

## A Simple HEPA Filtering Facepiece

### Authors:

Phillip W. Clapp, PhD<sup>1</sup>; Conor A. Ruzycki, MS<sup>2</sup>; James M. Samet, PhD<sup>3</sup>, MPH; Kirby L. Zeman, PhD<sup>4</sup>; Jon Berntsen, PhD<sup>5</sup>; Emily Sickbert-Bennett, PHD, MS<sup>6</sup>; David J. Weber, MD, MPH<sup>6</sup>; Warren H. Finlay, PhD<sup>2</sup>; Andrew R. Martin, PhD<sup>2</sup>; William D. Bennett, PhD<sup>7</sup>; and Kenneth H. Wilson, MD<sup>8</sup>, for the Centers for Disease Control and Prevention (CDC) Prevention Epicenters Program

### Author Affiliations:

1. Department of Pediatrics, University of North Carolina at Chapel Hill, NC, USA
2. Department of Mechanical Engineering, University of Alberta, Edmonton, Canada
3. Center for Public Health and Environmental Assessment, U.S. Environmental Protection Agency, Research Triangle Park, NC USA
4. Center for Public Health and Environmental Assessment, University of North Carolina at Chapel Hill, NC, USA
5. TRC, Raleigh, NC USA
6. Infection Prevention Department, UNC Health Care, Chapel Hill, NC, USA
7. Department of Medicine, University of North Carolina at Chapel Hill, NC, USA
8. Department of Medicine, Duke University Medical Center, Durham, NC, USA

Conflicts of interest: No author has a conflict of interest to report.

### Corresponding Author:

Kenneth H. Wilson, MD  
Division of Infectious Diseases  
Box 102359  
Duke University Medical Center  
Durham, NC 27710  
Email: [kenneth.wilson@duke.edu](mailto:kenneth.wilson@duke.edu)  
Telephone: 919-932-5391  
Fax 919-684-8902

Running title: A Simple HEPA Filtering Facepiece

Keywords: aerosols; communicable disease transmission; airborne particulate matter; personal protective equipment; COVID-19, mask; N95 respirator.

## GRAPHICAL ABSTRACT



## HIGHLIGHTS

- The public is sometimes exposed to damaging small particle aerosols including SARS-Cov-2
- During shortages, facepieces available to the public do not protect against small particle aerosols
- We report designing homemade masks from home air purifier "true HEPA" filters
- These homemade masks function similar to an N95

## ABSTRACT

Shortages of efficient filtering facepiece respirators leave the public vulnerable to transmission of infectious diseases in small particle aerosols. This study demonstrates that a high-filtration-efficiency facepiece capable of filtering out >95% of 0.05µm particles while being worn can be simply produced with available materials.

## BACKGROUND

The novel coronavirus (SARS-CoV-2) pandemic has led to shortages of protective respirators across the U.S. and the Centers for Disease Control has advised that available respirators be reserved for healthcare personnel and first responders. The recommendation for the public is to use fabric face coverings in public settings as source control to limit droplet transmission (1). Although studying face coverings in real life situations is difficult, some studies cast doubt on the effectiveness of surgical or cloth masks at limiting infection by airborne pathogens. For instance, in a randomized trial in Denmark, wearing masks prevented only 18% of SARS-CoV-2 infections (2). In an epidemiological study of high-risk contacts in Thailand, mask use was generally supported, but at a boxing match, where the exposure was presumably intense, the population attributable fraction of infections due to not consistently wearing a mask was only .08, indicating that masking made little difference (3). COVID-19 super-spreader events have shown that SARS-CoV-2 can be transmitted over distances far beyond those seen for droplet spread (4-6), indicating spread by particles  $<10\ \mu\text{m}$  (7). Unlike measles virus and *Mycobacterium tuberculosis*, both known to be transmitted by small particle aerosol, viable SARS CoV-2 has been isolated from room air (8). Experimentally, the virus can remain viable suspended in air for long periods in small particles (9). Face coverings available to the public in this setting have two shortcomings. First, they do not maintain a tight seal with the wearer's face, so not all inspired air is filtered, and second, they are mostly made of materials with limited filtration efficiency (10-12). Thus, they are suboptimal for limiting transmission of diseases spread by small particle aerosols, a concern with COVID-19 (13, 14). A homemade substitute for the N95 respirator made by fitting a portion of a T-shirt to the face has been reported previously

(15). However, it did not pass a standard fit test used for N95 respirators. Since that report, available materials have improved. We report here a design for a simple high efficiency filtering facepiece (HEFF) that improves face seal and incorporates materials that we show are capable of filtering 0.02-3.00 $\mu\text{m}$  particles with an efficiency of >95% under conditions of use. This was achieved by using meltblown polypropylene home air purifier filters with electret properties similar to material used in construction of N95 respirators.

## **MATERIALS AND METHODS**

The novel HEFF design presented here is made from quilting cloth and the filter from a home air purifier. Polypropylene filters claiming “True HEPA” performance were tested with the exception of Filti material, which is a micropore product not using electret properties.

Borosilicate filters were not used due to possible carcinogenicity of inspired fibers (16). Equal sized squares of the cloth and filter were cut with the size based on a facial measurement. The two materials were bonded with silicone adhesive at the edges and then folded in half to make a rectangle. The shorter sides of the rectangle were sealed with silicone adhesive, forming a pocket, and the longer open side was fitted with a metal nose bridge and a foam nose pad. The inner edge of the respirator was coated with food-safe silicone sealant to enhance the seal to the face. Elastic head straps were placed as in an N95 respirator. More details are provided in Appendix A.

Fitted Filtration Efficiency (FFE) tests were performed as described previously (12). Briefly, respirators were fitted with sampling probes using a Fit Test Probe Kit for Disposable Facepieces 8025-N95 (TSI) to allow sampling of aerosol inside of the respirator. Particles (0.02-3.00 $\mu\text{m}$ ) in the chamber just outside of the face mask (ambient) and behind the face mask were continuously

monitored. This range includes the most penetrating particle size for electret filters (17). FFE was measured during a series of repeated movements of the torso, head, and facial muscles to simulate typical occupational activities experienced by a mask wearer. A Particle Generator 8026 (TSI) was used to supplement ambient particle counts in the chamber, with sodium chloride particles having a count median diameter of  $0.05\mu\text{m}$ . Each HEFF was tested once. Following FFE analysis, HEFFs were subjected to material filtration testing which assessed particle penetration over a range of particle sizes. Detailed methods are provided in Appendix B.

## **RESULTS**

Results of the FFE tests are shown in Table 1.

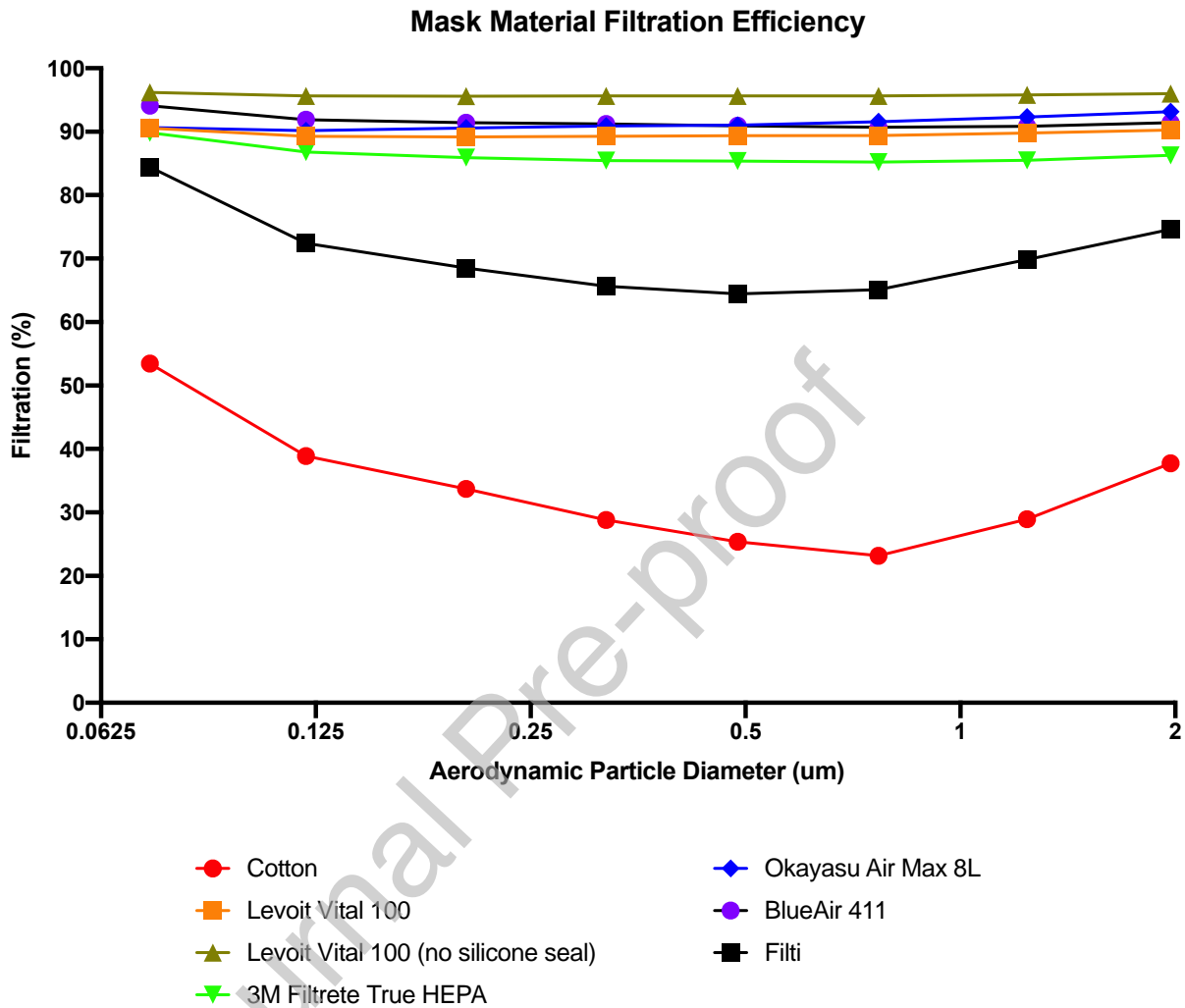
Face Covering	Type	Bending at Waist (50 sec)	Reading Aloud (30 sec)	Looking L/R (30 sec)	Looking U/D (30 sec)	Overall FFE (avg over all tests)
		% FFE $\pm$ sd	% FFE $\pm$ sd	% FFE $\pm$ sd	% FFE $\pm$ sd	% FFE $\pm$ sd
* Honeywell DC301 N95 with head straps	NIOSH N95	94.7 $\pm$ 3.5	96.4 $\pm$ 1.5	98.1 $\pm$ 0.8	98.8 $\pm$ 0.3	97.0 $\pm$ 1.5
Shine Ya Procedure Mask with ear loops	Medical Mask	44.5 $\pm$ 4.5	53.2 $\pm$ 7.6	33.3 $\pm$ 8.6	42.8 $\pm$ 8.9	43.5 $\pm$ 7.4
Flannel control	HEFF	53.9 $\pm$ 4.6	51.1 $\pm$ 11.3	45.7 $\pm$ 5.2	50.7 $\pm$ 5.3	50.4 $\pm$ 6.6
* Levoit Vital 100	HEFF	99.1 $\pm$ 0.1	98.8 $\pm$ 0.3	98.9 $\pm$ 0.3	99.1 $\pm$ 0.2	99.0 $\pm$ 0.2
Levoit Vital 100 medium, no silicone facial seal	HEFF	91.8 $\pm$ 0.3	93.3 $\pm$ 0.9	87.6 $\pm$ 2.7	93.3 $\pm$ 1.5	91.5 $\pm$ 1.7
* 3M Filtrete "True HEPA"	HEFF	98.9 $\pm$ 0.3	98.6 $\pm$ 0.3	99.3 $\pm$ 0.2	99.2 $\pm$ 0.1	99.0 $\pm$ 0.2
* Okayasu AirMax 8L	HEFF	97.4 $\pm$ 0.4	95.7 $\pm$ 1.1	96.9 $\pm$ 0.9	98.1 $\pm$ 0.3	97.0 $\pm$ 0.7
* BlueAir 411	HEFF	96.8 $\pm$ 0.4	95.4 $\pm$ 0.9	96.3 $\pm$ 0.5	96.2 $\pm$ 0.6	96.2 $\pm$ 0.6
Filti	HEFF	88.2 $\pm$ 1.3	87.8 $\pm$ 3.0	83.6 $\pm$ 3.1	85.0 $\pm$ 2.2	86.2 $\pm$ 2.4

**Table 1. Face covering Fitted Filtration Efficiency (FFE) of 0.02 – 3.0  $\mu$ m particles.**

\* Designates mask functioned at or above 95% filtration efficiency in the average over all tests.

Face coverings were worn by a single male subject in an atmosphere enriched with NaCl particles having a count median diameter (CMD) of 0.05  $\mu$ m. High efficiency filtering facepiece (HEFF) using filter materials from five manufacturers were compared with flannel used in the same design and with two commercial face coverings (NIOSH N95 respirator and Medical Mask). Percent FFE corresponds to  $100 \times [1 - \text{behind the mask particle concentration} / \text{ambient particle concentration}]$ . Overall FFE percentage and standard deviation (SD) were calculated across the length of the test.

Results of material filtration efficiency testing over a range of particle sizes are shown in the figure below.



## DISCUSSION

The rationale for the general public to have available high efficiency filtering face-pieces is strong. The risk of small particle aerosol spread of SARS-CoV-2 in the healthcare setting is considered high enough to warrant N95 use (18, 19). Infected people are most infectious just before and after becoming symptomatic (20) and shedding of viable virus is usually diminished or over by the time of hospital admission (21). It follows that the most infectious people are

likely to be found in public and sometimes not wearing masks. Thus, the risk of exposure is at least as high for the general public. Recent studies report that homemade cloth masks filter out 0–70% of particles in the size range tested here (10-12). This filtration efficiency can be improved by enhancing the face seal with a nylon stocking overlay or changing the shape of the mask to a cone or duck-bill design (11). Using nonwoven materials like those used in MERV 16 room air filters in a duck-bill design has been reported to achieve approximately 90% filtration efficiency (10).

Most of the HEFF's tested in this report performed at well over 95% FFE when used by a volunteer under typical conditions of use. However, material filtration results for several HEFFs were slightly lower than 95%. Lower material filtration was possibly due to changes in the filter media resulting from environmental preconditioning (85% relative humidity and 38 °C for 25 hours) or testing with a higher air velocity than the mask was exposed to during FFE testing. A NIOSH-approved N95 respirator is required to achieve >95% material filtration efficiency even under these conditions. Thus, the HEFF's reported here did not meet full N95 standards. Though simple to make, the design reported here improved on most home-made mask designs in that the silicone seal improved the fit and reduced inward leakage around the wearer's face. Cost of materials was approximately two USD per HEFF and each required approximately 1 hour of time to make. Based on our data, silicone sealant should be investigated further as potentially helpful for improving the fit of face coverings in general. The "True HEPA" filter facepieces tested in this study achieved high FFE. However, it should not be presumed that all such filters will provide the same level of FFE. Because manufacturers of home air purifier filters are not required to certify the filtration efficiency of their media, filtration efficiencies between brands may vary.



While the data provided here indicate that HEPA home air filters can be effective media for HEFF construction, there are limitations to this study. First, all FFE tests were performed on a single individual to allow for a controlled comparison between HEFF designs. Interperson variability in facial geometries may result in variability of HEFF fit and differences in FFE. Second, the scope of this work is limited with only a single HEFF of each material tested. However, despite the limited scope, all of the HEFFs achieved a high FFE, demonstrating the effectiveness of this design. Third, while the focus of this work was to assess the feasibility of using HEPA home air filters to create an effective HEFF, it is unclear whether extensive use of these filtration materials could lead, in turn, to acute shortages of home HEPA air filters. Additionally, it is important to note that although the filter media tested here are designed to process air for human consumption, HEPA home air purifier filters are not manufactured to be used as facemask media and have not been evaluated by manufacturers for this purpose. Thus, key factors such as airflow resistance (pressure drop) and material conformity to meet health requirements may not meet respirator certification standards. Intentional release of a biological agent, rapid emergence of a respiratory pathogen, or smoke from wildfires can potentially create a sudden need for NIOSH-approved respirators that exceeds supply. The simple HEFF design presented here could help mitigate such shortages and provide effective PPE to those who need respiratory protection.

## **CONCLUSIONS**

A respirator that, when worn, can seal and filter as efficiently as an N95 respirator can be made easily out of available materials, though it may function less well at high humidity and higher flow rates than encountered in normal breathing.

## ACKNOWLEDGEMENTS

This work was supported by the Duke-UNC Prevention CDC Epicenters Program for Prevention of Healthcare-Associated Infections U54CK000483, Natural Sciences and Engineering Research Council of Canada Alliance Grant ALLRP 554468-20, and Mitacs Accelerate Grant IT18395.

Funding sources were not involved in study design, collection, analysis or interpretation of data, writing of this paper or the decision to submit for publication.

## DISCLAIMERS

The research described in this article has been reviewed by the Center for Environmental Public Health and Environmental Assessment, U.S. EPA, and approved for publication. The contents of this article should not be construed to represent Agency policy nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

## COMPETING INTERESTS

None of the authors have competing interests to report.

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