Standardized Synthesis of Face Masks as a Harm Reduction Strategy in Times of PPE Shortage - COVID-19

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Purpose
Recognizing the unpreparedness to the COVID-19 pandemic that many hospital systems and civilians face with shortages in PPE, this proposal aims to discuss the creation of a homemade cloth mask that can be used in subideal conditions. This proposal does not suggest that a cloth mask protocol is an alternative to surgical or respirator masks for providers, but offers it based on analysis of previous research for manufacturers or civilians. This proposal focuses on standardization of these handmade cloth masks as a harm-reduction strategy in times when PPE supplies are unavailable.

Background
The new decade was faced with the introduction of a novel coronavirus, named SARS-CoV-2 which causes the disease COVID-19. This dangerous airborne virus has spread to over 170 countries in just three months, and has resulted in over 425,000 confirmed infections as of the 24th of March, 2020 according to Johns Hopkins Coronavirus Resource Center [1,30]. The rapid spread of this coronavirus has led to a pandemic that government officials neither anticipated nor prepared for, leaving many frontline healthcare providers without access to needed resources such as personal protective equipment (PPE). Additionally, the public has been left without a method of protecting themselves en masse to prevent community spread, and civilian hysteria has led to hoarding of much needed PPE, especially surgical and respirator masks. As PPE stores dwindle, the question of utilizing other resources as an alternative to PPE has been considered, most commonly around homemade masks made of cloth.

Many communities, noticing the extreme shortages in masks, have begun hand sewing masks made only of cloth for use by civilians as well as healthcare providers who have no other option. In fact the CDC, recognizing the lack of PPE stores, recently lowered their minimum requirements for protective gear for healthcare providers stating that “In settings where facemasks are not available, HCP might use homemade masks (e.g., bandana, scarf) for care of patients with COVID-19” [2]. However, these homemade masks made only of cloth have no function as protective gear and should never be given to a healthcare worker except in the most subpar conditions. A randomized clinical trial in Hanoi found that providers who used face
masks made only of cloth compared to medical-grade masks had a relative risk up to 13.00 of contracting respiratory illnesses [3].

In order to make homemade face masks a more viable idea, their production needs to be upgraded from plain cloth to include some type of filter that can actually offer some protection. A problem that grows exponentially with increasing the complexity of handmade masks is their variability due to lack of standardization. There are thousands of combinations of materials, filters, and ways to stitch them together that can be found all over the internet. Because of the lack of adequate previous research, there is little evidence on the efficacy of these homemade masks based on various materials, filters, and prototypes. This reduces their overall efficacy and greatly increases risk of exposure to healthcare professionals. The NEED PPE Advocacy Team from Boston Medical Center and Boston University School of Medicine recognizes there are countless issues with creating masks at home and using them in public and in the hospital. Yet, in the interest of offering some type of standardization as a method of harm reduction in a global crisis, the team has reviewed past research and literature to isolate the most viable options for creation of a cloth-based filtered face mask at home and for possible manufacturing.

**Methods**
This protocol is an adaptation of the crisis capacity strategy, as per the CDC, for optimizing utilization of surgical masks in healthcare settings when there is limited supply.

**Fabric.** The most commonly recommended fabric for use in homemade face masks is a 100% cotton plain weave. This material is readily available as dish or tea towels used in kitchens. The SARS-CoV-2 virus has a diameter of 0.06 to 0.14 microns [4], and according to a study from Cambridge University [5] on homemade masks for protection during an influenza epidemic, dish towels were found to be 73% effective at blocking 0.02 micron bacteriophages. This is 16% lower than that of a surgical mask (89%), but higher compared to household materials like woven cotton t-shirts, scarves, or bed linen. SARS-CoV-2 usually transports on the respiratory droplets of an infected individual which measure from 10-100 microns [6]. For the 1-micron sized bacteria used in the Cambridge study [5], dish towels were found to be 83% effective at blocking these particles, which was higher compared to the other household materials. Yet again, the effectiveness was 14% lower than that of a surgical mask (97%). The properties of cotton face masks can be compared to that of surgical-grade masks in Table 1.

While 100% plain weave cotton may be suitable for a civilian to create a homemade face mask by hand, designers and textile companies have the resources to further develop fabric for a face mask. In this regard, an upgraded alternative to using 100% plain weave cotton is the development of a trilaminate fabric, such as one commonly used in drysuits. A study from Coimbatore, India [7] developed a trilaminate made to be used in the manufacturing of reusable surgical gowns and drapes that could offer antiviral protection against HIV and Hepatitis B and C whose particle diameters are approximately 0.14 and 0.07 [8,9] microns respectively - which are approximately the same size as SARS-CoV-2. Figure 1 visualizes the composition of the antiviral trilaminate where polypropylene nonwoven comprises the outer layer,
polytetrafluoroethylene (PTFE) film is the middle layer, and polyester nonwoven is the inner layer. Table 1 demonstrates the properties of the proposed trilaminar fabric in addition to cotton and surgical-grade masks for comparison.

![Figure 1 - Proposed arrangement of materials for the trilamine fabric](image)

**Table 1**: Properties of a surgical-grade mask versus 100% cotton and trilaminate [17]-[22]

<table>
<thead>
<tr>
<th>Fabric</th>
<th>Surgical Mask</th>
<th>100% Cotton (Ideal for home use)</th>
<th>Trilaminate (Ideal for manufacture use)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fit</td>
<td>Comfortable, Hypoallergenic</td>
<td>Comfortable, Hypoallergenic</td>
<td>Comfortable, antiviral</td>
</tr>
<tr>
<td>Fibre Diameter</td>
<td>19 um</td>
<td>12 -20 um</td>
<td>Three layered non-woven fabric (0.187, 0.4, 0.147 respective pore size)</td>
</tr>
<tr>
<td>Breathability</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Filtration Efficiency</td>
<td>96.35</td>
<td>69.42</td>
<td>Unknown</td>
</tr>
</tbody>
</table>
Filter. HEPA (High Efficiency Particulate Air) Filters are readily available as *3M Filtrete 2800 Ultrafine Filters* and are commonly used in HVAC (Heating, Ventilation and Air Conditioning) systems, vacuum cleaners, and air purifiers. HEPA filters range in MERV (Minimum Efficiency Reporting Value), a measure of particle capture, from 1 (least efficient, least expensive) to 16 (most efficient, most expensive). Figure 2 shows the DSE (Dust Spot Efficiency) and arrestance of filters of all MERV ratings. While MERV ratings above 13 have very fine filtration slits and are suitable for masks, with an increase in efficiency there is an inverse decrease in breathability.

As demonstrated in a study by NASA (National Aeronautics and Space Administration), [8] the science behind the use of HEPA filters capturing nanoparticles, smaller than the diameter of borosilicate microfibres in these filters is explained by diffusion, and is an effective mechanism for the trapping of viral particles. Currently, Totobobo Dream Lab One Pte. Ltd in Singapore has already developed a face mask with an embedded HEPA filter [29]. Based on their filter test reports, the F92, F94 and F96 Totobobo HEPA filters demonstrate more than 99% particulate filtration efficiency and F96 demonstrates more than 99% virus filtration efficiency. While there is less evidence on the effectiveness of these masks, a study from Cambridge University [11] found that the HEPA masks were easier to breathe through, and more comfortable on the ears, nose, and face than an N95 respirator mask, meaning that the proposed HEPA mask is tolerable for healthcare providers. Taking note of the pros and cons, Table 2 compares the properties of surgical masks to that of a typical HEPA filter.
### Dust Spot Efficiency*
A measure (expressed as a %) of the ability of a filter to remove atmospheric dust from air.

### Arrestance*
The ability of a filter to remove injected standard dust from the test air. It is calculated as a % relationship on a weight basis.

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**Figure 2** - Chart displaying the typically controlled contaminants, typical applications of filter, DPE (Dust Spot Efficiency), and arrestance for the full range of MERV ratings for HEPA filters.
Table 2: Properties of Surgical mask (treated polypropylene) versus HEPA filters.

<table>
<thead>
<tr>
<th>Filter</th>
<th>Surgical Mask</th>
<th>3M Filtrete 2800 Ultrafine Filter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air Flow</td>
<td>Non obstructed</td>
<td>Obstruction increases with higher MERV</td>
</tr>
<tr>
<td>Diameter</td>
<td>5 microns</td>
<td>0.3 microns</td>
</tr>
<tr>
<td>Thickness</td>
<td>Thinner</td>
<td>Slightly Thicker</td>
</tr>
<tr>
<td>MERV</td>
<td>MERV &gt; 14</td>
<td>MERV = 14</td>
</tr>
<tr>
<td>Filtration Efficiency</td>
<td>14% - 99%*</td>
<td>up to 97%*</td>
</tr>
</tbody>
</table>

*includes household dust, pollen, dust-mite debris, mold spores, and pet dander, smoke, smog, bacteria, particles that can carry viruses > 0.3 microns, and particles that can carry odors.

Prototype. This section will discuss how the fabric and filter are made individually and how they can come together to create a homemade face mask. While there are many options and suggestions online on how to stitch together a mask, there have been no studies on if a particular approach produces a more effective safeguard. Based on the suggestion of Dr. Rachel Hunt, MD, a resident neurosurgeon at Henry Ford Hospital, the NEED PPE team has prioritized the prototype of a cotton or trilaminate mask that comes with a pouch that can hold the HEPA filter.

Table 3: Proposed 10 steps to create a cloth mask with a pouch for HEPA filter

Step 1 - Get clean, pre-washed, plain weave cotton as pictured or trilaminar material. Cut into a 20cm by 50cm.
<table>
<thead>
<tr>
<th>Step 2</th>
<th>Get a 15cm pipe cleaner or wire. Apply a soft stretch adhesive, some varieties may require heat to stick. Place the pipe cleaner or wire on the adhesive.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 3</td>
<td>With the pipe cleaner placed on the adhesive, roll the edge over by 1/2cm and then 1 cm. Sew this down to create the top of the mask that will cover the nasal bridge and cheeks.</td>
</tr>
<tr>
<td>Step 4</td>
<td>Fold the sheet so that the unsewn end is over the sewn-in wire end. This should create a double layered rectangle.</td>
</tr>
<tr>
<td>Step 5</td>
<td>Create a 1/2cm seam down the edge of both long sides, but be sure to start 1cm in and leave off 1 cm from the corner in order to make space to tie the elastic.</td>
</tr>
</tbody>
</table>
Step 6 - Flip the mask inside out. This is the pocket that can hold the disposable HEPA filter.

Step 7 - Tie the elastic through by making a secure tie at the top of the mask and leaving the bottom end of the elastic free so the wearer and adjust it to them.

This is an image of a furnace filter that is imbedded in the furnace cage. *(3M Filtrete 2800 ultrafine filter not pictured here).*
Step 8 - Obtain a new furnace filter, and carefully strip off the cardboard frame. The HEPA material will be attached to the cardboard, and there will be wires embedded. Shears work well.

Step 9 - Flatten the filter material and draw out a rectangle insert with proportions 20cm x 10cm. Note this can be completed 2x to yield a double layered inserted.

An image of the back of the filter material where the wires can be seen. These wires will help the filter mold to the shape of the wearer's face.
Step 10 - Cut the filter and place it into the pouch formed by the mask.

**Sterilization of masks.** 100% cotton fabrics are reusable and autoclavable [26]. Trilaminate is considered to be a FDA class 2 medical device [23] and can easily be sterilized per hospital guidelines without compromising fabric integrity [25]. Laundering of trilaminate can be completed using thermal or thermal-chemical disinfection followed by sterilization via the method below:

1. Pre-vacuum steam at 2700F/132C for 4 minutes
2. 100% ethylene oxide (EO) with a concentration of 725-735 mg/L at 131F/55C and 40%-80% relative humidity for 60 minutes

**Concerns & Practical Recommendations**

**Cloth masks as PPE.** It is important to reiterate that cloth masks made out of household materials such as cotton are not a viable alternative to standard surgical or respirator masks. As such, this proposal only endorses the use of cloth masks as last resort if commercial face masks or synthesized equivalents are no longer available. One study [12] assessed the filtration capacity of N95s vs common household fabrics including T-shirts, towels, scarves, and cloth masks against nano-size particles including viruses. When masks were subjected to dispersed aerosols at different velocities, cloth masks and other household fabrics had 40-90% instantaneous aerosol particle (20-1000 nm) penetration while N95s which had a 0.12% penetration. A similar study [5] assessed aerosol filtration capacity as well as the number of microorganisms isolated from coughs of volunteers wearing homemade cloth masks made of 100% cotton vs surgical masks. Their data showed an increase in the number of cough generated colony forming units (CFU) produced by individuals wearing cloth masks compared to surgical masks, such that surgical masks were 3 times more effective at blocking droplet transmission than cloth masks. While it is true that homemade masks did prevent droplet transmission relative to not wearing a mask at all [14], this data strongly suggests that homemade masks do not provide adequate protection for frontline healthcare workers and should only be used as a last resort.
**Cloth mask with HEPA filter.** As cloth masks are suboptimal, it’s thought their filtration efficacy could be moderately improved with the addition of an insertable and replaceable filter made from a repurposed double layered cutout from a HEPA air filter, such as the 3M Filtrete 2800 Ultrafine Filter. These filters are commonly used in HVAC systems and are readily available at most hardware stores. Some studies have explored the efficacy of non-fit tested HEPA filter masks, such as the Totobobo mask, compared to N95s, and while these masks have relatively good filtration capacity (16/22 >100% reduction of filtration), their performance is still inferior to N95s (19/22 >100% reduction of filtration) and therefore should be used with caution and require further investigation[9]. It should also be noted that 3M Filtrete MP 2800 are advertised to filter out particles as small as 0.3 microns, the size of some viruses, while SARS-CoV-2 is reported to be 0.06-0.14 microns in size, so its relative efficacy to efficiently filter pathogens during this current pandemic is truly unknown [4]. Another factor to consider is the reusability of HEPA filters. Opinions are mixed as to whether such filters can be washed and anecdotally side against reuse. However one study tested the performance of polypropylene filters (similar to 3M Filtrete) after being washed. HEPA filters were soaked in 4% nitric acid for 24 hours, rinsed with deionized water and gradually dried at ambient temperature under a laboratory hood. Results showed that after cleaning, polypropylene HEPA filters maintained their particulate capture capacity at 99.97% at 0.3 microns, thereby suggesting feasibility of reuse [16]. An anticipated challenge would be streamlining the laundering and maintenance of reusable filters on hospital premises given the demand for additional space, equipment and staff for processing, so alternative decontamination and sterilization methods such as ultraviolet germicidal irradiation and autoclaving could be explored.

**Conclusion**

In unprecedented times such as the current COVID-19 pandemic, healthcare providers and civilians alike are faced with the issue of protecting themselves from community spread of respiratory viral infection. Although homemade protective masks are not endorsed, in the effort of harm reduction in a global crisis, the BMC NEED PPE Advocacy Team has collated a standardized protocol for the manufacturing of a reusable filtered face mask based off of pre-existing literature and scientific data. This protocol is feasible and cost effective, ideally done by a mass production corporation to ensure optimal standardization of production that would positively contribute to maintaining the health of the workforce and prolonging civilian wellness in the absence of medical grade PPE.

**References**


