Supporting Information for

Household Materials Selection for Homemade Cloth Face Coverings and Their Filtration Efficiency Enhancement with Triboelectric Charsging

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Symptoms and Transmission of COVID-19

Patients exhibit symptoms including fever, difficulty breathing, cough, chills, muscle pain, sore throat, and loss of taste or smell.[1] Complications include pneumonia and acute respiratory distress syndrome (ARDS) and may require intensive hospital care.[2–4] The incubation period of 2–14 days[3,5,6] and the presence of asymptomatic or pre-symptomatic carriers makes early identification of infections difficult,[7,8] and contributes to community transmission. Persons at higher risk for severe illness include older adults and those of any age with certain underlying medical conditions.[9] Emergency responders and healthcare workers are at higher risk of becoming infected. Asymptomatic or mildly ill infected persons can spread the infection.[10,11]

Coughing, sneezing, and even singing, breathing, or speaking, can release a substantial amount virion-containing particles into the air (vocalization of "aah" for the duration of a cough emitted more particles than a series of coughs).[12–17] This has been seen previously in influenza A and B, in which a large portion of viral RNA (collected from coughs and exhalation) was found in particles ranging from dried sub-micron aerosols to ten micron droplets.[18,19] However, relative humidity (RH) can significantly impact particle size during transmission. Dry conditions can lead to rapid vaporization of larger droplets to become fine aerosols and remain airborne for much longer time periods due to slight air currents. Higher RH has also been found to affect the rate of viral inactivation, as the concentration of influenza A virus in air was 2.4 times higher at 10% RH compared to 90% RH after 10 min in a residential setting, growing more pronounced over longer periods of time.[20]

N95 FFRs and Medical Masks: Testing Procedures and Usage Cases

The N95 FFR designation is determined by the CDC's National Institute for Occupational Safety and Health (NIOSH), and indicates a minimum filtration efficiency of 95% for particle sizes 0.022–0.259 μm (count median diameter of 0.075 ± 0.02 μm), according to 42 Code of Federal Regulations (CFR) Part 84.[21] To measure the filtration efficiency, N-series FFRs are tested at a flow rate of 85 L/min using a charge neutralized polydisperse NaCl aerosols with particle size ranges from 0.022–0.259 μm, count median diameter of 0.075 ± 0.02 μm (mass mean diameter of 0.26 μm), and a geometric standard deviation < 1.86. NIOSH approval testing is a worst-case method, because of the use of charged neutralized aerosol sizes close to the most penetrating particle size (~0.050 μm for N-type respirators) at relatively higher flow rate (face velocity) to produce maximum penetration or conservative filtration efficiency. Similarly, the European Centers for Disease Control recommends the use of filtering facepiece mask (FFP) of type FFP2 (94% filtration efficiency), for aerosol-generating procedures involving patients with COVID-19.

Surgical masks are cleared for sale by the Food and Drug Administration (FDA) in the United States. Manufacturers submit test results for fluid resistance, filtration efficiency for polystyrene latex (PSL) and *Staphylococcus aureus* bacterial aerosol particles, differential pressure, and flammability for surgical masks clearance. For particle filtration efficiency testing, un-neutralized 0.1μm polystyrene latex particles are used as per FDA guidance document at 0.5 to 25 cm/sec face velocities as recommended by the ASTM F2299 standard test method for determining the initial efficiency of materials used in medical face masks to penetration by particulates using latex spheres. Bacterial filtration efficiency is measured using un-neutralized *S. aureus* bacteria contained within an aerosol droplet with a mean particle size of 3 ± 0.3 μm diameter at a flow rate of 28.3 L/min as per FDA guidance and ASTM F2101 method. As indicated in the standards, these masks are not recommended for respiratory protection.[22] In addition, surgical masks are designed and intended as a form of barrier protection and provide fluid resistance for use in hospitals (require passing ASTM F1862 for fluid resistance to synthetic blood).

The World Health Organization (WHO) recommends the use of medical face masks when caring for patients with suspected or confirmed COVID-19 except during aerosol-generating procedures, and the CDC recommends facemasks if NIOSH-approved N95 FFRs are not available when caring for patients with known or suspected COVID-19.[23–25] The CDC recommends the use of N95 or higher grades of FFR for aerosol generating procedures and procedures involving anatomical regions where the viral load may be higher (e.g. respiratory tract).[26]

Additional Health Precautions and Face Covering Usage

Additional measures to slow the spread of COVID-19 to be used in conjunction with facial coverings include maintaining physical distance from other individuals, performing hand hygiene frequently, avoiding touching one's eyes, nose, and mouth; practicing respiratory hygiene, and routinely cleaning and disinfecting frequently touched surfaces.[23,27] While more data are required to confirm our findings, we suggest that cloth face coverings worn by the public may be useful not only as source control but also provide limited filtration of particles. If designed, constructed, and worn correctly, cloth face coverings may reduce the wearer's exposures to infective droplets, although their use would not be appropriate for respiratory protection in a workplace or another environment where respiratory protection is required or needed. In these work environments, respirators approved by NIOSH are the most appropriate method of respiratory protection.[24]

Methods

Material Selection: Due to the COVID-19 pandemic, materials were limited to common materials. Reference materials used a meltblown fabric (Guangdong Meltblown Technology Co., Ltd. under the sample name TM95 with a 20 g/m^2 basis weight and initial filtration efficiency of ≥95%). Medical face mask data was collected by removing the meltblown fabric from the medical face mask (CLK Medical Supply, Inc. and Gaoyou Qinyou Biological Technology Co., Ltd.) to test, to be comparable with the meltblown used in FFRs.

From the common materials, cotton, polyester, nylon, and silk were cut from either clothing or household items. Polypropylene spunbond was available to us (Hongxiang New Geo-Material Co., Ltd.) and we selected a variety of spunbond samples to test due to availability.

For the other paper-based cellulose products, these were directly used as-is.

Testing Information: All tests were conducted with an Automated Filter Tester 8130A (TSI, Inc.) The TSI 8130A used a 0.26 μm, mass mean diameter (0.075 ± 0.02 μm count median diameter) of sodium chloride (NaCl). The test size of the filter tester is 100 cm^2, with a circular gasket outer diameter of approximately 13 cm. All samples were cut to a size greater than a 13 cm × 13 cm square. All samples were tested with a flow rate of 32 L/min.

Charging Information: Samples were vigorously rubbed with latex gloves (Microflex MF-300-M Diamond Grip Exam Gloves) on for 30 seconds, unless otherwise specified. This is provided in the supporting movie file, M1. In the case of charging in a humid environment, immediately after charging the sample was tested, based on the methods in the Testing Information section, then placed in an environmental chamber (SH-642), set to 38 °C, 85%. The samples were collected from the chamber at the times given in the main text and tested. Samples were then placed back into the chamber until the next designated time.

Scanning electron microscope (SEM) images: All samples were tested using a Phenom Pro SEM using 10 kV.

Movie file: M1_Triboelectric_Charging.mp4: Video demonstrating the simple charging of the fabric. The fabric clearly has static charge after the charging is complete due to the attractive nature of the fabric.

Supplementary Information Figures

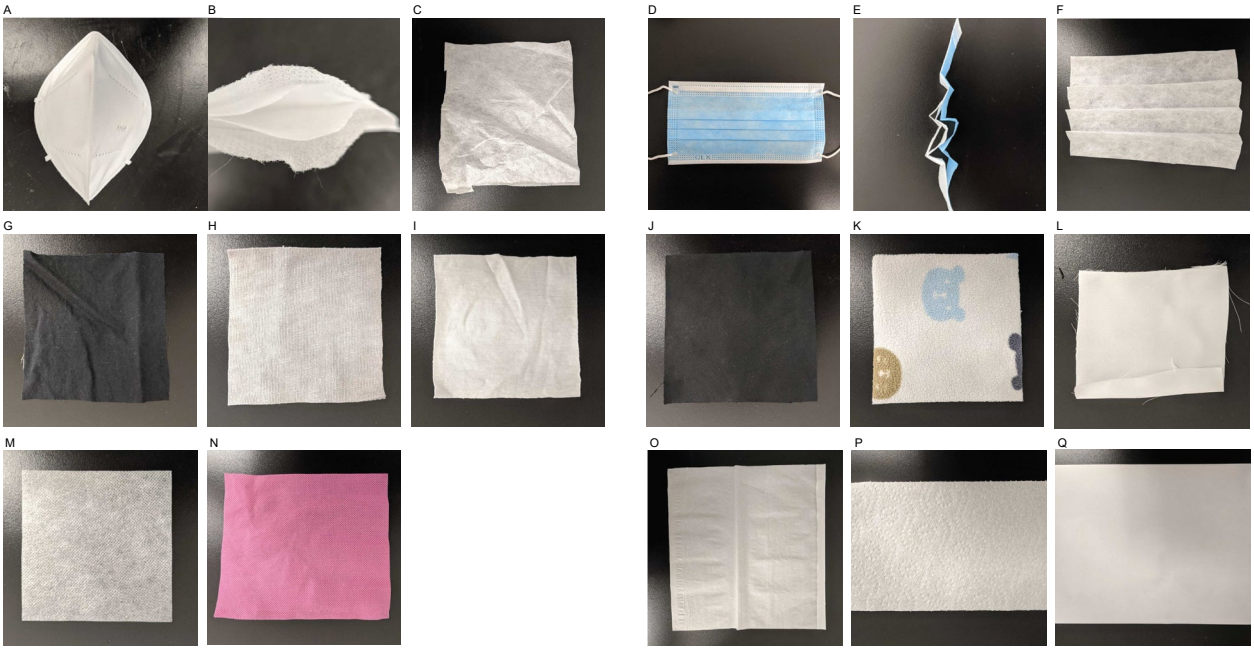

Figure S1. Optical images of reference and common materials. a-c. Reference material, 95% FFR. a. Image of a folded-style FFR. b. Cross section of said FFR showing layers of spunbond fabric (outer layers) and meltblown layers (inner layers). c. Meltblown fabric used in the actual experiments, it does not come from the FFR shown in a-b, due to limited amount of meltblown that can be used for testing from an FFR in a whole sheet. d-f. Reference material, medical face mask. d. Image of the surgical flat mask. e. Cross section of the medical face mask showing spunbond, meltblown, spunbond structure. f. Meltblown extracted from the mask used in main text Table 1, to be comparable with the 95% meltblown. g-i. Common materials, cotton 1-3 (respectively). A variety of cotton with different thickness and structure were selected, the data is given in Table 1. j-l. Common materials, nylon, polyester, and silk, respectively. m-n. Common materials, polypropylene spunbond 30 (PP-4) and 70 g/m^2 (respectively). o-q. Common paper-based cellulose materials, tissue paper, paper towel, copy/printing paper, respectively.

Layers	Filtration Efficiency (t_0, %)	Pressure Drop (t_0, Pa)	Q (t_0, kPa^{-1})	Filtration Efficiency (t_{c60}, %)	Pressure Drop (t_{c60}, Pa)	Q (t_{c60}, kPa^{-1})
1	7.65 ± 0.93	1.5 ± 0.5	23.8 ± 11.6	20.35 ± 5.34	2.2 ± 0.8	48.9 ± 17.7
2	11.94	5	11.0	30.16	3	52.0
3	16.41	5	15.6	40.83	4	57.0
4	20.64	5	20.1	47.42	8	34.9
5	23.95	8	14.9	53.12	8	41.1

Table S1. Multilayer polypropylene spunbond filtration efficiency. We tested multilayers of the PP-4 (30 g/m^2) stacked in multilayers initially (t_0), and after charging each layer, stabilized after an hour (t_{c60}). A total of five PP-4 samples were used. All five were initially tested to yield the standard deviation given as the uncertainty here. Subsequent stacking of layers used these five samples (tested once). This data reveals that the filtration efficiency of a multilayer polypropylene structure can reach much higher efficiencies (single layer is ~7% to ~20% after charging). The quality factor is also dramatically increased. The pressure drop is not exactly linear due to the non-uniformity in the pressure across the PP-4 samples.

Material	Basis weight (g/m^2)	Filtration Efficiency (t_0, %)	Pressure drop (t_0, Pa)	Q (t_0, kPa^{-1})	Filtration Efficiency (t_c, %)	Pressure drop (t_c, Pa)	Q (t_c, kPa^{-1})
PP-4	30	6.16 ± 2.19	1.7 ± 0.6	16.9 ± 3.4	23.93 ± 0.54	2.3 ± 0.6	52.6 ± 10.3
PP-5	25	12.27 ± 0.04	2.5 ± 0.7	22.7 ± 6.8	21.57 ± 2.2	2 ± 0	52.7 ± 6.1
PP-6	40	8.49 ± 1.82	3 ± 0	12.8 ± 2.9	24.11 ± 3.59	1.5 ± 0.7	79.9 ± 27
PP-7	60	47.76 ± 2.55	130.5 ± 21.9	2.2 ± 0.2	65.63 ± 2.74	127.5 ± 21.9	3.6 ± 0.4
PP-8	70	16.29 ± 0.62	7.5 ± 0.7	10.3 ± 1.4	25.18 ± 0.9	8 ± 1.4	15.7 ± 2.2

Table S2. Different polypropylene spunbond filtration properties. We tested polypropylenes of different basis weight initially (t_0), and after charging, immediately (t_c). Uncertainties here represents the standard deviation between the samples (samples of 3). We see that between the samples PP-4, 5, 6 are all similar in Q, however PP-7, 8 both have a higher pressure drop, especially so in PP-7 (though it also comes with a much higher initial filtration efficiency).

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