

PROTOCOL FOR 3D PRINTING MASKS

Released and continually updated

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This protocol details using a conventional FDM 3D printer to create a reusable face mask that aims to be a *mask of last resort* if no N95 (or similar) masks are available.

Masks bodies are cleanable and reusable if the filter media is replaced.

This protocol uses easily sourced commercially available filters which have the capability to remove particles as small as 0.3 microns from air. This is the same performance as the widely used N95 medical mask. Any HEPA rated filter can be used - additional filter types include: vacuum filters, car cabin filters, air purifying filters.

**THE PERFORMANCE OF ANY 3D PRINTED MASK IS UNTESTED.
USE AT YOUR OWN RISK.**

MANY FILTERS ARE MADE OF FIBERGLASS WHICH WHEN CUT RELEASE PARTICLES THAT CAUSE RESPIRATORY IRRITATION. SEE FILTER PRECAUTIONS.

TO GET INVOLVED SEE 'NEXT STEPS'. SHARE USING THE LINK: <http://kosta.is/covid>

Parts & Tools

Parts needed:

- **Filter:** [AC/HVAC filter](#) that has one (or more) of the following ratings:
 - MERV 13 or higher MERV 15 or 16 is preferred
 - [HEPA](#) designation
 - [MPR](#) of 1500 or higher MPR of 2200 preferred
 - FPR 10
- **Fastening strap:** [Elastic cord](#)
- **Print material:** PLA, 1.75mm
- **Print File & Cut Template:** [Mask 3D .stl file](#)
- **Optional Mask to face sealant:** [Foam Sealant tape](#)
- **Optional Finishing:** [320 Grit or Higher Sandpaper](#)

Tools needed:

- 3D Printer with a minimum bed size of 6 x 6"
 - Sharp Scissors
 - Puncture resistant gloves (gardening or similar)
 - Sharpie or equivalent pen
 - Vacuum Cleaner & hose with a HEPA filter bag
 - Hair dryer
 - Tape measure
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PART 1: PRINT AND FORM MASK

1. **Measure Face:** Masks come in three sizes (small, medium, large) to fit different size faces.



Measure from the bridge of the wearers nose to chin.
Approximate faces sizes for each mask are:

Large: 4.5 - 5.25"

Medium: 4 - 4.5"

Small: 3.5 - 4"

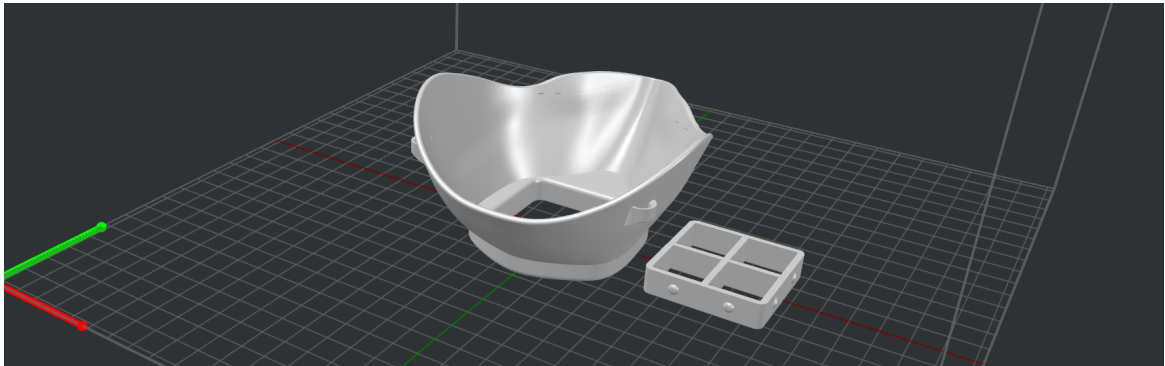
NOTE: *Please* provide feedback on this sizing: kg@kosta.is.

NOTE: Masks that are too small or too large for the wearers face will not create an airtight fit.

2. **Download:** [Mask 3D.zip](#) package and open the .stl file of the appropriate size mask you'd like to print.

3. **Print:** 1 Mask and 1 Filter Screen of the appropriate size. Printer settings are as follows:
- 25% infill
 - Layer height <0.1mm or less
 - Rafts ok
 - Use standard PLA
 - Position mask on build plate with the front facing down, see picture below.

NOTE: UNDER-EXTRUDED PRINTS MUST BE DISCARDED AS THEY MAY NOT BE AIRTIGHT.



4. **Inspect Print:** Inspect Dual Filter mask for any under-extruded areas. Under-extruded prints may allow air to permeate through the mask rendering it ineffective. You can test the layer adhesion by bringing a portion of the plastic up to your mouth, making a seal, and blowing hard. If air leaks through the mask, it's a bad print and should be discarded. Try to blow through different areas of the mask.
5. **Test Fit Mask:** You can test the fitment of your mask by placing your hand over the filter hole of the mask, pressing in to create a seal, and gently breathing in to create a suction. If the mask leaks you'll need to adjust the fitment of the mask using the 'Adjust Fitment' instructions below. If the mask does fit, you can skip this step.

NOTE: Masks will not seal adequately when facial hair is present.

6. **Adjust Fitment:** If the mask is not airtight you may need to adjust fitment. To do so heat the Mask using a hair dryer until the plastic is soft enough to be bent (approximately 55 - 60°C / 131 - 149°F).

CAUTION: BURNS ARE POSSIBLE, DO NOT OVERHEAT MASK.

Step 1: Holding the mask with the nose piece pointed away from you and your hand away from the center filter hole, use a hairdryer to heat the right and left side of the mask until slightly pliable.



Step 2: Bring mask to face, and gently squeeze to fit until you feel a light pressure on your cheeks. Do not over-squeeze.

NOTE: ENSURE THE FILTER SQUARE DOES NOT WARP. IF IT WARPS THE FILTER WILL NO LONGER SEAL.



Step 3. Heat up the nose bridge of the mask until pliable.



Step 4: Bring mask to face and gently pinch the nose bridge to fit. Do not over-squeeze.



Step 5: Heat up the chin section of the mask.



Step 6: Bring mask to face and gently push the chin piece up until it fits to your face.

7. **Test Mask Fit:** Again, test the fitment of your mask by placing your hand over the filter hole of the mask, pressing in to create a seal, and gently breathing in to create a suction. If the mask leaks re-adjust.
8. **Improving Sealing:** If a good seal is difficult to achieve users can:
 - a. Line the interior of the mask with a foam tape
 - b. Sand the interior of the mask using a fine grit sandpaper

PART 2: HEPA FILTER PREPARATION

1. **Buy a Filter:** Filters come in many ratings, sizes, and specifications. The most important feature is that they block a high percentage of particles that are 0.3µ in size. The [N95 mask](#) blocks 95% of particles this size, but not all filters can match that specification.

The table below details the common filter standards. All block particles that are 0.3µ in size, but some are more effective than others. The higher the rating the better, all bolded items meet or exceed the N95 specification. Which one should you choose? The highest rating you can afford and/or is readily available.

NOTE: A table of filters with purchase links is at the end of this document.

% 0.3 µm Filtered	MERV	MPR	FPR	HEPA
<75%	MERV 13	1500	10	-
75 - 84%	MERV 14	1900		-
85 - 94%	MERV 15	2800		-
95%	MERV 16*	2800*	-	-
>99.97	-	-	-	HEPA*

* Are equivalent or greater in performance than N95 masks

Sources: [MERV](#), [HEPA](#), MPR, [FPR](#)

2. **Setup Vacuum:** Particles created by dismantling HEPA filters are an irritant and can cause respiratory issues - especially for those with respiratory illness (like COVID-19, asthma, or bronchitis). A vacuum cleaner fitted with a HEPA filter bag can alleviate some of the risk of dismantling a HEPA air conditioning filter. The vacuum should have a hose with a wide suction attachment affixed and placed or held by another person as close to where the HEPA filter is being dismantled / cut.

3. **Disassemble AC/HVAC Filter:** Carefully cut the cardboard housing of the filter and remove the internal material. Video overview can be found [here](#). These instructions apply only to common household HVAC filters. Your filter may be different.

NOTE: ANY PUNCTURED, CUT, OR DAMAGED FILTER MATERIAL MUST BE DISCARDED AS IT IS NO LONGER VIABLE.

CAUTION: THE METAL MESH IN THE FILTER IS SHARP, WEAR GLOVES.

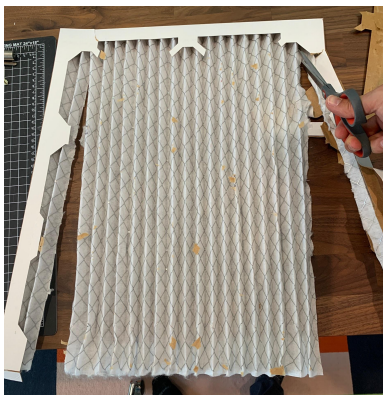
CAUTION: FILTER PARTICLES CAN IRRITATE LUNGS. Many filters are made of blown glass (fiberglass) which are an irritant. A rash can appear when the fibers become embedded in the outer layer of the skin. No long-term health effects should occur from touching fiberglass. Eyes may become red and irritated after exposure to fiberglass. Soreness in the nose and throat can result when fibers are inhaled. **Asthma and bronchitis can be aggravated by exposure to fiberglass** ([source](#)).



Step 1: Cut the internal cardboard bracing on the sides of the filter.



Step 2: Remove the internal bracing and mark any damaged areas of the filter with a sharpie or equivalent pen so they can be discarded later.



Step 3: Carefully cut and Remove the cardboard surrounding edges of the filter and remove them.

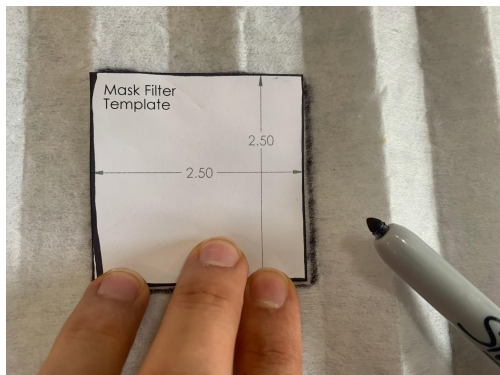


Step 4: With the creases of the filter parallel to your arms use one hand to hold the filter and the other to hold the mesh. Gently peel the two apart like opening a book. Mark any damaged areas.



Step 5: Inspect filter for damage and mark any damaged areas, remove cardboard remnants

4. **Mark and Cut Filters:** A 2.5" square of filter material is required for each mask. The HEPA Filter Cut Template can be printed and used as outlines to assist in making filters.



PART 3: FINISHING MASK

1. **Install filter:** Lay the filter inside the mask press the Mask Filter Screen into the filter until it's firmly in place.

NOTE: Ensure that there are NO GAPS between the filter and mask.

NOTE: If the wearer believes they may be sensitive to residual particles that may be left on the edges of a cut filter you can wrap filter edges in tape.

Step 1: Lay Filter



Step 2: Press in Screen



Finished Mask



2. **Create fastening straps:** Cut two elastic cords that are of appropriate size of the wearer. Thread each cord through it's corresponding mounting hole on the mask. Tie a knot to affix. A [taut line hitch](#) knot will allow the fastening straps to be adjustable.



3. **Ready for use:** Affix the mask to face and ensure that there are no air leaks.

CAUTION: If disseminating a mask to a 3rd party ensure they are aware that the mask is not disinfected and should be before use. 3rd parties can use the Disinfection Method below.

4. **Share & Provide Feedback:** To continue improving this protocol leave any comments or thoughts in the 'Next Steps' section. Share this protocol using the link:
<http://kosta.is/covid>

Disinfection Method

CAUTION: In studies conducted by National Institutes of Health, CDC, UCLA and Princeton University it was demonstrated that COVID-19 can [live on plastics for up to 3 days](#).

1. Remove the HEPA filter from the mask, discard - do not attempt to disinfect.
2. Remove all foam tapes and elastic cords, discard - do not attempt to disinfect.
3. Fully submerge and agitate mask and mask components in a bath that is made of either:
 - a. [70% or higher concentration](#) of isopropyl alcohol for 1 minute.
 - b. 6% or higher sodium hypochlorite (bleach) for 5 minutes.
4. Re-apply new optional foam tape and new filter in a decontaminated environment.

NOTE: Disinfection method was informed by [EPA's list N of disinfectants](#), please refer to their documentation for disinfection timing as it is evolving. Disinfection technique is untested.

Filter Precautions

As mentioned elsewhere in this document, dismantling filters can be dangerous - especially for those whose respiratory function is already impacted by COVID-19 or other respiratory diseases like asthma, bronchitis, or pneumonia.

Ironically, only a N95 (or better) mask or a filter itself has the capability to filter out released filter

particles. However, many household vacuums are equipped with HEPA rated filters which can assist in removing unwanted particles from your work area.

Skin and eye irritation can also occur from filter particles. You can learn more [here](#).

It should be noted that little is known about how filters deteriorate over time and if the edges of the filters will disperse into the lungs of the wearer of the mask with use. New mask designs are being tested to mitigate this potential problem, but the ability to test these is limited without specialized equipment.

Purchase Links for Appropriate Filters

To our knowledge all of the filters listed here are made of blown polypropylene (plastic) which is safer than blown glass. This list is not exhaustive and pricing / availability subject to change.

The Filtrete brand seems the most suitable.

Make / Model	Standard	Link	Effectiveness	Cost
Premium 2 HEPA Filters and 8 Pack of Pre-Filters compatible with Air Purifier Model	HEPA	Purchase	>99.97	\$29.99
VEVA Premium HEPA Replacement Filter 2 Pack	HEPA	Purchase	>99.97	\$49.99
Filtrete MPR 1900: 2-pack	MERV 13	Purchase	<75%	\$43.30
AC Furnace Air Filter, MPR 1900: 4-pack	MERV 13	Purchase	<75%	\$ 79.95
Filtrete MPR	MERV 14	Purchase	75-84%	\$59.97

2800: 2-pack				
Filtrete S-EA01-2PK-6E Smart Filter: 2-pack	MPR 2200	Purchase		\$59.98
MERV 13 Pleated Air Filter: 4-pack	MERV 13	Purchase		\$39.96
Airx Health MERV 13 Pleated Air Filter- Box of 6	MERV 13	Purchase	<75%	\$39.43
Lennox X5424 PMAC-20C MERV 16 25x20x6 Furnace Filter Media: 1-pack	MERV 16	Purchase	95%	\$94.95 + shipping If 2-pack \$189.90 + free shipping
Air Filters Delivered - MERV 13	MERV 13	Purchase	<75%	
LifeSupplyUSA 2-pack Replacement Filter	HEPA	Purchase	>99.97	\$39.98

Considerations

Considerations for Hospitals, Medical Providers, & 3rd Party Recipients of Masks

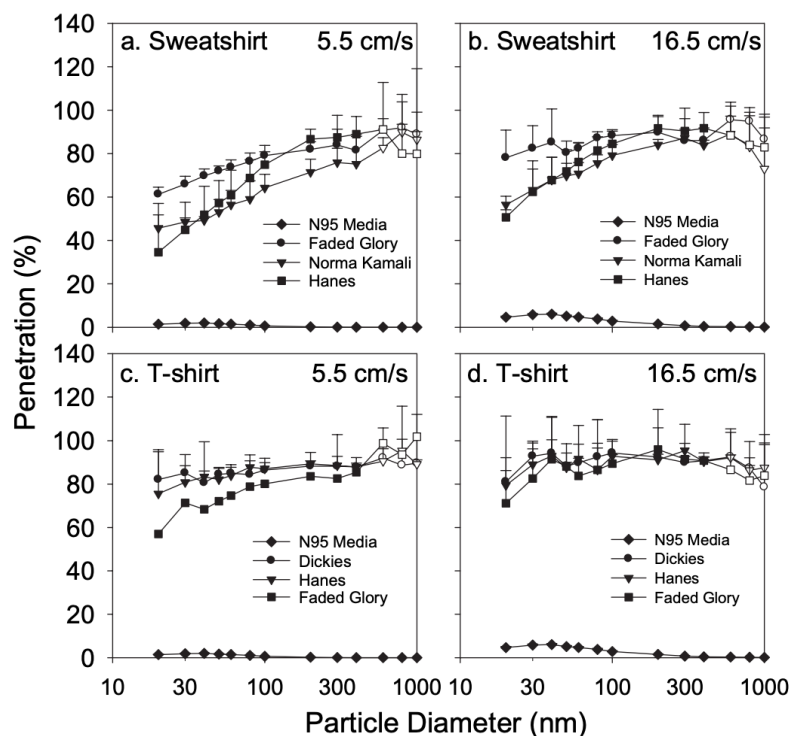
- **Pre-use Testing:** Providers should conduct a Porosity Test on any mask they are given to ensure the plastic does not allow air to permeate through the plastic because of a print failure. This can be done by creating a seal with your mouth on various parts of the mask and blowing. If air can escape through the plastic, it is a dysfunctional mask.
- **Mask Decontamination & Reuse:** COVID-19 can [live on plastics for up to 3 days](#). Crowdsourced masks made by the public are **NOT** sterile. Users of crowdsourced 3D printed masks should disinfect masks using the Disinfection Method and create their own filters in appropriate conditions.
- **Autoclave:** 3D printed PLA cannot be autoclaved and there are some chemicals like acetone that can damage the material.
- **Splash Considerations:** Air conditioning / HVAC filters are not tested to the splash standards like N95 masks and their performance when exposed to liquids at any velocity is unknown.
- **Lung Irritation:** HEPA filters are made from blown glass which can be irritating to lungs, inflame asthma, and likely cause issues with patients inflicted with COVID-19 when inhaled.
- **Mask Rubbing:** if irritation or chaffing occurs because of rubbing between mask and face, try applying [nexcare tape](#), steri tape, Duoderm, over the affected area. Make sure you do a seal test after.

FAQ

Q: Why can't I use a t-shirt (or other material) as a filter?

A 3D printed mask is worthless without an appropriately rated filter.

Producing something 'mask like' is simple: use a bandana, shirt, scarf, and other material. But they all [provide some but very limited protection](#) against small viruses - especially so in a hospital environment. Below is a chart illustrating how far a particle penetrates through a sweatshirt or T-shirt at different velocities. The bottom-most line in each graph is an N95 mask, the medical standard. ([source](#))



Filters designed to stop viruses are specialized and challenging to manufacture. There is currently a shortage of this material - which makes it near impossible to make any mask (3D printed or not) using the conventional and tested filtering materials.

The filter material is made of melt-blown fabric, as [described by NPR](#), "it's an extremely fine mesh of synthetic polymer fibers that forms the critical inner filtration layer of a mask, allowing the wearer to breath while reducing the inflow of possible infectious particles."

The machines that make these fibers cost upwards of 3.8 million euros (\$4.23 million) apiece. NPR describes them, "the machine that creates this fabric melts down plastic material and blows it out in strands, like cotton candy, into flat sheets of melt-blown fabric for face masks and other filtration products. A similar line of machines can create a related kind of fabric, called spun-bond fabric, also used in face masks and in medical protection suits worn by health-care workers."

Q: Why do I need to spend so much time making sure the mask fits and doesn't leak?

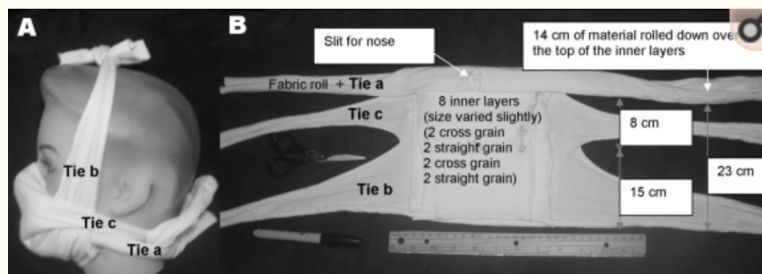
A 3D printed mask is worthless if it doesn't fit.

N95 masks, again the standard for medical workers, are specially fitted to ensure that there are no gaps between the face of the wearer and the mask. Air will take the path of least resistance, and as such, any holes or cracks will allow unfiltered air into the lungs of the wearer.

The metric of measurement of fit is called a 'fit factor' and N95 masks require a fit factor of 100 to be considered adequately fit.

3D printed masks made of PLA are quite rigid, requiring the addition of non-permeable foam strips to ensure a good seal, we don't actually know what the fit factor is, it's probably quite variable.

There has been research done into creating masks out of pre-shrunk t-shirts that can get close to the 'fitment' performance of a N95 mask. The diagram below illustrates a mask that scored a fit factor of 65. As you can tell, even 8 layers of pre-shrunk t-shirt material can hardly match the performance of the N95. ([source](#))



Figure

Prototype mask. A) Side view, B) Face side. This mask consisted of 1 outer layer ($\approx 37 \text{ cm} \times 72 \text{ cm}$) rolled and cut as in panel B with 8 inner layers ($< 18 \text{ cm}^2$) placed inside (against the face). The nose slit was first placed over the bridge of the nose, and the roll was tied below the back of the neck. The area around the nose was adjusted to eliminate any leakage. If the seal was not tight, it was adjusted by adding extra material under the roll between the cheek and nose or by pushing the rolled fabric above or below the cheekbone. Tie b was tied over the head. A cloth extension was added if tie b was too short. Finally, tie c was tied behind the head. The mask was then fit tested.

Q: Aren't filters 'directional' do I need to observe their directionality?

HVAC filters are directional (designed for air to flow in a specific direction). Many filters should be an arrow on the filter denoting where the intake is. Many filters are designed as layers of filter material of varying porosity. The reason behind this is so that big filters get trapped in the front of the filter and smaller at the rear - it adds to their longevity reducing how quickly they get clogged. After speaking with multiple vendors all said directionality was not important for this application.

Q: I don't have a 3D printer, what should I do?

There are other mask designs that don't require 3D printers, however they only work

Next Steps // Improvements

1. People with smaller faces can't use this mask. It needs to come in sizes.
 - a. 3/29 - Fixed w/ small, medium, large sizes
 2. The HEPA filter edges are on the inside of the mask, they should be on the outside so remnants are not breathed in.
 3. Create a table denoting the filtering efficacy of different rated filters.
 4. Find and confirm all the filters that are made of blown polypropylene (filtrete) as it is safer than fiberglass filters. Cross reference with amazon links.
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On a personal note: Thanks for scrolling down this far. I run a prototyping and design company (<http://sidecarlab.com>) and like many, my clients have cancelled. It's been a pleasure to put my time and resources into helping this global effort.

I hope you, dear reader, are safe and healthy wherever you are in the world. I'm sending you a no-contact safety hug. We got this, let's make some masks. -Kosta

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Credits:

- The folks at Billings Clinic for the draft mask design || [Link](#)
- Jonathan for the socially distanced chicken pot-pie dinner delivery after a long work day

Legalese:

The information presented here is intended to assist the general public during the current a global pandemic related to COVID-19 and the related nationwide shortage of personal protective equipment. Please be aware that this mask design is not intended to replace standard protective equipment such as

N-95 masks or surgical masks when that equipment is available. The use of these 3D printed masks has not been fully tested and has not been approved by federal or state authorities. No representations or guarantees are made regarding the safety, efficacy, or appropriate use of these masks in any particular situation. Use of this information for any purpose is at the maker's and user's own risk.