants have tightly knit filters in the outer layers. The N95, which is the gold standard for protection, consisted of four layers in which the last two are tightly knitted with pore sizes ranging...
from 11 to 17µm. Figure 3A presents the triboelectric voltage values generated after frictional rubbing. Brand KS, although advertised as cotton material, obtained the highest generated voltage (most negative) followed by the surgical mask AD. Raw cotton is slightly neutral in the triboelectric series. However, commercialized face masks have surfactant additives that make the surface insulative [8] thereby generating more negative electrostatic charge upon frictional contact.

Figure 2. Simulation setup with three main locations: (A) for simulated COVID-19 virus inlet with a total of 1,000 particles; (B) is the simulated face mask divided by the number of layers with corresponding pore sizes; and (C) the location of the accumulator for counting the simulated number of transmitted COVID-19 viral particles.

The AD brand is similar in structure and appearance with that of the other three listed surgical masks but the difference in the generated triboelectric voltage was due to the base materials used for manufacturing. A slight change in the base material or additive could have affected its triboelectric charging characteristics. All the face masks exhibited negative charge affinities (except VD) due to construction materials which constituted mainly of inorganic polymers classified below the triboelectric series (Figure 3A). Figure 3B shows the plot of the first layer pore size and transmission relative to the electric field strength. The three single layered non-surgical face masks KS, WT, and VD (boxed in yellow), afforded higher transmission values relative to generated electrostatic field (VD > WT > KS). It is inferred that the highly negative electrostatic voltage on the KS (~−7kV) created an electric field which attracted and trapped the positively charged COVID-19 viral particles therefore significantly affecting filtration capability. Meanwhile, the higher transmission rates for WT and VD were mainly attributed to larger pore sizes despite having weakly negative and weakly positive electric fields, respectively.

The novelty type afforded the lowest filtration efficiency since the constructive design involved an opening along the chin area that allows air to freely pass through. This is primarily the reason why this face mask type is not recommended in medical facilities, hospitals, and by the local administration [9].

3.2. Microbial filtration
All the face masks evaluated exhibited certain degrees of blocking microbial aerosol filtration challenge (Table 3). While N95 and its variants afforded the highest filtration efficiency (99%), it was generally observed that surgical-type face masks with two to three layers showed 96-98% effectiveness. Meanwhile, the fabric-based (cloth and polyurethane) materials resulted to only 60%, an efficiency score which can only infer slightly above 50% protection. Interestingly, the novelty-type material characterized with metal infuse showed only 10% efficiency, probably because of a design flaw with a hole on the chin part of the mask. The filtering efficiencies of the fabric-based masks may have resulted to more than 50% because the pores sizes were most likely capable of moderately filtering microbial size dimensions which are larger compared to the smaller sizes of coronavirus particles.
Table 2. SEM images (200x) of the different layers of each face mask. The measurement of electrostatic field values were taken from the outermost layer.

| Type                | Brand | Layers | Outer | Middle | Inner | Other side |
|---------------------|-------|--------|-------|--------|-------|------------|
| Surgical 3Ply       | AD    |        | ![Image] | ![Image] | ![Image] | ![Image] |
| Surgical 3Ply       | ID    |        | ![Image] | ![Image] | ![Image] | ![Image] |
| Surgical 3Ply       | Xt    |        | ![Image] | ![Image] | ![Image] | ![Image] |
| Surgical 3Ply       | AD-G  |        | ![Image] | ![Image] | ![Image] | ![Image] |
| Surgical 2Ply       | AD-B  |        | ![Image] | ![Image] | ![Image] | ![Image] |
| Non-woven Cotton Fabric | KS |        | ![Image] | ![Image] | ![Image] | ![Image] |
| Polyurethane - (foam like) | WT |        | ![Image] | ![Image] | ![Image] | ![Image] |
| Metal infuse with non woven filter | Novelty Type |        | ![Image] | ![Image] | ![Image] | ![Image] |
| WovenPolyester      | VD    |        | ![Image] | ![Image] | ![Image] | ![Image] |
| N95 variant         | K95   |        | ![Image] | ![Image] | ![Image] | ![Image] |
| N95 variant         | KF94  |        | ![Image] | ![Image] | ![Image] | ![Image] |
| N95 variant         | N95   |        | ![Image] | ![Image] | ![Image] | ![Image] |
Table 3. Pore size of face mask layers and filtration efficiency to aerosols of *Escherichia coli*.

| Type                     | Brand | 1st layer | 2nd layer | 3rd layer | 4th layer | Mean bacterial filtration efficiency (%) |
|--------------------------|-------|-----------|-----------|-----------|-----------|------------------------------------------|
| Surgical                 | AD-B  | 61.2      | 17.3      | -         | -         | 96                                       |
|                          | AD-G  | 41.0      | 17.3      | -         | -         | 96                                       |
|                          | AD    | 56.8      | 8.4       | 57.5      | -         | 96                                       |
|                          | ID    | 71.3      | 5.1       | 155.2     | -         | 98                                       |
|                          | Xt    | 28.4      | 7.0       | 41.0      | -         | 96                                       |
| N95 and variants         | N95   | 32.4      | 98.2      | 11.6      | 19.79     | 99                                       |
|                          | KN95  | 14.5      | 29.8      | -         | -         | 99                                       |
|                          | KF94  | 4.4       | 21.7      | -         | -         | 99                                       |
| Foam type / Fabric       | WT    | 56.5      | -         | -         | -         | 60                                       |
|                          | VD    | 32.3      | -         | -         | -         | 60                                       |
|                          | KS    | 43.1      | -         | -         | -         | 60                                       |
| Others                   | Novelty type | 22.7      | -         | -         | -         | 10                                       |

Figure 3. (A) Triboelectric voltage profiles of the outer layers of face masks structurally featured in Table 2. All face masks (except VD) exhibited negative electrostatic voltage after unidirectional frictional rubbing. (B) Shows the plot between the first layer pore size and transmission relative to electric field. KS had the lowest transmission among single layered face masks.

3.3. Particle transmission relative to electric field

Transmission relative to the electric field generated in relation to triboelectrification are plotted in Figure 4A. The novelty type mask was excluded since the filtration efficiency is very low to be considered safe for general use. A trend was observed showing decreasing particle transmission against increasing negative electric field. The outliers were due to samples VD and WT both of which have large pore sizes and low filtration efficiencies (Figure 3A).

Figure 4A shows the relationship of bacterial filtration efficiency and transmission relative to the electric field. A clear correlation showed that a negative electric field generated by triboelectric charge can mitigate the transmission of the virus. In both Figures 4A and 4B, the N95 and its variants are still superior when it comes to filtration and mitigation properties due to the small pore sizes and negative electrostatic voltage. Majority of the surgical masks (AD-G, AD-B, Xt, and ID) are likewise effective in terms of filtration and repulsion due to their small pore sizes and the negative electric fields generated on the first filter layer. Surprisingly, despite having a high transmission rate relative to electric field, AD had a 99% filtration efficiency because of small pore size and three-ply design. This shows that regardless of surgical masks having similarity in appearances, their material properties brought about
by manufacturing process may be different. Surgical face masks are generally cheaper alternatives for N95 and its variants and are easily accessible to the local public. On the other hand, the reusable-type and washable face masks WT, VD, and KS demonstrated similar filtration efficiencies, but the KS sample showed better mitigation properties because of the highly negative electric field it generated (Figure 3A), trapping the positively charged virus as a result. Reusable face masks with highly negative electrostatic voltage may specially mitigate virus transmission by uniquely trapping positively charged viral particles in the fibers (Figure 4B). This can be perfectly coupled with filters comprised of very small pore sizes for maximum filtration efficiency.

**Figure 4.** (A) Virus transmission relative to the triboelectric voltage generated. A trend shows that materials with negative affinity can repel the virus. WT and VD had high transmission rates due to large pore sizes. (B) Relationship with filtration efficiency and transmission relative to the electric field.

The correlation charts in Figures 3B, 4A, and 4B, have shown the interrelation of electrostatic voltage, transmission efficiency, and filtration efficiency. A highly negative electrostatic charge plays an important role in mitigating virus transmission due its trapping properties even for a single layer facemask like KS. Furthermore, the negative electrostatic voltage assists in reducing transmissions even for a low filtration efficiency (larger pore sizes) face mask samples such as KS and WT (Figure 4B). Concurrently, several layers of filters with very small pore sizes can additionally offer optimal and effective filtration capacity.

**4. Conclusion**

Twelve locally available face masks were studied based on electrostatic field response, pore size, and filtration efficiency. Results showed that there is a clear correlation between the mitigation effects of electric field and filtration efficiency due to pore sizes. Reusable face masks with a high value of electric field generated by negatively charged raw materials can moderately mitigate viral transmission due to particle trapping. Positively charged COVID-19 particles can be trapped in the first layers of filter which is are composed of negatively charged materials, even if these materials have low filtration efficiency (or larger pore sizes). Reusable or washable face masks are common in the local market and are economical alternatives to single-use face masks. However, based on the gathered data, these face masks may only be used for low-risk areas (open spaces) and not in enclosed populated places like malls and air-conditioned public transportation. It is recommended to collect more types of reusable face masks to have a larger sampling size for further study.

This study can also open avenues for analysing locally available materials such as polyester, nylon-based, and plant-based fabrics which can be potentially manufactured into face masks. This would help and positively affect small scale industries to locally produce and fabricate face masks with scientifically proven efficacies. The generated baseline information can aid local regulating bodies for evaluating face mask efficacies within testing facilities and help create awareness among the public. The study can also facilitate in the discovery and identification of locally available and indigenous environmentally friendly and natural fabrics that can be suitable as raw materials for the manufacture of face masks.
Acknowledgement
The authors would like to acknowledge the Central Instrumentation Facility of the Office of the Vice Chancellor for Research and Innovation (OVCRI-CIF) for the use of the SEM. The authors would also like to express their appreciation to Mr. Jacinto Selorio of JATEC Philippines for providing the face masks used in this study and to Dr. Romeric Pobre of the DLSU Physics Department for providing the COMSOL Multiphysics® software.

Conflict of Interest
The authors declare that there is no competing conflict of interest in publishing this paper.

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