Covid-19 Face Shields

Deniz K. Armani[1], Andreas Schubert[1], Alexis Scholtz[2], Andrea M. Armani[2]
[1]SMP Engineering, [2]University of Southern California

BACKGROUND

Since the first cases were reported in China in December 2019[1,2] and the World Health Organization (WHO) declared it a global pandemic on March 11 2020, the novel coronavirus 2019-nCov (Covid-19)[2,3] has swept across the globe, straining healthcare facilities of even the most wealthy nations through sheer case numbers. Among other symptoms, the Covid-19 virus causes fever, cough, and shortness of breath that can vary from mild to severe, requiring hospitalization and ventilation for the most critical cases[4]. It is thought to be transmitted from person-to-person primarily through respiratory droplets spread through the infected person's coughs or sneezes or through droplets that remain on surfaces to which others are later exposed.

As hospitals and healthcare clinics increasingly test and treat patients with Covid-19, healthcare workers expose themselves to the virus at much higher rates than the average person. As they are unable to observe social distancing procedures and other potential methods of mitigating risk as they carry out their jobs, they are not only subject to increased risk of infection themselves but also of transmitting the disease to other individuals[5,6]. It is therefore of vital importance that healthcare workers have proper personal protection equipment (PPE), including N-95 respirators, face masks, and face shields, to not only prevent further transmission but also to prevent further strain to the healthcare system that may occur if these clinicians are unable to work due to personal illness.

However, as the healthcare industry is stretched thin with the volume of patients, healthcare workers face increasing risk of exposure with dwindling supplies of PPE as they are confronted with particularly severe shortages of face masks and N-95 respirators[7,8]. Some hospitals and clinics have gotten so desperate that single-use items are now reused repeatedly[9,10]. Although face masks and N-95 respirators require strict fabrication methods that are difficult, if not impossible, to fully replicate outside of specialized industrial settings, face shields remain as an item that may be easier to supplement through widespread manufacturing efforts and material availability.

The key design criteria for an effective, reusable face shield are that it is cleanable using a standard EPA hydrogen peroxide solution, that the transparent shield fully covers the face and sides of the face, and that there are no gaps or holes. As hospitals and healthcare clinics face increasing shortages of PPE, innovators have stepped up to try to fill supply deficits, in particular by leveraging at-home or personal production capabilities[11]. For face shields in particular, numerous open-source designs that can be produced using 3D printers, laser cutters, and CNC machines have been developed and are being produced for local hospitals. Most released designs utilize 3D printers, which have become more widespread over the last few years, allowing for the employment of resources not associated with industry or academia. Two designs are particularly prominent in the current landscape: one made by the 3D printer company Prusa and one developed by Columbia University and Budmen Industries. Both have specific advantages and disadvantages when addressing the previously stated goals.

In collaboration with the Czech Ministry of Health, Prusa Research has released a face shield design (**Figure 1a**)[12] in keeping with its values of open-source design while taking advantage of the huge wealth of 3D printing knowledge of its employees and the vast 3D printing farm that is available at their facilities. Their model consists of four parts: a 3D printed headband, a 3D printed bottom reinforcement for the shield, the shield itself, and an elastic band. Both 3D printed parts are made from PETG filament, which is cleanable and reusable. The headband itself is designed to allow for flexibility to fit against the user's forehead while offsetting the shield from the user's face. The shield, made from a laser cut sheet of PETG, fits over pegs that protrude from the front of the headband and snaps into the bottom reinforcement piece to hold its shape. The face shield is ultimately secured to the user's head by attaching an elastic strap to the back of the headband. However, a large air gap between the headband and the shield mount allows for particulates to reach a user's face. Additionally, access to a laser cutter is out of reach or many users, resulting in the replacement of the PETG with less robust (and non-reusable) transparency sheets.

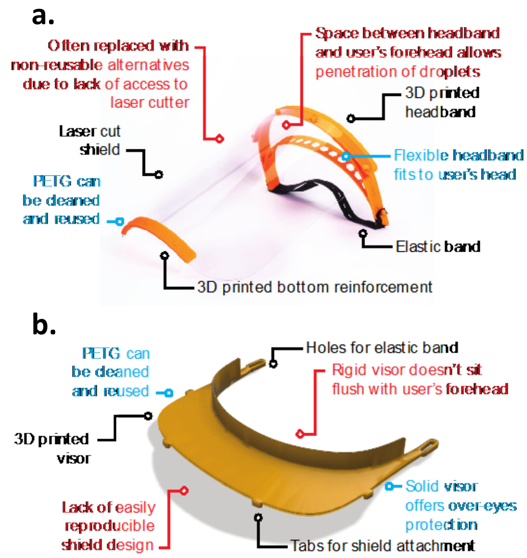

Figure 1.a. A photo of the Prusa headband design and **b.** a rendering of the Budmen and Columbia visor design.

This limitation was solved in the design released originally by Budmen Industries, and subsequently, when Columbia University released a face shield assembly guide integrating the Budmen design (**Figure 1b**)[13]. Their shield requires only three pieces: a 3D printed visor, the shield, and an elastic band. They recommend using PLA or ABS filament to print the visor, which, unlike the Prusa design, has a solid brim and rigid shape. The shield fits over four tabs along the edge of the visor, but must be measured and cut by hand, from a transparent sheet; the guide recommends mylar or acetate. An elastic band, also cut by hand, secures the visor to the user's head. While the visor design eliminates the ability of particulates to transport to a user's face, the use of mylar or acetate as the shield limits the cleanability of the system. Therefore, a comprehensive solution that meets all requirements is still needed.

DESIGN REQUIREMENTS

In collaboration with Keck Medicine of USC, we developed our own set of design criteria (**Figure 2**) based on the needs of our clinicians and input from infectious disease prevention experts.

1. The transparent shield must protect the full front of the face and extend around the sides of the head, until just before the ears.

As Covid-19 is thought to be transmitted through the exposure to respiratory droplets from an infected individual, it is important to protect three major entry points on the face: the mouth, eyes, and nose. To fully protect the face from any infected droplets, the face shield must wrap around the cheeks to prevent droplets from entering the air space immediately in front of the face from the side.

2. The face shield protect the user's forehead and area above the eyes.

To fully protect the eyes, part of the face shield visor should extend to cover above the eyes up to the hairline. There should be no gaps in coverage over the top of the face.

3. The components must be able to withstand standard disinfection procedures, including the standard hydrogen peroxide wipes and UV-C disinfection systems utilized by Keck.
To help combat material and supply shortages, the face shield should be fully reusable, which means it must be sterilized between uses. This requires that the material selected must demonstrate sufficient chemical resistance to hydrogen peroxide and UV-C radiation. From a design standpoint, all surfaces must be accessible, so the design cannot contain any small cavities or cracks that cannot be fully disinfected.

4. The face shield must fit properly on different people.
Because each individual will have a different face structure and head diameter, the face shield should allow for size adjustments so that it still fits properly and provides sufficient protection on different people.

5. The pieces should be as easy and quick to manufacture in mass quantities as possible.
To meet the current need, these face shields will have to be produced as quickly as possible. Although 3D printers are arguably the most widespread manufacturing method due to the prevalence and accessibility of 3D printing technology throughout society, other manufacturing methods should not be discounted due to the extensive time 3D printing can require. It would be preferable to have a design that can be both 3D printed and produced by other, quicker methods, in order to fully take advantage of all available resources.

	Full Face Coverage	Over Eyes Coverage	Disinfection	Proper Fit	Production
Prusa headband	Insufficient protection on sides of face	Open gap in front of forehead	Elastic not resuable and must be cut to size	Flexible headband	3D printing, laser cutting
Budmen-Columbia visor	Insufficient protection on sides of face	Mostly covers forehead with small gaps	Elastic and shield not reusable	Rigid front leaves gaps	3D printing, scissors
Proposed design	Sufficient protection on front and sides of face	Fully covers forehead	Elastic not resuable, but easy to replace	Fits flush to forehead	3D printing or molding, laser cutting

Requirement Not Met — Requirement Met

Figure 2. Summary of the design requirements and current solution landscape.

In addition, a supplier for the face shields should be identified to allow universal access to high quality PETG shields.

PROPOSED DESIGN

Material selection

To satisfy our requirement for reusability, material selection was of the utmost importance. After considering various filaments and materials, we decided to fabricate our parts out of PETG. As a 3D printing filament, PETG is fairly easy to print, widely available, compatible with most common 3D printers, and flexible, which will help with the adjustability of the final design. It already has FDA approval for use in medical devices and implants. Previous studies have indicated PETG has good chemical resistance to hydrogen peroxide. Furthermore, PETG is available in transparent sheets, which would allow for its use in shield as well as the visor component. Taken in full, these attributes make PETG a good candidate material for our face shield design and simplifies our design by requiring only a single material, albeit in two forms.

Design

Our frame features two distinct components: 1) a visor and 2) a transparent shield.

The visor has three shield attachment points, and it extends further around the sides of the head than previous designs to provide more protection. The visor sits higher on the face and has a flexible front, providing more protection above the eyes. Similar to previous designs, the frame is secured with an elastic band, but unlike those designs, any piece of elastic, knotted at each end, can be used to secure the face shield. There is no need to cut holes in the elastic to secure it to the headband. The design boasts a sleek form that has few corners, making it easy to disinfect with standard hydrogen peroxide wipes. Perhaps most importantly, the frame can be both 3D printed as well as manufactured via a mold, drastically speeding up production.

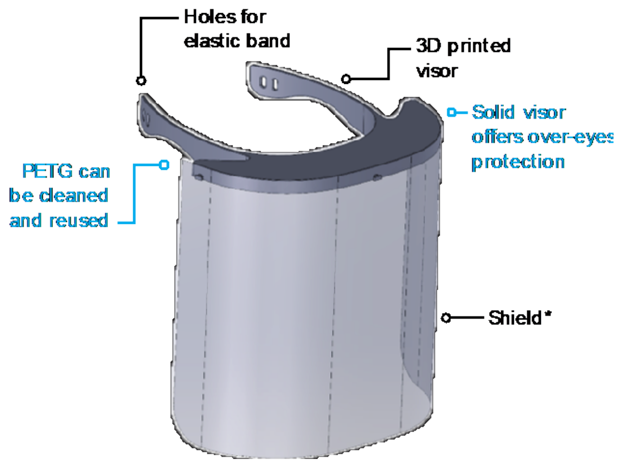

Figure 3. A rendering of the proposed design. *Note that the shield will be fully transparent.

The shield is designed to be at least 8.5” long (though 9.5” is preferred) and 13” wide when laying flat. The edges are curved to eliminate snags or tears, and the PETG shield piece can be laser cut, as well as cut via a water jet, from a drawing file.

METHOD AND RESULTS

All .stl files for 3D printing have been uploaded to the NIH 3D printing repository. Image of a final face shield is shown to help in assuring correct printing.

Figure 4. An image of a completed face shield.

Our frame features a wider visor brim, with three shield attachment points, that extends further around the sides of the head than previous designs to provide more protection. The visor sits higher on the face and has a flexible front, providing more protection above the eyes. Similar to previous designs, the frame is secured with an elastic band, but unlike those designs, any piece of elastic, knotted at each end, can be used to secure the face shield. There is no need to cut holes in the elastic to secure it to the headband. The design boasts a sleek form that has few corners, making it easy to disinfect with standard hydrogen peroxide wipes. Perhaps most importantly, the frame can be both 3D printed as well as manufactured via a mold, drastically speeding up production. Lastly, the PETG shield piece can be laser cut, as well as cut via a water jet, from a drawing file.

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