Performance of fabrics for home-made masks against spread of respiratory infection through droplets: a quantitative mechanistic study

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Abstract

Respiratory infections may spread through droplets, airborne particles, and aerosols from infected individuals through coughing, sneezing, and speaking. In the case of Coronavirus Disease 2019 (COVID-19), droplet spread can occur from symptomatic as well as pre-symptomatic and asymptomatic persons. The U.S. Centers for Disease Control and Prevention (CDC) has therefore recently recommended home-made cloth face coverings for use by the general public in areas of significant community-based transmission. Because medical masks and N95 respirators are in short supply, these are to be reserved for healthcare workers. There is, however, little information on the effectiveness of home-made face coverings in reducing droplet dissemination. Here, we ascertained the performance of ten different fabrics, ranging from cotton to silk, in blocking high velocity droplets, using a 3-layered commercial medical mask as a benchmark material. We also assessed their breathability and ability to soak water. We reason that the materials should be as breathable as possible, without compromising blocking efficiency, to reduce air flow through the sides of the mask since such flow would defeat the purpose of the mask. We found that most home fabrics substantially block droplets, even as a single layer. With two layers, blocking performance can reach that of surgical mask without significantly compromising breathability. Furthermore, we observed that home fabrics are hydrophilic to varying degrees, and hence soak water. In contrast, medical masks are hydrophobic, and tend to repel water. Incoming droplets are thus soaked and “held back” by home fabrics, which might offer an as of yet untapped and understudied advantage of home-made cloth masks. Overall, our study suggests that most double-layered cloth face coverings may help reduce droplet transmission of respiratory infections.

Introduction

At the crux of any pandemic is the transmission of a pathogenic agent, e.g. a novel virus, that spreads in populations on a global scale. Current knowledge from influenza, SARS-1, and MERS indicates three major routes of transmission: droplets, aerosols, and contact [1,2]. Although the mechanism of spread of the current novel coronavirus (SARS-CoV-2) is not clearly understood, it is thought that spread can occur through droplets containing virus particles when infected persons sneeze, cough, or speak [2–4]. Larger droplets tend to fall nearby by gravity, and the smaller ones can travel longer [1,5,6]. Droplets inhaled by a healthy individual allow the virus to enter the respiratory system and cause infection. The larger droplets can also give rise to short range *direct transmission* mediated through hand contacts [6,7]. Face masks can offer a physical barrier against virus transmission. This is particularly true for SARS-CoV-2 virus that are shed by symptomatic, pre-symptomatic, and asymptomatic carriers [8–11]. During the COVID-19 pandemic, the supply of commercially manufactured facemasks has not been able to meet the demand. This raises the question whether home-made face masks can be used by the general public to reduce transmission.

Recently, the U.S. CDC has provided new guidance for the public to use non-commercial alternative to facemasks such as cloth face coverings in order to slow the spread of COVID-19 [12]. However, it is not yet clear what kind of fabric would be the most efficient material or how many layers of cloth would protect against both spreading and contracting the virus. Existing literature on home-made masks have mostly focused on the filtration efficacy of the masks against aerosol or dry airborne particles less than 1μm in size under prescribed flows or pressure differentials [13–17]. These studies are relevant for situations where an individual is breathing in an atmosphere with pathogenic aerosol particles. In contrast, when a patient or an asymptomatic person coughs, sneezes, or talks into a mask, the droplets that hit the inside of the mask are relatively large, and they have high momentum [6]. Also, when healthcare providers provide care to patients, they can be on the receiving end of such droplets that may be loaded with pathogens. How home-made masks can be effective in these scenarios remains elusive. This has led to controversies on the use of home-made masks and their effectiveness. To address this issue in the current context of COVID-19, we evaluated medical masks along with ten regular household fabrics for their droplet blocking efficiency against high and low velocity droplets in a laboratory setting. We also assessed their breathability, i.e., the ease of breathing through these fabrics. We first define the scope of our study.

Problem definition

In order to understand the effectiveness of any mask against droplets carrying 100 nm particles, we asked the following two questions:

1. What are the essential parameters in determining the mask material against droplets?
2. What is the physical mechanism by which a mask material can block incident droplets?

This study did not consider steps for producing a facemask, e.g., how they should be stitched, how their boundaries should be designed, how to attach them to the face, and how they should be used or decontaminated. Similarly, blocking efficiency of mask fabric against aerosolized and dry airborne particles (usually less than 1μm in size) is beyond the scope of this study. Our goal is to provide scientific insight in the use of home-made facemask fabrics against droplet dissemination.

In order to answer the first question, we note that there are two groups of mask users: (a) infected individuals releasing droplets by sneezing, coughing, and speaking, and (b) healthy individuals receiving the droplets. For the former, the mask is most challenged when droplets land on the mask cloth with high momentum (high mass and velocity) [18,19]. For the recipient, the droplet momentum is small or negligible. If a common mask is to be applicable to both, then the mask material (i) must be able to resist the high momentum droplets, and (ii) still be breathable enough so that air does not go through the sides of the mask. Large fraction of air flow through the sides defeats the purpose of the mask, as droplets can be carried with the side flow, and the mask provides a false sense of protection. Thus, the two critical parameters for any mask material are breathability, β, and efficiency of blocking droplets, ε. High breathability may reduce blocking efficiency, and vice versa. The problem of finding an appropriate material for a home-made mask thus reduces to picking a fabric that maximizes both the parameters. We consider a set of ten common household fabrics. Their properties are compared with a medical mask fabric (Face Mask, FM-EL style) consisting of three layers (Fig. 1). This medical mask serves as our benchmark.

Fabrics considered in this study

The ten fabric samples considered here include 100% cotton, 100% polyester, several combinations of cotton and polyester, used dishcloth, and silk, as well as the 3-layered medical mask fabric (Fig. 1). Fabric sample descriptions and study results are listed in Table 1. Each fabric and the medical mask were characterized in terms of their (1) droplet blocking efficiency, (2) breathability, (3) weight, (4) hydrophilicity and water soaking ability, and (5) microscopic texture. Evaluations of (3), (4), and (5) can offer physical insight into the mechanisms of breathability and droplet blocking efficiency of the fabrics. The measurement of droplet blocking efficiency and breathability are detailed in the corresponding sections below. The weight (mass per unit area) of each fabric was measured using a high precision weighing scale. To assess the hydrophilicity and water soaking ability of fabrics, a 100μl droplet of water was dispensed onto the fabric and videos of the process of wetting and soaking were recorded. Supplementary Video 1 provides a qualitative comparison of the hydrophobic non-soaking medical mask, a slow-soaking fabric, and a highly hydrophilic fast-soaking fabric. Water soaking ability was quantified by processing the droplet soaking videos and calculating the rate of change of soaked fabric area (soaking speed in mm^2/s in Table 1). The microscopic texture of each sample was inspected under a microscope and are shown in Fig. 1.

Measurement of droplet blocking efficiency, ε

A schematic illustration of our experimental method for measuring droplet blocking efficiency is shown in Fig. 2a. To generate droplets with high initial velocity, we used a metered-dose inhaler (Ventolin HFA) [23,24] and loaded the nozzle of the inhaler with 10µl of a suspension of 100nm-diameter fluorescent beads (Invitrogen) in distilled water (3.6×10^{10} beads/ml). The fluorescent beads serve two purposes: (1) mimic SARS-CoV-2 virus (70-100nm-diameter) in terms of size [25,26], and (2) allow to quantify the blocking efficiency of the fabric samples. When the inhaler is pressed, the internal pressure of the inhaler pushes the bead suspension out of the nozzle, creating high speed droplets moving along the direction of the inhaler tube. The droplets then hit the fabric sample that is placed in front of the inhaler (Fig. 2b). We used a high-speed camera (Fastcam, Photron) to record the motion of the droplets with 10,000 frames per second (Supplementary Videos 2-5). Image analysis revealed that the velocity of the droplets is about 17m/s near the inhaler and decreases as they travel through air (Fig. 2c). The velocity reduces to about 2.7m/s at 300mm (~12 inch) from the inhaler.

We placed the inhaler at mid-height of an acrylic channel open at both ends (Fig. 2b). The channel prevents air flow in the room from interfering with the tests. A 35mm petri dish was placed at a distance of 25mm (~1 inch) from nozzle of the inhaler to receive the droplets. Fig. 2d shows brightfield and fluorescence images of the droplets that were collected in the petri dish without a fabric barrier. For testing the fabric samples, we covered petri dishes by attaching the fabric cut-outs to the rim of the dish using double-sided tape. The inhaler nozzle was again loaded with the bead suspension and droplets were shot at the sample by pressing the inhaler. Droplets that penetrate the fabric were collected in the petri dish. Since the fluorescent beads are uniformly dispersed in water, we can use the number of beads collected with and without a fabric barrier to measure the droplet blocking efficiency.

However, the droplet images in Fig. 2d cannot be used to count the beads because many beads are clustered together and cannot be counted separately. To solve this problem, we first coated the bottom of the petri dish with 1ml of warm gelatin solution (5% wt/v in distilled water). Gelatin forms a hydrogel at and below room temperature and melts at higher temperatures [27]. We let the gelatin solution gel inside the petri dishes at 4°C, then shot droplets as before, with and without fabric samples (separate petri dish for each test). Now the droplets containing beads were collected on the gelatin layer. Next, we warmed the samples to 37°C in an incubator to liquify the gelatin layer and allow the beads to dissolve into the gelatin solution. This solution was transferred to a vial, vortexed for 20s, then sonicated for 30min to uniformly disperse the fluorescent beads in solution. 400µl of this homogenized bead-gelatin mixture was pipetted into the well of a glass-bottom petri dish, the well was covered with a glass coverslip, and the sample was returned to 4°C to allow the solution to gel. The beads were thus frozen in place in the hydrogel.

We imaged the gels containing beads on a confocal laser scanning microscope (LSM 710, Zeiss) using a 40X water-immersion lens. For each sample, we picked at least three random fields of view and took z-stacks with 10µm spacing (to ensure the same set of beads were not imaged twice) and 25-30 slices. The bead distribution was reasonably uniform in plane and across the gel thickness. Fig. 2e shows representative images of beads embedded in the gel layer from experiments with and without a blocking fabric. Images were processed in MATLAB to count the average number of beads per field of view. The average number of beads per field of view, $n_{with-fab}$ and $n_{without-fab}$, with and without a fabric barrier are used to quantify droplet blocking efficiency, ε, of the fabric:

$$\varepsilon = 100 \times (1 - \frac{n_{with-fab}}{n_{without-fab}})$$

Blocking efficiencies were measured for the medical mask, for all ten fabrics with one layer, and for 2 and 3-layered T-shirt fabric (Table 1, Fig. 2f-g). In all cases, the fabrics were placed at a distance of 25mm (~1 inch) from the nozzle of the inhaler. These tests represent the case of mask users releasing droplets with high momentum on the mask by sneezing, coughing, and speaking. We find that most fabrics have reasonable efficiency in blocking high momentum droplets with a single layer. With two layers, their efficiency can reach that of the medical mask. It is thus expected that the efficiency will be even better for low momentum droplets, which is the case for users receiving droplets from a distance.

To test our expectation, we measured ε for the medical mask and 1 and 2-layered T-shirt at a distance of 300mm (~12 inch) from the inhaler. At this distance, high speed imaging of the droplets shows an average velocity of 2.7m/s (Fig. 2c, Supplementary Video 5). The droplet size appears to be much smaller than those near (at 25mm) the inhaler. Thus, the impact of the droplet has significantly decreased. As expected, we find ε at 300mm is much higher for the T-shirt fabric (Table 1, Fig. 2g).

Measurement of breathability, β

We define breathability, β, of a fabric as, $\beta = df/dp$, where df is a change in the flow rate of air through unit area of fabric and dp is the corresponding change in the pressure differential across the sample that is required to induce df. Fig. 3a illustrates the concept of measuring β. We used a plug flow tube [20,21] for the measurements. Here, the sample fabric seals the opening of a plug flow tube. Pressurized air was pumped through the tube. Pressure outside the tube is atmospheric and the pressure inside the tube was measured with respect to the atmosphere. Thus, air was forced through the fabric by the gauge pressure, p. Since the area of the fabric sample subjected to air flow is the same as the cross-sectional area of the plug flow tube, the change in flow rate through unit area of fabric, df, is equivalent to the change in average flow velocity, dv inside the tube. Hence, breathability can be written as $\beta = dv/dp$. In a plug tube, flow velocity is approximately uniform across the tube cross section [21,22]. We measured velocity, v, at the center of the tube, while the gauge pressure, p, was measured at around 1/3 radius from the center. Note that the velocity profile remains the same along the length of the plug tube, while pressure is uniform at any cross section orthogonal to the tube, but it decreases along the length of the tube giving a pressure gradient.

Our plug flow apparatus consists of an acrylic tube with 100mm inner diameter, a pump on one end, and a set of long aluminum tubes aligned with the acrylic tube on the other end (Fig. 3b) [20–22]. Flow through the tube can be controlled by varying the pump speed with an analogue dial. We measured flow velocity, v, and pressure, p, at the mid-length of the tube using a pressure gauge and an anemometer. A small hole in the acrylic tube was used to insert the pressure probe and the anemometer and the hole was sealed with clay dough. An O-ring at the open end of the tube was used to seal the sample fabric, ensuring that the pumped air flows through the fabric only (Fig 3b). . Fig. 3c shows velocity vs. pressure measured at various pump speeds for single and double layered T-shirt (Fabric 5) and the medical mask. Plots for all 10 fabric samples and the medical mask are provided in Supplementary Fig. 1. Note the linearity of the velocity-pressure relationship. The slope of the velocity vs. pressure plots gives the value of breathability, β. Table 1 and Fig. 3d show the β values for ten fabric samples, medical mask, and the multiple layers of T-shirt fabric.

Physical intuition suggests that breathability and droplet blocking efficiency might be anti-correlated, *i.e.*, the higher the breathability the lower is the blocking efficiency. To assess this correlation, we plot the droplet blocking efficiency of all ten fabric samples and of the medical mask against their breathability (Fig. 3e). We find that indeed this is the case. The single-layered T-shirt (Fabric 5) has high breathability (7.8mm/Pa·s) and poor blocking efficiency (43.3%). But interestingly, the addition of a second layer increases droplet blocking efficiency by more than a factor of 2 (to 98.6%), while reducing breathability by less than a factor of 2 (to 4.6 mm/Pa·s).

The data presented so far clearly demonstrates that most home fabrics with one layer can block both high and low impact droplets reasonably well. With 2 or 3 layers, their blocking efficiency may exceed that of medical masks while still having comparable or higher breathability. However, the materials of the medical mask and that of the home fabrics are very different. How do the home fabrics achieve their blocking efficiency? We address this question below.

Origin of droplet blocking efficiency by home fabrics: a mechanistic study

Commercially manufactured medical masks (Fig. 1a-c) use 3 layers of hydrophobic fabric (non-woven plastic material, *e.g.*, polypropylene) with contact angle nearly 180 deg (Fig. 4a and Supplementary Video 1). They do not wet. This hydrophobicity and small porosity offer them high droplet blocking efficiency. Most home fabrics, on the other hand, are hydrophilic to different degrees. They soak water (Supplementary Video 1).

To understand the underlying mechanism of droplet blocking by hydrophilic home fabrics, we recorded high speed videos (10,000 frames per second) of the incident droplets from the inhaler and subsequent transmission through the medical mask, as well as 1 and 2 layers of T-shirt (Fabric 5) (Fig. 4b and Supplementary Videos 2-4). In all cases, the samples were attached to a 40mm-diameter wire ring using double-sided tape. The ring was placed 25 mm (1 inch) from the inhaler. Image analysis reveals that the droplets impact and push on the fabric (medical mask or T-shirt fabric) with a velocity of about 17m/s. They also bend and stretch the fabrics. A few droplets penetrate the fabrics and split into smaller droplets as they exit (Fig. 4b).

With a single layer of T-shirt fabric, a significant number of small droplets pass through, giving a blocking efficiency of $\varepsilon = 43.3\%$, whereas the medical mask allows only a few small droplets to go through ($\varepsilon = 96.3\%$). The average velocity of the small droplets leaving the single layer of T-shirt fabric is about 8.5m/s, significantly lower than their incident velocity of 17m/s. The kinetic energy of the incident droplets is spent in deforming the fabric (bending and stretching) and in splitting the droplets (Fig. 4a). The exiting small droplets do not have much momentum left to impact the second layer, if present. Many of them might even be soaked by the second layer. Indeed, high speed imaging reveals very few droplets exiting the 2-layered T-shirt fabric sample (Fig. 4b). This reduction of momentum and the ability to soak water may explain the high blocking efficiency of 2-layered T-shirt fabric sample ($\varepsilon = 98.6\%$). Thus, energy dissipation and soaking appear to be the key mechanisms of droplet blocking efficiency of home fabrics. After completion of the impact and partial transmission, the T-shirt fabric soaks and retains the remaining drop volume, whereas hydrophobic medical mask does not soak any liquid. Large droplets may just roll down the medical mask by gravity.

The above scenario involving high-speed droplets applies to users coughing and sneezing on the mask. As for a mask user receiving the droplets arriving with low momentum (Fig. 2c, Supplementary Video 5), the droplets are likely to be soaked by the outer layer before even reaching the inner layer, giving a high droplet blocking efficiency, similar to that of the medical mask (Fig. 2g). Thus, hydrophilicity or soaking ability of home fabrics do not prevent them from blocking droplets. They provide an alternative mechanism of droplet blocking, in contrast to the water repellant hydrophobic medical masks.

Simple home tests

The methods applied in this study to measure droplet blocking efficiency of fabrics and their breathability involved specialized laboratory equipment not available to the general public. We therefore offer simple, but approximate home testing methods to assess relative droplet blocking efficiency and breathability of available fabrics for masks. We suggest that the home tests should be carried out, if necessary, only to evaluate *relative measures* between fabrics and not to determine absolute values of breathability or efficiency.

Home breathability test: This test uses water flow instead of air, and requires the fabric sample, a rubber band, a 500ml water bottle, and a stopwatch. First, a small hole is punched at about mid-height of the bottle. A cup of water is then added (~250ml, filled below the hole, see Fig. 5a). The sample fabric is then wetted with water, placed on the bottle mouth without wrinkles, and tied in place with rubber bands. Next, the bottle is flipped, and the time that it takes water to drain out, T_{drain}, is recorded using the stopwatch. We stopped the time when water stops streaming and starts to drip. Typically, the higher the breathability, the lower is the time required for draining. Hence, inverse of the draining time ($1/T_{drain}$) gives a measure of breathability of the fabric sample. Fig. 5b shows β and $1/\ T_{drain}$ are strongly correlated. This validates the home test of comparing breathability between fabrics.

Droplet soaking test: We dispensed a small droplet (100µl) of water with food color on each of the ten home fabrics, and recorded videos as the fabric soaked the water (Fig. 5c). The fabrics soak the drop with varying speeds, but the medical mask does not (see Supplementary Video 1). To quantify the soaking speed, we performed image analysis, measured the soaked fabric area as a function of time, and computed the maximum rate of change of soaking area, *i.e.*, maximum soaking speed (Supplementary Fig. 2). We found that the max. soaking speed is correlated with breathability (Fig. 5d) and anti-correlated with droplet blocking efficiency (Fig. 5e). In order to compare the relative blocking efficiency of different fabrics at home, one can dispense a given volume of droplet (using a dropper or syringe if available) on different fabrics and observe how fast the fabrics soak the water droplet. The fabric that soaks water faster is likely to be more breathable and less efficient.

Discussions and summary

In this study, we asked whether face coverings made by home fabrics can be effective against dissemination of droplets carrying 100nm size infectious viruses, such as SARS-CoV-2, and if so, will their resistance efficiency be comparable with commercial medical mask (Face Mask, FM-EL style). We studied ten different common fabrics, 100% cotton to 100% polyester and silk, from shirts, T-shirts, quilt cloths, dishcloth, and bed sheet. We characterized these fabrics quantitatively for their ability to block high impact droplets from dissemination that occurs during sneezing and coughing, as well as for their breathability, weight, and their ability to soak water. We found that all of these fabrics have considerable efficiency at blocking droplets, even when used as a single layer. For example, a 1-layer T-shirt fabric had the lowest droplet blocking efficiency (43.3%) among all the fabrics studied for high impact droplets. However, when used in two and three layers, the efficiency increases to 98.6% and 99.98%, respectively, compared to the 96.3% efficiency of the 3-layered medical mask. Yet, the 3-layered T-shirt still has comparable breathability to the medical mask. Breathability is a critical parameter for any mask design. A high efficiency mask material with low breathability will have air flow through the sides allowing droplets to enter or exit the respiratory system. Home-made face coverings from such fabrics will only give a false sense of protection.

For low velocity droplets, we find that blocking efficiency of T-shirt fabric is much higher compared to that for high velocity droplets. And 2-layered T-shirt shows 98% efficiency for the low impact droplets. This scenario arises when a mask user receives droplets from an infected individual. It thus follows that a 2-layered home-made mask with most common fabrics may help prevent dissemination of droplets by infected individuals, and protect healthy individuals from inhaling droplets with efficiencies similar to that of commercial medical masks.

Most home fabrics are hydrophilic (water soaking), compared to highly hydrophobic medical masks. This does not prevent home fabrics from blocking droplets. In contrast to medical masks, they soak and hold the droplets. This holding ability may offer additional untapped and under-studied advantage of home-made masks.

We thus conclude that during pandemics and mask shortages, home-made mask can be effective against transmission of infection through droplets. Mask wearing by all individuals, supported by proper education and training of mask making and appropriate usage, can be an effective strategy in conjunction with social distancing, testing and contact tracing, and other interventions to reduce disease transmission.

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Table 1: Sample descriptions and results.

Sample	Description	Weight (g/m^2)	Blocking Efficiency at 25mm (%)	Breathability (mm/Pa·s)	Water Soaking Speed (mm^2/s)
Medical Mask	FM-EL style medical/dental quality	53.9	96.3	2.5	0
Fabric 1	Used shirt 100% cotton	114.2	91.1	1.8	10.0
Fabric 2	New quilt cloth 100% cotton	89.1	60.1	10.6	10.1
Fabric 3	Used T-shirt 75% cotton 25% polyester	148.2	42.6	15.3	160.7
Fabric 4	Used shirt 70% cotton 30% polyester	107.5	90.1	2.4	1.6
Fabric 5	New T-shirt 60% cotton 40% polyester	183.2	1 layer: 43.3 2 layers: 98.6 3 layers: 99.98	1 layer: 7.8 2 layers: 4.6 3 layers: 3.1	72.4
Fabric 6	New quilt cloth 35% cotton 65% polyester	95.4	71.8	6.2	23.6
Fabric 7	New bed sheet 100% polyester	81.1	83.1	5	28.5
Fabric 8	Used dishcloth 85% polyester 15% nylon	380.5	97.9	4.9	6.2
Fabric 9	Used silk shirt	49.9	91.3	5.6	6.7
Fabric 10	Used silk shirt	49.4	92.3	3.9	5.8

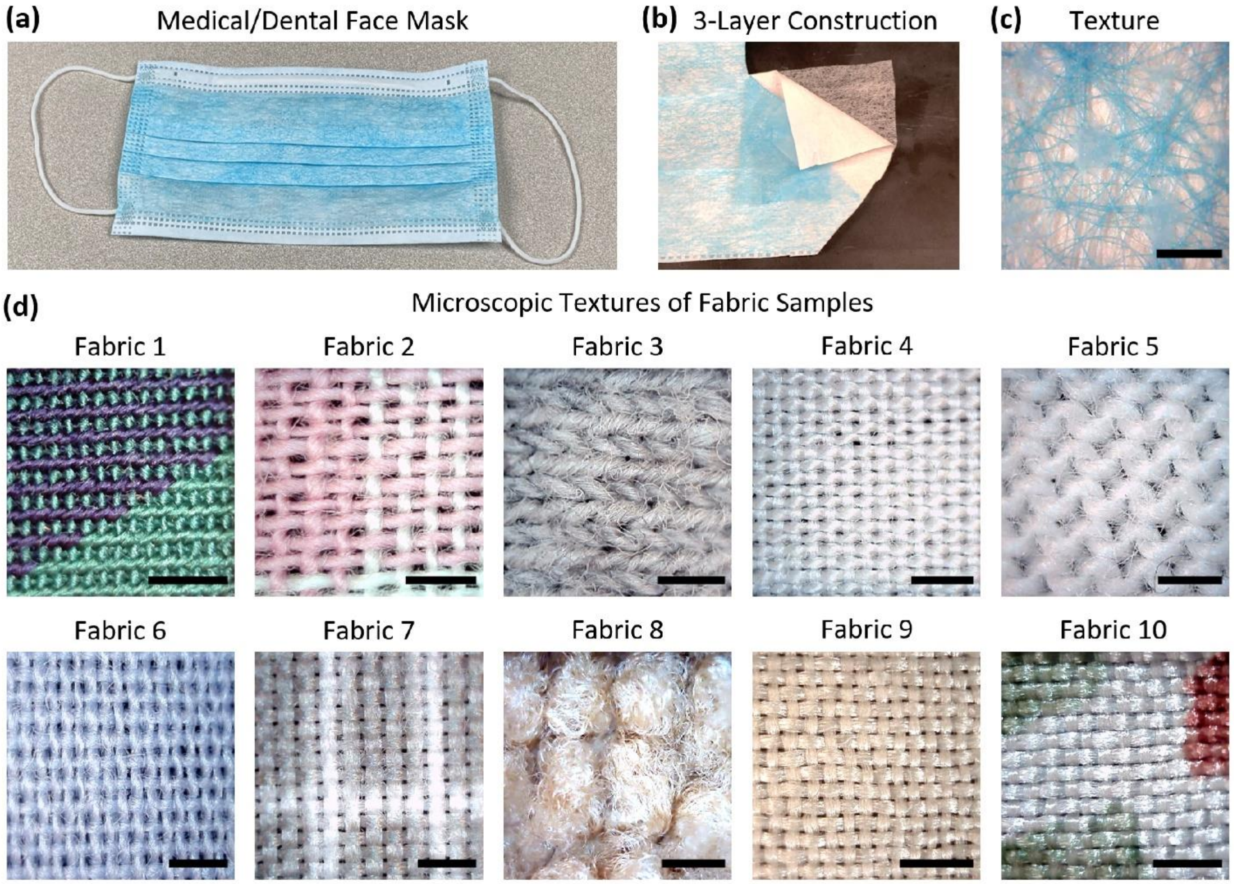


Figure 1. Samples used in this study. (a) Image of a medical/dental quality FM-EL style face mask with **(b)** 3-layer construction, which was used as a benchmark. **(c)** Microscopic texture of the outer surface of the medical mask. **(d)** Microscopic textures of the 10 different home fabric samples. All scale bars: 1mm.

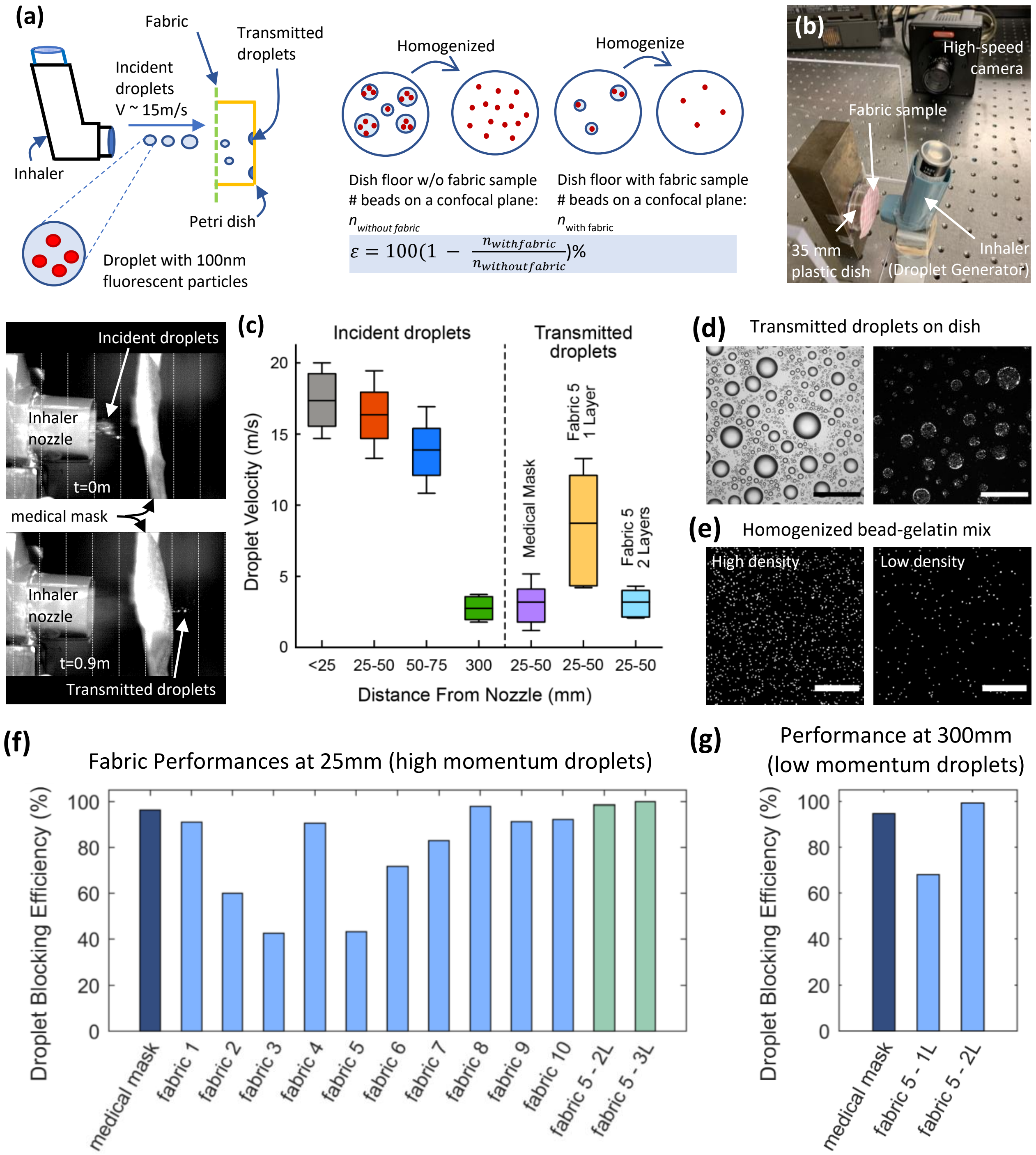


Figure 2. Measuring droplet blocking efficiency. (a) Schematic illustration of experimental method and **(b)** image of lab set-up. **(c)** High-speed snapshots of droplets hitting and penetrating the mask. Box plots show droplet speeds at various distances from the inhaler nozzle, and exit speeds through medical mask and single and double-layered Fabric 5 samples. **(d)** Brightfield and fluorescence images of droplets collected on a petri dish. Scale bars: 200µm. **(e)** Confocal images of homogenized bead collection; representative samples from no fabric (high bead density) and medical mask tests (low bead density). Scale bars: 100µm. Results of droplet blocking efficiency at **(f)** 25mm and **(g)** 300mm from the nozzle.

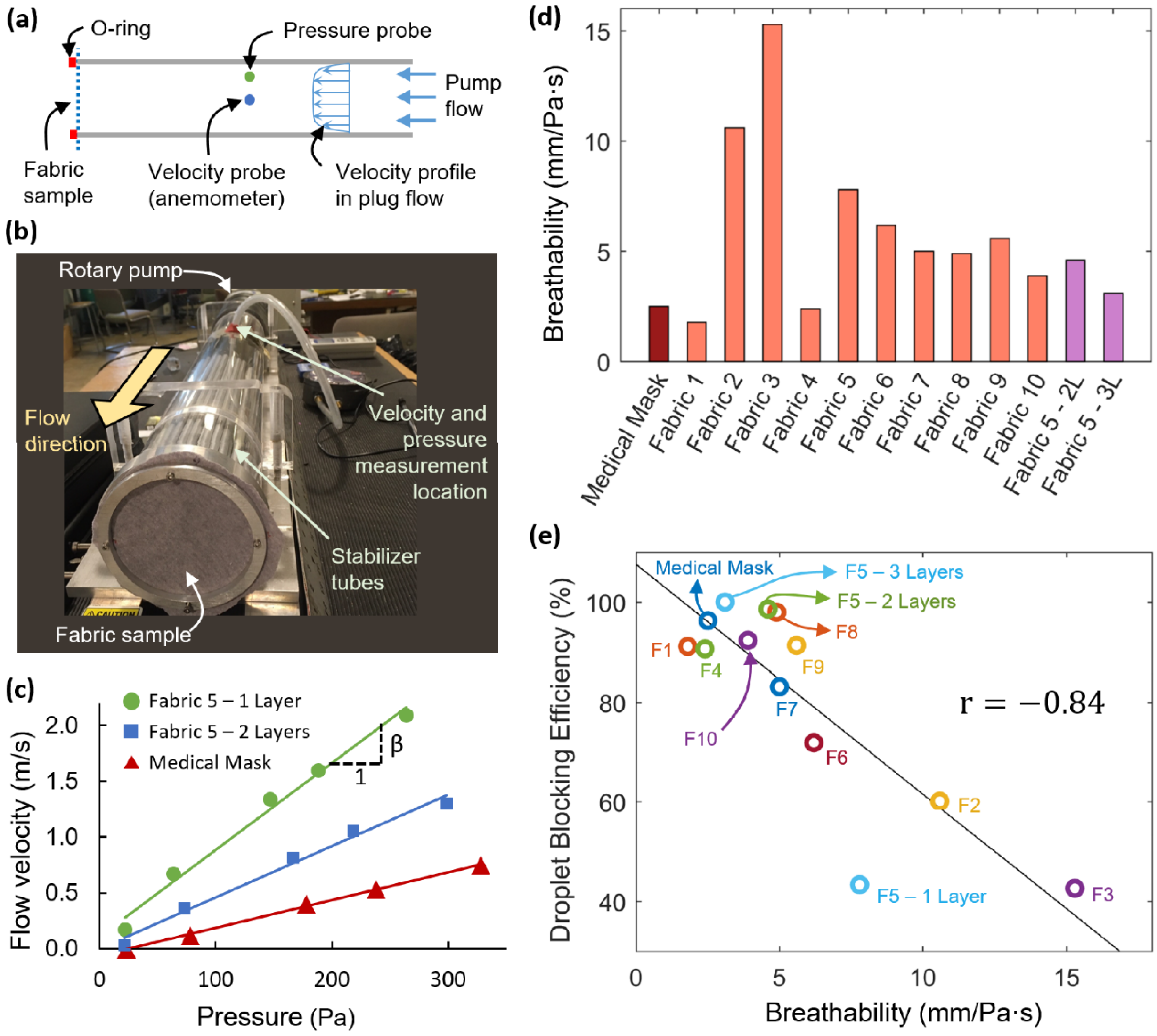


Figure 3. Measuring breathability. (a) Schematic illustration of experimental method and **(b)** image of plug flow tube set-up. **(c)** Flow velocity vs. pressure plots for selected samples. **(d)** Breathability measurement results for all samples. **(e)** Droplet blocking efficiency vs. breathability plot with a regression line illustrating strong negative correlation.

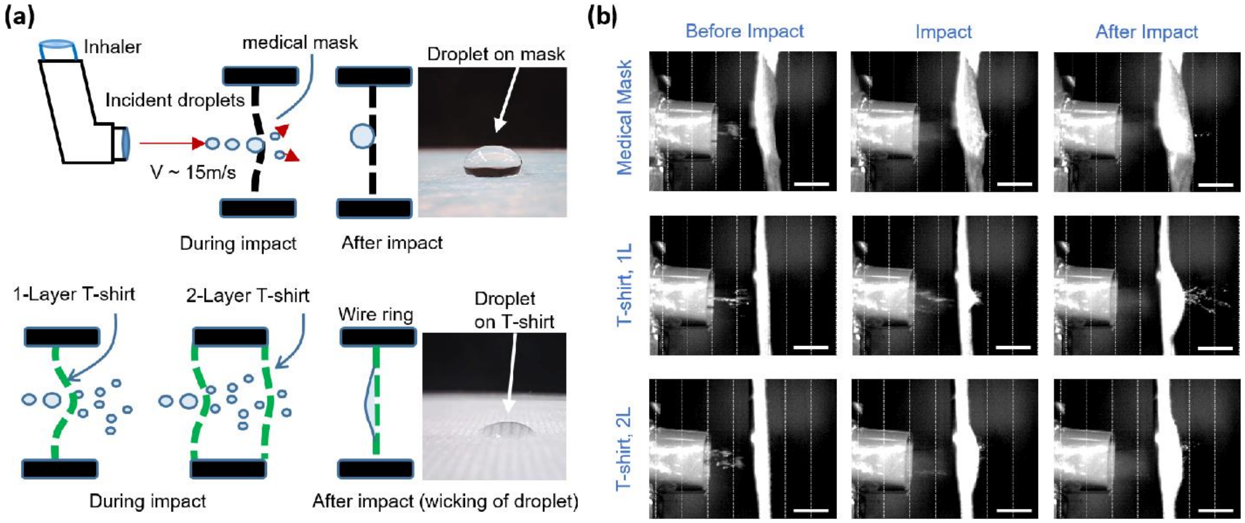


Figure 4. Mechanism of high impact droplet resistance by T-shirt fabric and medical mask. (a) Schematic representation of the processes during high speed impact of droplets on medical mask and cotton T-shirt fabric (Fabric 5). Note that the gap between the 2-layered fabric is exaggerated to highlight the droplets between the layers. Images show water droplets on medical mask and T shirt fabric. While the mask is highly hydrophobic, T shirt fabric is hydrophilic. **(b)** Impact response of various samples. Top row: medical mask, middle row: T shirt - 1 layer, bottom row: T shirt - 2 layers. It is apparent that mask material does not bend much, compared to the T-shirt fabric samples that undergo extensive bending deformation due to impact. Scale bars: 10mm.

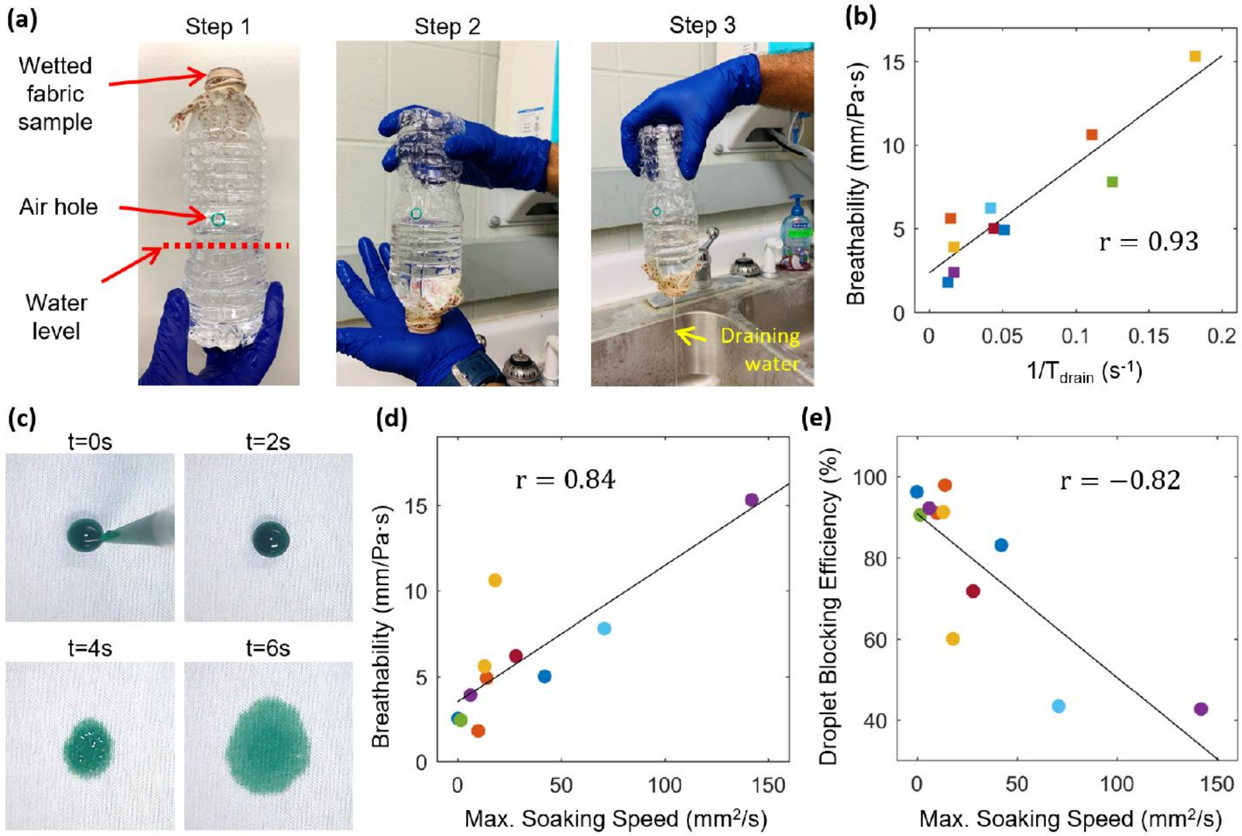
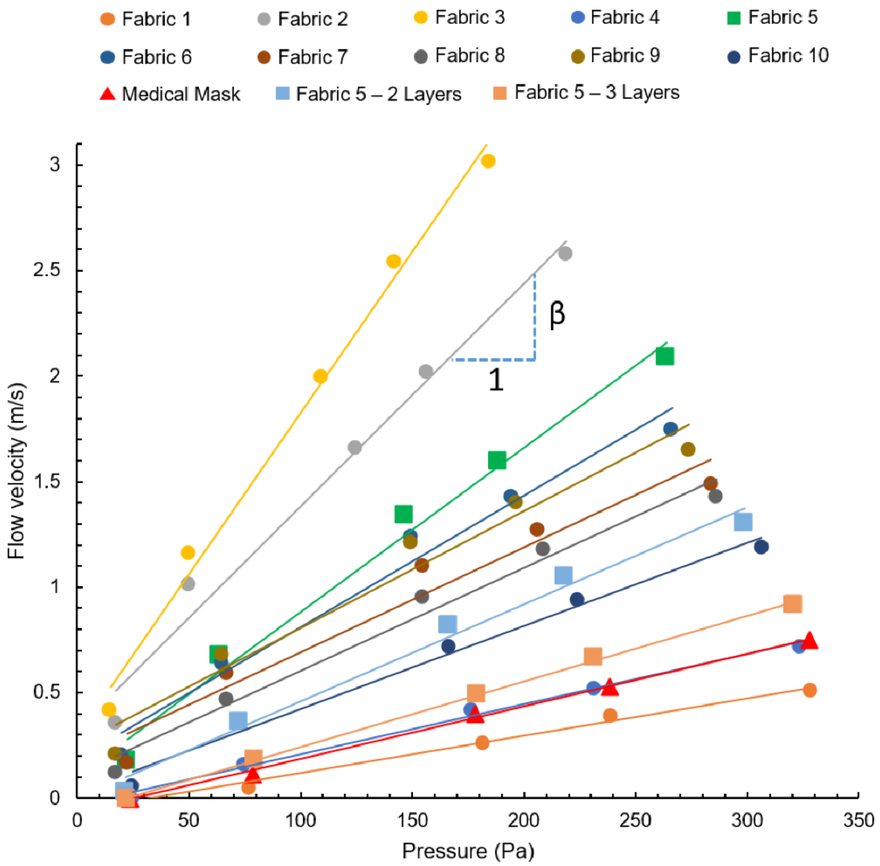
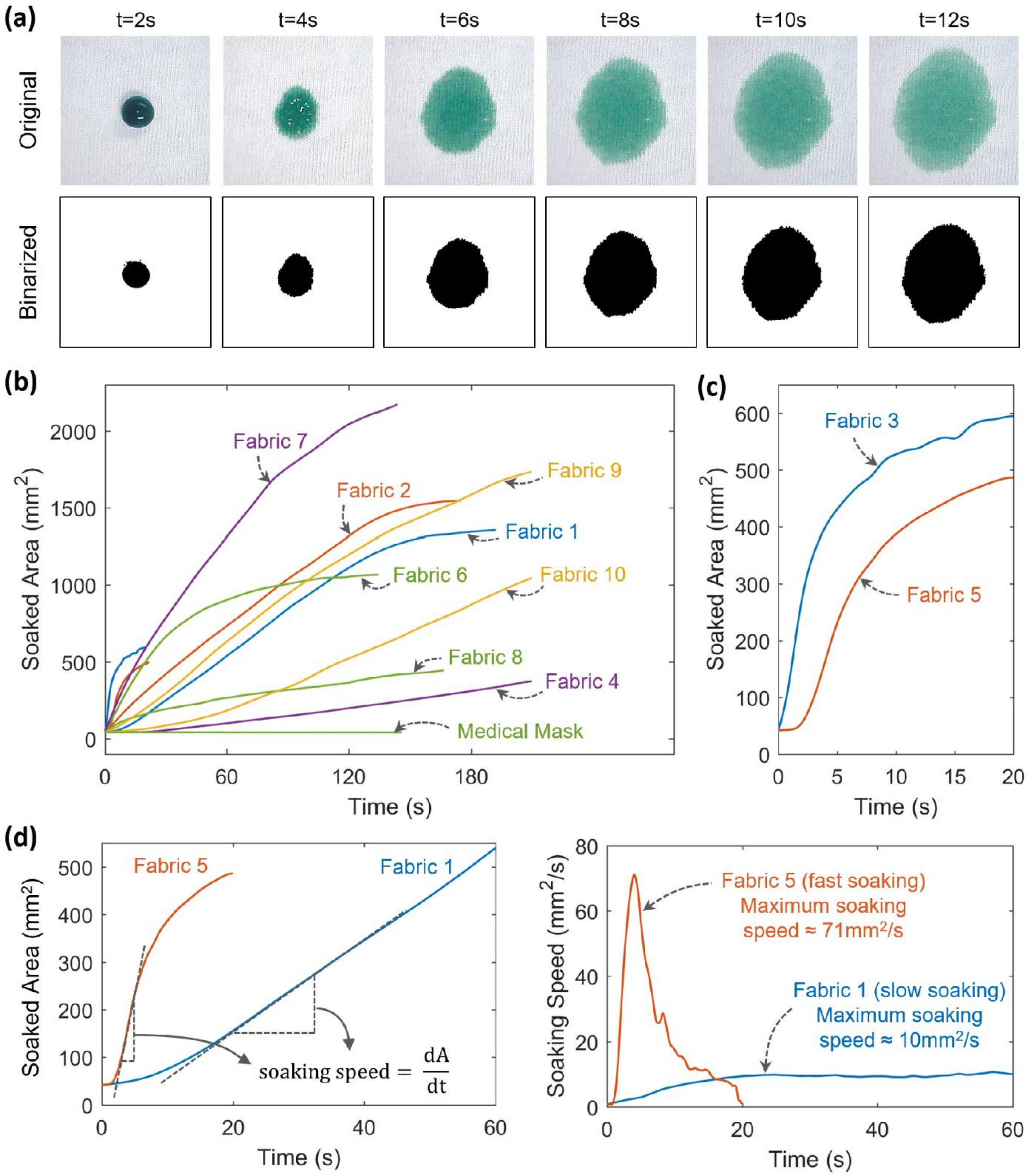


Figure 5. Home tests and their predictive ability. (a) Step-by-step demonstration of the water draining test. **(b)** Breathability vs. inverse of the draining time, showing strong positive correlation. **(c)** Snapshots from water soaking test on T-shirt fabric (Fabric 5). Green food coloring is added to the water droplet to provide contrast. **(d)** Breathability and **(e)** droplet blocking efficiency plotted against maximum water soaking speed for all samples, along with regression lines.

Supplementary Information



Supplementary Figure 1. Flow velocity vs. pressure plots for all samples. All fabrics tested, as well as the medical mask material, exhibit highly linear velocity-pressure relationship.



Supplementary Figure 2. Measurement of water soaking speed. (a) Top row: Snapshots from water soaking test on T-shirt fabric (Fabric 5) with green food coloring added for contrast. Bottom row: Binary images generated by applying appropriate threshold on the original image. (b, c) The soaked area is calculated from the binary images and plotted against time for all fabrics tested. (d) Calculation of maximum soaking speed illustrated with two examples. Fabrics 5 and 1 exhibit fast and slow soaking, respectively. The soaking speed is calculated by taking the derivative of soaked area vs. time data (plotted on the right-hand-side for Fabrics 5 and 1). The maximum value of the derivative gives the maximum water soaking speed.