



Forgotten Technology in the COVID-19 Pandemic: Filtration Properties of Cloth and Cloth Masks—A Narrative Review

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Abstract

Management of the global crisis of the coronavirus disease 2019 pandemic requires detailed appraisal of evidence to support clear, actionable, and consistent public health messaging. The use of cloth masks for general public use is being debated, and is in flux. We searched the MEDLINE and EMBASE databases and Google for articles reporting the filtration properties of flat cloth or cloth masks. We reviewed the reference lists of relevant articles to identify further articles and identified articles through social and conventional news media. We found 25 articles. Study of protection for the wearer used healthy volunteers, or used a manikin wearing a mask, with airflow to simulate different breathing rates. Studies of protection of the environment, also known as source control, used convenience samples of healthy volunteers. The design and execution of the studies was generally rigorously described. Many descriptions of cloth lacked the detail required for reproducibility; no study provided all the expected details of material, thread count, weave, and weight. Some of the homemade mask designs were reproducible. Successful masks were made of muslin at 100 threads per inch (TPI) in 3 to 4 layers (4-layer muslin or a muslin-flannel-muslin sandwich), tea towels (also known as dish towels), made using 1 layer (2 layers would be expected to be better), and good-quality cotton T-shirts in 2 layers (with a stitched edge to prevent stretching). In flat-cloth experiments, linen tea towels, 600-TPI cotton in 2 layers, and 600-TPI cotton with 90-TPI flannel performed well but 80-TPI cotton in 2 layers did not. We therefore recommend cotton or flannel at least 100 TPI, at least 2 layers. More layers, 3 or 4, will provide increased filtration but there is a trade-off in that more layers increases the resistance to breathing. Although this is not a systematic review, we included all the articles that we identified in an unbiased way. We did not include gray literature or preprints. A plain language summary of these data and recommendations, as well as information on making, wearing and cleaning cloth masks is available at www.clothmasks.ca.

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Severe acute respiratory syndrome coronavirus (SARS-CoV) 2 resulting in coronavirus disease 2019 (COVID-19) has, at the time of this writing, claimed at least 600,000 lives.¹ The management of this global crisis requires detailed appraisal of evidence to support clear, actionable, and consistent public health messaging. The use of cloth masks for general public use is being debated, and is in flux: in April 2020, the World Health

Organization (WHO) changed its position from “not recommended under any circumstance”² to “there is no current evidence to make a recommendation for or against their use,”³ recognizing that, “decision makers may be moving ahead with advising the use of non-medical masks,” as was indeed occurring.⁴⁻⁸ On June 5, 2020, the WHO updated its guidance further “to advise that to prevent COVID-19 transmission effectively in areas of

community transmission, governments should encourage the general public to wear masks in specific situations and settings as part of a comprehensive approach to suppress SARS-CoV-2 transmission.⁹

In early March 2020, the WHO estimated that 89 million masks would be needed each month, globally, for medical purposes alone,¹⁰ highlighting the importance of directing the supply of medical masks and respirator-type masks (eg, N95s) to medical use. Nonmedical masks will be needed for the other purposes outlined. Cloth masks potentially offer a reusable, sustainable, and environmentally friendly solution.

METHODS

We searched the MEDLINE and EMBASE databases and Google for articles on the filtration properties of flat cloth or cloth masks or face coverings using the search terms *cloth*, *fabric*, *gauze*, *cotton*, *mask*, and *filtration* and synonyms. We reviewed the reference lists of relevant articles and identified further articles. Our selection of articles for this review was unbiased, ie, it did not depend on the direction of the results. We did not conduct a systematic review or search gray literature. We identified 25 articles that described filtration properties of cloth or cloth masks, some of which included medical masks and N95 respirators as comparators. This review summarizes a century of evidence on the efficiency of cloth and cloth masks to reduce transmission of droplets and aerosols (Supplemental Table, available online at <http://www.mayoclinicproceedings.org>).¹¹⁻³⁵ We argue that this body of work should inform decisions in the context of reducing the transmissibility of COVID-19. Physical distancing, hand washing, and disinfection of surfaces remain the cornerstones of policy, and we stress that we are not discussing cloth masks as a means of relaxing these interventions or as a replacement for formal personal protective equipment (PPE) for high-risk workers.

WHAT ARE THE STANDARDS IN THIS LITERATURE?

When we breathe, eat, speak, sing, cough, or sneeze, particles are released into the

ARTICLE HIGHLIGHTS

- Of the 25 articles that described studies of the filtration properties of cloth or cloth masks, some of which included medical masks and N95 respirators as comparators, most used surrogates for filtration, sometimes graded by particle size, and some used bioaerosols, usually bacterial. A minority of studies used virus; no study used severe acute respiratory syndrome coronavirus 2.
- Studies of the filtration properties of flat cloth used a variety of methods, few of which were the equivalent to the standard methods used by ASTM International (formerly known as the American Society for Testing and Materials).
- The design and execution of the studies was generally rigorously described; the number of replicates and variance of estimates was less well described, and it was unusual to find statistical comparisons between different types of cloth or types of mask.
- Many descriptions of cloth were lacking in the detail required for reproducibility; no study gave all the expected details of material, thread count, weave, and weight.
- Although no direct data with clinically important outcomes are available, this study found that cloth masks can offer substantial filtration, in some cases equivalent to some medical masks.

environment. The size distribution of these particles varies with the activity, as does their velocity and their trajectory. Although technically all these particles of liquid (respiratory secretions) suspended in gas (air) are aerosols, we recognize a useful distinction between coarse particles (sometimes called *droplets*), which are usually defined as greater than 5- μm aerodynamic diameter, and aerosols, which are particles of less than 5- μm aerodynamic diameter. Exhaled secretions may contain virus particles, which are nanoparticles of much less than 1- μm .

Filtration efficiency is the proportion of particles blocked by a filter (usually expressed as a percentage) and assessed using surrogate markers, not directly with transmissible pathogens (Figure; Supplemental Figure 1, available online at <http://www.mayoclinicproceedings.org>). Some surrogates are nonbiological, such as ambient particles, or aerosols of diesel combustion or saline; others are

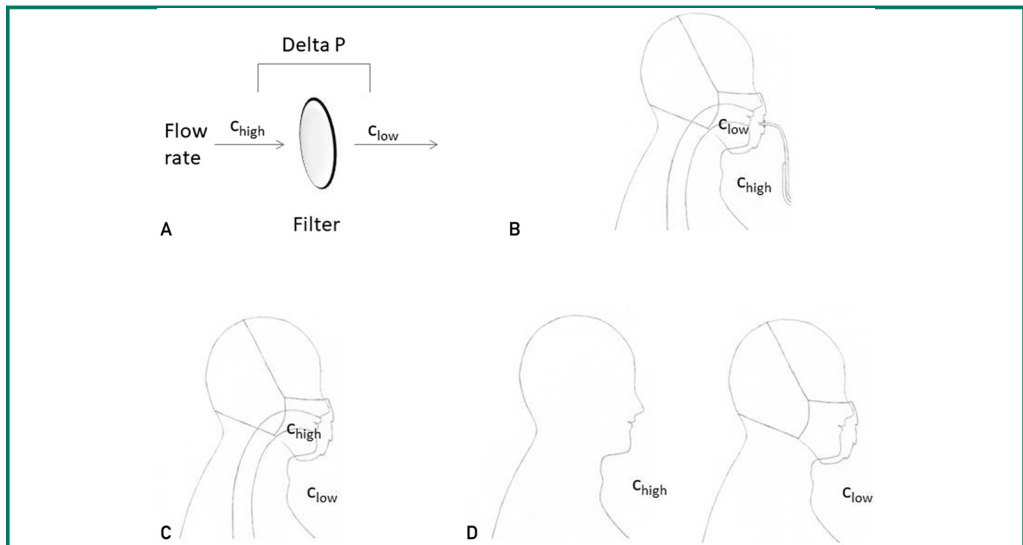


FIGURE. Schematic showing different types of filtration experiments. A, An experiment on a flat cloth sample or mask material sample (the filter). The surface area of the sample tested, the particle size, particle composition, and flow rate should be defined. The pressure drop across the filter under these or other specified conditions can be measured. There is no edge leak. All the particles that contribute to the concentration on the protected side of the filter have penetrated the material. The TSI 8130 filter tester (TSI Incorporated) is an example of such a system. Using this type of experiment, ASTM International (formerly known as the American Society for Testing and Materials) defines the standards for testing material for medical masks, and the National Institute for Occupational Safety and Health defines the standards for testing material for respirators (N95-type masks). B, An inward protection experiment on a mask using a human volunteer or a manikin. For human volunteers, the concentration inside the mask is measured using a thin-walled tube called a probe that fits across the mask material. For a manikin, a pump will simulate breathing, and the concentration inside the mask can be measured at any point in the circuit. The concentration outside the mask is measured from the surrounding air. The TSI PortaCount is an example of such a system and can be used with human volunteers or with a manikin. When the particles to be measured are inert and harmless, such as the saline aerosol typically used with the PortaCount, the experiment can be conducted in an ordinary room without special conditions. The concentration of particles on the protected side (the inside) is a combination of penetration of the mask (through the material) and edge leak (around the material); it measures both the material and the fit. In experiments using human volunteers, a variety of activities can be undertaken to further challenge the mask (eg, deep breathing, head movement, bending). In experiments using manikins, the flow rate can be adjusted to simulate different levels of minute respiration corresponding to different activity levels. For medical masks, no relevant standards have been defined. For respirators (N95-type masks), the US Occupational Safety and Health Administration requires that N95 masks be fitted to the individual who will wear them. Fitting can be done quantitatively using a device such as the PortaCount or nonquantitatively using a strong-tasting substance such as saccharin. C, An outward protection experiment on a mask using a manikin. The aerosol is generated and passed through the manikin into the mask. The concentration of the aerosol on the source side can be measured at any point in the circuit. The concentration of the aerosol on the protected side is measured from the environment. The apparatus is protected in a chamber filled with filtered air to ensure that all particles outside the mask have come from the manikin. The concentration of particles on the protected side (the outside) is a combination of penetration of the mask (through the material) and edge leak (around the material). There are no standards that relate to this design. D, An outward protection experiment using human volunteers. The aerosol is generated through human activity—breathing, talking, or coughing. Usually these tests are bioaerosol experiments measuring normal human mouth flora or pathogens from volunteers who are unwell. (In some experiments, to standardize the experiment and to increase the concentration of bacteria in the aerosol, volunteer investigators contaminated their mouths with nonpathogenic bacteria and studied transmission specifically of that species.) There are no standards that relate to this design. C_{high} = particle concentration on the source side of the filter; C_{low} = particle concentration on the protected side of the filter; Delta P = pressure drop across the filter.

bioaerosols, usually bacterial. Filtration standards specify detail for testing of mask materials (equipment, surface area tested, air flow, particle type and size). Medical masks (also known as *dental masks* and *surgical masks*) are certified according to the standards set by ASTM International (formerly known as the American Society for Testing and Materials).³⁶ Canada uses these US standards for mask materials, which define 3 levels (1 to 3) of mask according to particle filtration efficiency greater than 95%, 98%, and 98% for the flat material, respectively. Increasing resistance to splashing with synthetic blood further distinguishes level 2 and level 3 masks. Particle filtration efficiency of the flat mask material is assessed using latex spheres of 0.1 μm and bacterial filtration efficiency using aerosolized *Staphylococcus aureus* at a mean particle size of 3 μm .³⁶ The material for respirator-type masks, in North America called N95s, is certified according to standards set by the US National Institute for Occupational Safety and Health.³⁷ The relationship between particle size and filtration efficiency is not linear, with small particles having consistently lower efficiency, but U-shaped, with the lowest filtration efficiency usually around 0.3 μm , which is sometimes called the *most-penetrating-particle size*.^{23,37} Mask material for respirators is therefore tested at 0.3 μm , and particle filtration efficiency greater than 95% is required.³⁷ The US Occupational Safety and Health Administration and Canadian Standards Association standard Z94.4 further require that N95 masks be fitted to the individual who will wear them.^{38,39} Fit assesses both penetration through the mask material and leak around the mask edge. A quantitative fit testing device, the TSI PortaCount, measures saline particles in the 0.02- to 1- μm range, inside and outside the mask. A ratio of 100 particles outside the mask to 1 particle inside, known as a *fit factor*, is required; this ratio is equivalent to filtration efficiency of 99% (Supplemental figure 1). A nonquantitative alternative standard is to test with a hood and a strong-tasting aerosol such as saccharin.³⁸ No fit testing is required for medical masks.

The diameter of SARS-CoV-2 virus has been reported as between 0.065 and 0.140

μm .⁴⁰ In contrast, the space between threads in many woven cloths is visible to the naked eye, and even in high thread count fabric, the gaps between fibers are of the magnitude of 5 to 15 μm .²³ In lower thread count fabric, gaps as large as 50 to 200 μm are expected and observed.^{23,41,42} It is counterintuitive that cloth stops particles smaller than 5 μm ; however, particles of this size encounter cloth fibers and are filtered through the 3 physical principles of impaction, sedimentation, and diffusion.⁴³

Transmission of virus is usually not as isolated virions but in larger particles combined with respiratory secretions. Although the literature describing the size distribution of particles generated by activities such as breathing, coughing, and sneezing is not completely consistent, it appears that even for the less explosive activities, a proportion of particles are greater than 1 μm , and for coughing and sneezing, particles in the 10- μm and even 100- μm range have been observed,⁴⁴ although other reports suggest peak particle size around 1 to 5 μm .⁴⁵ The reasons for these large differences among studies are not apparent. The particle size used for testing medical masks is 0.1 μm .³⁶ If individual particles contain more than one virion and larger particles contain more virions than smaller particles, filtration efficiency for virions reaching the environment may exceed expectations based on testing using latex test nanoparticles.

Cloth is woven (crossing threads, known as *warp* and *weft*), knitted (interlocking loops of fiber), or felted (compressed disorganized fibers). Woven cloth is further described by its weave. In plain weave, fibers cross at 90 degrees. Twisted weave gives a diagonal stripe to the finish and is known as *twill weave*; a common example is denim. When the warp and the weft are different numbers of threads in a given distance (conventionally, an inch), thread count may be expressed by 2 numbers, eg, 20 \times 14. Thread count expressed as a single number, threads per inch (TPI), is the sum of the warp plus weft thread count per inch. The finish may be plain or raised to fuzziness, which is called a *nap*. Some fabrics, called

TABLE 1. Summary of Filtration Efficiency for Flat Cloth. Including Details of Methodology: Aerosol Used, Aerosol Size, and Flow Rate^{a,b}

Reference, year	Composition	Weight, weave, thread count	Efficiency		Aerosol	Measured aerosol size	Flow rate (L/min)	Standard
			1 Layer	2 Layers				
Cotton								
Konda et al, ²³ 2020	“Quilters’ cotton”	80 TPI	4%	32%	NaCl solution	75-100 nm	~3.5 ^c	No
		80 TPI	3%	NA	NaCl solution	75-100 nm	~9 ^c	No
		80 TPI	6%	50%	NaCl solution	2-3 μm	3.5 ^c	No
		80 TPI	34%	NA	NaCl solution	2-3 μm	~9 ^c	No
Konda et al, ²³ 2020	Cotton 600 TPI (#1 in “Hybrids” below)	600 TPI	76%	85%	NaCl solution	75-100 nm	~3.5 ^c	No
		600 TPI	98%	99.5%	NaCl solution	2-3 μm	~3.5 ^c	No
Jung et al, ²¹ 2014	Gauze, cotton	NA	1%	1%; 4 layers, 4%	NaCl solution	75 nm ^d	85	NIOSH
Davies et al, ¹⁴ 2013	T-shirt: 100% cotton	Knit	69%	71%	<i>Bacillus atrophaeus</i>	NA	30	No
		Knit	51%	NA	Bacteriophage MS2	NA	30	No
Rengasamy et al, ²⁹ 2010	T-shirt, Hanes: 100% cotton	Knit	9%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	12%	NA	NaCl solution	1 μm	17 cm/s	No
Zhao et al, ³⁵ 2020	T-shirt, cotton	Knit 157 g/m ²	22%	NA	NaCl solution	75 nm ^d	32	No
Zhao et al, ³⁵ 2020	Sweater, cotton	Knit 360 g/m ²	26%	NA	NaCl solution	75 nm ^d	32	No
Rengasamy et al, ²⁹ 2010	Towel, Pem-America: 100% cotton	NA	23%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	49%	NA	NaCl solution	1 μm	17 cm/s	No
Rengasamy et al, ²⁹ 2010	Towel, Pinzon: 100% cotton	NA	30%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	58%	NA	NaCl solution	1 μm	17 cm/s	No
Rengasamy et al, ²⁹ 2010	Towel, AQUIS: 100% cotton	NA	33%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	0%	NA	NaCl solution	1 μm	17 cm/s	No
Davies et al, ¹⁴ 2013	Scarf: cotton	NA	62%	71%	<i>B atrophaeus</i>	NA	30	No
		NA	49%	NA	Bacteriophage MS2	NA	30	No
Rengasamy et al, ²⁹ 2010	Scarf, Pocket Square: 100% cotton	NA	0%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	0%	NA	NaCl solution	1 μm	17 cm/s	No

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TABLE 1. Continued

Reference, year	Composition	Weight, weave, thread count	Efficiency		Aerosol	Measured aerosol size	Flow rate (L/min)	Standard
			1 Layer	2 Layers				
Rengasamy et al, ²⁹ 2010	Scarf, Seed Supply: 100% cotton	NA	1%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	7%	NA	NaCl solution	1 μm	17 cm/s	No
Davies et al, ¹⁴ 2013	Pillowcase	NA	61%	62%	<i>B. atrophaeus</i>	NA	30	No
		NA	57%	NA	Bacteriophage MS2	NA	30	No
Zhao et al, ³⁵ 2020	Pillowcase: 100% cotton	116 g/m ²	5%	NA	NaCl solution	75 nm ^d	32	No
Jung et al, ²¹ 2014	Handkerchief, cotton	NA	1%	2%; 4 layers, 4%	NaCl solution	75 nm ^d	85	NIOSH
Linen								
Davies et al, ^{14,46} 2013	Tea towel, linen	NA	83%	97%	<i>B. atrophaeus</i>	NA	30	No
		NA	72%	NA	Bacteriophage MS2	NA	30	No
Davies et al, ¹⁴ 2013	Linen	NA	60%	NA	<i>B. atrophaeus</i>	NA	30	No
		NA	62%	NA	Bacteriophage MS2	NA	30	No
Silk								
Davies et al, ¹⁴ 2013	Silk	NA	58%	NA	<i>B. atrophaeus</i>	NA	30	No
		NA	54%	NA	Bacteriophage MS2	NA	30	No
Konda et al, ²³ 2020	Silk, 100% (#2 in "Hybrids" below)	39 g/m ² 145 TPI ^e	54%	65%; 4 layers, 84%	NaCl solution	75-100 nm	~3.5 ^c	No
		39 g/m ² 145 TPI ^e	55%	66%; 4 layers, 89%	NaCl solution	2-3 μm	~3.5 ^c	No
Zhao et al, ³⁵ 2020	Napkin, silk	Woven84 g/m ²	5%	NA	NaCl solution	75 nm ^d	32	No
Manmade								
Konda et al, ²³ 2020	Chiffon: 90% polyester, 10% spandex (#3 in "Hybrids" below)	195 TPI ^e	58%	86%	NaCl solution	75-100 nm	~3.5 ^c	No
		195 TPI ^e	24%	NA	NaCl solution	75-100 nm	~9 ^c	No
		195 TPI ^e	73%	90%	NaCl solution	2-3 μm	~3.5 ^c	No
		195 TPI ^e	53%	NA	NaCl solution	2-3 μm	~9 ^c	No

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TABLE 1. Continued

Reference, year	Composition	Weight, weave, thread count	Efficiency		Aerosol	Measured aerosol size	Flow rate (L/min)	Standard
			1 Layer	2 Layers				
Zhao et al, ³⁵ 2020	Interfacing material: polypropylene	Spunbond 30 g/m ²	6%	NA	NaCl solution	75 nm ^d	32	No
Rengasamy et al, ²⁹ 2010	Scarf, Walmart fleece: 100% polyester	NA	25%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	14%	NA	NaCl solution	1 μm	17 cm/s	No
Zhao et al, ³⁵ 2020	Toddler wrap: polyester	Knit 200 g/m ²	18%	NA	NaCl solution	75 nm ^d	32	No
Zhao et al, ³⁵ 2020	Exercise pants: nylon	Woven 164 g/m ²	23%	NA	NaCl solution	75 nm ^d	32	No
Composites								
Davies et al, ¹⁴ 2013	Cotton mix	NA	75%	NA	<i>B. atrophaeus</i>	NA	30	No
		NA	70%	NA	Bacteriophage MS2	NA	30	No
Konda et al, ²³ 2020	Flannel: 65% cotton, 35% polyester (#4 in "Hybrids" below)	90 TPI ^e	55%	NA	NaCl solution	75-100 nm	~3.5 ^c	No
		90 TPI ^e	13%	NA	NaCl solution	75-100 nm	~9 ^c	No
		90 TPI ^e	44%	NA	NaCl solution	2-3 μm	~3.5 ^c	No
		90 TPI ^e	46%	NA	NaCl solution	2-3 μm	~9 ^c	No
Rengasamy et al, ²⁹ 2010	Norma Kamali sweatshirt: 85% cotton, 15% polyester	NA	8%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	26%	NA	NaCl solution	1 μm	17 cm/s	No
Rengasamy et al, ²⁹ 2010	Hanes sweatshirt: 70% cotton, 30% polyester	NA	19%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	15%	NA	NaCl solution	1 μm	17 cm/s	No
Rengasamy et al, ²⁹ 2010	Faded Glory sweatshirt: 60% cotton, 40% polyester	NA	6%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	12%	NA	NaCl solution	1 μm	17 cm/s	No
Rengasamy et al, ²⁹ 2010	Dickies T-shirt: 99% cotton, 1% polyester	NA	8%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	20%	NA	NaCl solution	1 μm	17 cm/s	No
Rengasamy et al, ²⁹ 2010	Faded Glory T-shirt: 60% cotton, 40% polyester	NA	0%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	15%	NA	NaCl solution	1 μm	17 cm/s	No

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TABLE 1. Continued

Reference, year	Composition	Weight, weave, thread count	Efficiency		Aerosol	Measured aerosol size	Flow rate (L/min)	Standard
			1 Layer	2 Layers				
Paper								
Zhao et al, ³⁵ 2020	Paper towel: cellulose	Bonded 43 g/m ²	10%	NA	NaCl solution	75 nm ^d	32	No
Zhao et al, ³⁵ 2020	Tissue paper: cellulose	Bonded 33 g/m ²	20%	NA	NaCl solution	75 nm ^d	32	No
Zhao et al, ³⁵ 2020	Copy paper: cellulose ^f	Bonded 73 g/m ²	99.9%	NA	NaCl solution	75 nm ^d	32	No
Hybrids								
Konda et al, ²³ 2020	Cotton/silk (1 layer of #1 above, ^g 1 layer of #2 above)	NA	96%	NA	NaCl solution	75-100 nm	~3.5 ^c	No
Konda et al, ²³ 2020	Cotton/chiffon (1 layer of #1 above, ^g 1 layer of #3 above)	NA	97%	NA	NaCl solution	2-3 μm	~3.5 ^c	No
Konda et al, ²³ 2020	Cotton/flannel (1 layer of #1 above, ^g 1 layer of #4 above)	NA	99.5%	NA	NaCl solution	2-3 μm	~3.5 ^c	No
Konda et al, ²³ 2020	Cotton/flannel (1 layer of #1 above, ^g 1 layer of #4 above)	NA	95%	NA	NaCl solution	75-100 nm	~3.5 ^c	No
Konda et al, ²³ 2020	Cotton/flannel (1 layer of #1 above, ^g 1 layer of #4 above)	NA	96%	NA	NaCl solution	2-3 μm	~3.5 ^c	No
Cloth mask material								
Furuhashi, ¹⁶ 1978	Commercial mask fabric A, bleached cotton	96 TPI	69%	NA	<i>Staphylococcus aureus</i>	NA	8	US military standard, 1978
Furuhashi, ¹⁶ 1978	Commercial mask fabric D, bleached cotton	86 TPI	43%	NA	<i>S aureus</i>	NA	8	US military standard, 1978
Furuhashi, ¹⁶ 1978	Commercial mask fabric B, calico	160 TPI	73%	NA	<i>S aureus</i>	NA	8	US military standard, 1978
Furuhashi, ¹⁶ 1978	Commercial mask fabric C, twill weave	NA	94%	NA	<i>S aureus</i>	NA	8	US military standard, 1978
Jang & Kim, ²⁰ 2015	Cloth mask A: 50% nylon, 40% polypropylene, 10% polyurethane	1.22-mm thick	29%	59%; 4 layers, 75%	NaCl solution	0.3-0.5 μm	NA	No
Jang & Kim, ²⁰ 2015	Cloth mask A: 50% nylon, 40% polypropylene, 10% polyurethane	1.22-mm thick	60%	70%; 4 layers, 94%	NaCl solution	2-5 μm	NA	No
Jang & Kim, ²⁰ 2015	Cloth mask B: 84% nylon, 12% polyester, 4% spandex	0.62-mm thick	28%	32%; 4 layers, 67%	NaCl solution	0.3-0.5 μm	NA	No
Jang & Kim, ²⁰ 2015	Cloth mask B: 84% nylon, 12% polyester, 4% spandex	0.62-mm thick	63%	71%; 4 layers, 77%	NaCl solution	2-5 μm	NA	No

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TABLE 1. Continued

Reference, year	Composition	Weight, weave, thread count	Efficiency		Aerosol	Measured aerosol size	Flow rate (L/min)	Standard
			1 Layer	2 Layers				
Jang & Kim, ²⁰ 2015	Cloth mask C: 100% polyester	0.29-mm thick	18%	50%; 4 layers, 55%	NaCl solution	0.3-0.5 μm	NA	No
		0.29-mm thick	45%	78%; 4 layers, 81%	NaCl solution	2-5 μm	NA	No
Jang & Kim, ²⁰ 2015	Cloth mask D: 100% polyester microfiber	0.30-mm thick	9%	45%; 4 layers, 62%	NaCl solution	0.3-0.5 μm	NA	No
		0.30-mm thick	45%	59%; 4 layers, 99%	NaCl solution	2-5 μm	NA	No
Jang & Kim, ²⁰ 2015	Cloth mask E: 100% polyester microfiber	2.77-mm thick	27%	NA	NaCl solution	0.3-0.5 μm	NA	No
		2.77-mm thick	80%	NA	NaCl solution	2-5 μm	NA	No
Jung & Kim, ²⁰ 2015	Cotton mask: surgical type, 4 distinct masks	NA	23%, SD 27%	NA	NaCl solution	75 nm ^d	85	NIOSH
MacIntyre et al, ²⁶ 2015	Cloth mask	NA	3%	NA	NaCl solution	75 nm ^d	NA	AS/NZS 1716
Rengasamy et al, ²⁹ 2010	Respro Bandit	NA	22%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	34%	NA	NaCl solution	1 μm	17 cm/s	No
Rengasamy et al, ²⁹ 2010	Breathe Healthy	NA	13%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	44%	NA	NaCl solution	1 μm	17 cm/s	No
Rengasamy et al, ²⁹ 2010	Breathe Healthy fleece	NA	22%	NA	NaCl solution	1 μm	5.5 cm/s	No
		NA	13%	NA	NaCl solution	1 μm	17 cm/s	No
Medical mask material								
Davies et al, ¹⁴ 2013	Mölnlycke Health Care Barrier 4239	NA	96%	NA	<i>B. atrophaeus</i>	NA	30	No
		NA	90%	NA	Bacteriophage MS2	NA	30	No
Furuhashi, ¹⁶ 1978	Hopes	Fine glass fiber with nonwoven fabric	98%	NA	<i>S. aureus</i>	NA	8	US military standard, 1978
Furuhashi, ¹⁶ 1978	Medispo	Fine glass fiber with nonwoven fabric	99%	NA	<i>S. aureus</i>	NA	8	US military standard, 1978
MacIntyre et al, ²⁶ 2015	Medical mask material	NA	56%	NA	NaCl solution	75 nm ^d	NA	AS/NZS 1716
Jang & Kim, ²⁰ 2015	R class respirator material	1.81-mm thick	91%	NA	NaCl solution	0.3-0.5 μm	NA	No

Continued on next page

TABLE 1. Continued

Reference, year	Composition	Weight, weave, thread count	Efficiency			Measured aerosol size	Flow rate (L/min)	Standard
			1 Layer	2 Layers	Aerosol			
		NA	100%	NA	NaCl solution	2-5 μm	NA	No
Jung et al, ²¹ 2014	Medical mask: surgical type, 4 distinct masks	NA	41% SD 38%	NA	NaCl solution	75 nm ^d	85	NIOSH
Jung et al, ²¹ 2014	Medical mask: dental type, 5 distinct masks	NA	71% SD 12%	NA	NaCl solution	75 nm ^d	85	NIOSH

^aAS/NZS = Australia/New Zealand Standard; NA = not available; NaCl = sodium chloride; NIOSH = National Institute for Occupational Safety and Health; TPI = threads per inch (number of threads in warp plus number of threads in weft).

^bFor experimental details and additional studies, see [Supplemental Table](http://www.mayoclinicproceedings.org) (available online at <http://www.mayoclinicproceedings.org>).

^cKonda et al²³ measured cloth using a system that produced initial flow rates of 35 L/min and 90 L/min, respectively; however, when cloth was inserted, increasing the resistance, the flow rate decreased, probably by an order of magnitude (Supratik Guha, written communication, month year; and Konda et al²³ correction). We have reflected this by reporting a flow rate that is the initial divided by 10 and by indicating that it is approximate (~); we thought this was preferable to giving no indication. The experiments in this article included some readings done with a gap past the filter, to simulate edge leak. We have extracted these data in the Supplementary Material but here present the results of flat cloth with no gap. When multiple data points were available, we extracted data closest to 100 nm (used for testing particle filtration efficiency for medical masks, according to ASTM International standards) and 3000 nm (3 μm) (used for testing bioaerosol filtration efficiency for medical masks, according to ASTM International standards). To be conservative, we selected the closest point below the target particle size. Many original articles provided a measure of error variance. We have not included these data in this table for readability. They are often wide, in the 10% to 30% range. We report the SD for Jung et al²¹ because it reflects the differences in properties of a number of distinct masks of different materials (4 surgical, 3 dental, and 5 cotton; tested in triplicate for each design) that are not reported separately, not the error variance of a single mask. We did not extract data for N95 mask material and medical mask material from Konda et al²³ because the methodology used by these investigators for testing fabric were under conditions different than those used for specifying fitted protective equipment such as the N95 respirators, which are tested under higher differential pressures and flows (Supratik Guha, written communication, month year).

^dTSI filter tester generates NaCl aerosol with a count mean diameter of 75 nm and geometric SD of 1.75 nm.

^eCalculated from pitch, the distance between the center of one thread and the next.

^fThis was writing paper and obviously not breathable.

^gThe 600-TPI cotton was used in the hybrid experiments (Supratik Guha, written communication, month year).

TABLE 2. Filtration Efficiency According to Particle Diameter for Homemade 2-Layer T-Shirt and Disposable Commercial Medical . Masks From 21 Volunteers Coughing^a

Particle diameter (µm)	Filtration efficiency, outward		P value ^b
	2-Layer T-shirt mask	Medical mask	
>7	67%	44%	.14
4.7-7	61%	61%	>.99
3.3-4.7	20%	20%	>.99
2.1-3.3	85%	89%	.70
1.1-2.1	84%	94%	.31
0.65-1.1	71%	86%	.24
Total	79%	85%	.62

^aRecalculated from Davies et al.¹⁴ Bacterial filtration efficiency was calculated as (bacterial counts without mask – bacterial counts with mask)/bacterial counts without mask.

^bP values are our calculations, the difference between 2 proportions, using R (R foundation).

terry, have projecting loops of fiber to increase absorbance. The overall heaviness is described by its weight per surface area (g per square metre or gsm). Very high thread counts (>300) are usually obtained by using very thin fiber, and the resulting material may be very fine (light-weight, such as some bed linen).

Surgical gauze, plain woven cotton or linen (such as most dish towels [United States] or tea towels [United Kingdom], ie, flat cloths used for drying dishes), muslin, buttercloth (a cloth used for straining in the manufacture of butter), and some bed linen are plain-weave unnapped cloth. Flannel, commonly used for nightwear and some bed linen, is a plain-weave napped cloth, often of cotton. T-shirt material is usually knitted jersey; the proportion of cotton to man-made fiber and the weight vary. Terry is used for most bath and hand towels.

Commercial disposable masks are made from nonwoven synthetic fibers in bonded layers. These masks are unsystematically called *medical masks*, *face masks*, *surgical masks*, *dental masks*, and *procedure masks*. We use the term *medical masks*.

CAN FABRIC BLOCK COARSE AND FINE PARTICLES?

The increasing effectiveness of multiple layers of cloth to reduce transmission was demonstrated in 1919 in a series of

experiments using controlled sprays and real coughing to create bioaerosols.³⁴ Bacterial counts were used as the surrogate marker. Filtration efficiency increased with thread count and layers and was consistently greater, at any given total thread count, the fewer the layers (eg, 1 layer with a mean thread count of 42 provided greater filtration than 2 layers with a thread count of 22 [total thread count of 44]) (Supplemental Figures 2-4, available online at <http://www.mayoclinicproceedings.org>). At all distances, total thread counts above approximately 300 TPI were associated with greater than 80% filtration efficiency. Other investigators confirmed these observations using similar designs,^{16,19,22,24} one study observing that twill weave cotton was associated with 94% filtration efficiency compared with 98% and 99% for material from 2 medical masks.¹⁶

Filtration efficiencies of 28% to 73% were reported for single layers of bath towel and cotton shirt tested with 2-µm bacterial particles.¹⁸ For linen tea towel fabric, filtration efficiency for bacteria was 83% with 1 layer and 97% with 2 layers compared with medical mask material at 96%.^{14,46} For virus, one layer of tea towel had 72% efficiency, and one layer of T-shirt fabric had 50% efficiency compared with 89% for mask material.¹⁴

Results are dependent on the type of cloth studied. For sodium chloride aerosol, 3 commercially available cloth masks and single layers of scarfs, most sweatshirts, T-shirts, and towels were associated with filtration efficiency of 10% to 40%.²⁹ The cloth from the mask studied in the single randomized controlled trial (RCT) was tested using a TSI filter tester according to Australian and New Zealand standards for respirators.²⁶ Filtration efficiency for the cloth was 3% compared with the medical mask, which tested at 56%. The trial is described in detail subsequently.

Table 1 summarizes studies that use modern methodology Figure to test the filtration efficiency of flat cloth, organized by fabric type, and includes information on medical mask material and respirator material comparators.^{14,16,20,21,23,26,29,35,46} Few of these studies used standardized methodology, and their results are not directly comparable.

Collectively, they reveal that even at low thread counts and layers, and for aerosols, some kinds of cloth block substantial percentages of transmission. Filtration efficacy of greater than 50% has been observed for single layers of high thread count cotton, for linen and cotton tea towels, for some T-shirt materials, some towels, and some man-made materials sold as cloth masks; efficiency increases with layers, and efficiency for virus is of the same order of magnitude as that for bacteria.

An important variable is airflow. In general, other experimental conditions being constant, lower filtration efficiencies would be expected with higher airflows, although this is not consistently observed, perhaps because of random error.^{23,29} Most testing of flat materials aims to simulate breathing through a mask, sometimes at high minute ventilation to simulate exertion.^{14,21,23,35-37} Lower flow rates, as observed in some studies,²³ and flow rates as velocities²⁹ require consideration in interpretation. Peak flow rates of 200 to 1300 L/min and peak velocities of 29 m/s have been observed for human coughs.⁴⁵ None of the experiments that we identified on flat cloth aimed to simulate these conditions.

DOES WEARING A CLOTH MASK PREVENT COARSE AND FINE PARTICLES FROM REACHING THE ENVIRONMENT (OUTWARD PROTECTION OR SOURCE CONTROL)

In a design in which volunteers, talking or coughing, sat at a table on which agar plates were arranged, masks of 3 to 8 layers of buttercloth (TPI ~90) blocked 100% of bacteria at all distances (Figure).¹⁵ Similar results were obtained by others.^{27,47} In another study, a 3-layer, 46 × 46 gauze mask (ie, TPI of 92 in each layer) reduced bacterial counts by 64% compared with no mask in the zone immediately in front of healthy volunteers who were talking.³¹ In a controlled box experiment using volunteers talking, a mask made of a sandwich of thin muslin and 4-oz flannel (136 g/m²) reduced bacteria recovered on sedimentation plates by more than 99% compared with the recovery from unmasked volunteers.¹⁷ Total airborne microorganisms were reduced by more than

TABLE 3. Filtration Efficiency in Inward and Outward Directions for Homemade and Medical Masks, 0.02-1 μm particles^{a,b,c}

Mask	Filtration efficiency		
	Inward		Outward
	Immediate	After 3 h	Immediate
1-Layer tea towel	55%-69%	63%-77%	17%
Medical	76%-81%	74%-83%	58%

^aFrom 28 volunteers (inward, immediate), 22 volunteers (inward, after 3 hours), and data from a manikin wearing a mask (outward).
^bRecalculated from van der Sande et al.³² Filtration efficiency is calculated as 1 - (1/protection factor).
^cBoth adults and children were studied in short term, with somewhat lower performance in children; we extracted the adult data for consistency with the rest of the literature. For each experimental condition, we extracted the highest and lowest median efficiencies from the data provided. Outward data were read from graphs. Because medians were reported, statistical testing was not possible.

99% and bacteria recovered from aerosols (<4 μm) by 88% to 99% compared with those recovered from unmasked volunteers. Another controlled box experiment with talking volunteers compared 4 medical masks and one commercially produced 4-layer cotton muslin (92 TPI⁴⁸) reusable mask.²⁸ Filtration efficiency, assessed by bacterial counts, was 96% to 99% for the commercial disposable masks and 99% for the commercial 4-layer muslin mask. For aerosols (<3.3 μm), filtration efficiencies were 72% to 89% and 89%, respectively.

Using a pattern based on a pleated medical mask, but without assistance, volunteers made 2-layer T-shirt masks with over-the-head elastic.^{14,49} Wearing the mask they had made, volunteers coughed twice into a box; at each particle size, homemade and medical masks were similar, with 71% and 86% efficiency, respectively, at the smallest particle size measured (0.65 to 1 μm) (P=.24; Table 2). We identified one disconfirming report, a study using a PortaCount (0.02 to 1 μm) on a manikin in which the efficiency of a 1-layer tea towel mask in reducing aerosols reaching the environment was 17% (Figure and Table 3).³²

These studies reveal that some multilayered cloth masks can have remarkable filtration efficiency in the outward direction, reducing all particles emitted by the wearer by 64% to 99% and aerosols by 72% to 99%, for some designs comparable with commercial medical masks.

TABLE 4. Summary of Filtration Efficiency for Cloth Masks, Inward Protection (Protecting the Wearer), Assessed at Less Than 1- μ m Particle Size^a

Reference, year	Cloth mask detailed description	Testing	Device, particle size	Details	Cloth mask filtration efficiency		Medical mask filtration efficiency ^b	
					Initial	After the other exercises	Initial	After the other exercises
Dato et al, ¹³ 2006	T-shirt mask made by the authors to fit their own faces; 8-layer high-quality preshrunk cotton T-shirt fabric (Hanes heavyweight T-shirt) with 3 sets of ties	The authors as volunteers	PortaCount, 0.02-1 μ m	Author 1	99%		NA	
				Author 2	92%			
				Author 3	94%			
					Cloth mask		Medical mask	
					Initial		After the other exercises	
Davies et al, ^{14,49} 2013	T-shirt mask made with a pattern by unskilled volunteers without assistance; 2-layer T-shirt fabric, pleated design	Volunteers	PortaCount, 0.02-1 μ m	Normal breathing	50%	50%	83%	80%
				Heavy breathing	50%	NA	86%	NA
				Shaking head	50%	NA	80%	NA
				Nodding	50%	NA	80%	NA
				Bending over	0%	NA	67%	NA
				Talking	50%	NA	83%	NA
				Overall	50%	NA	80%	NA
					flow rate (L/min)		flow rate (L/min)	
					8 19		8 19	
Shakya et al, ³⁰ 2017 ^c	Purchased from street vendor, Kathmandu, Nepal, in 2014; simple cloth rectangles (layers unknown) with ear loop, cloth not specified	Manikin	Particle counter, 30 nm	Cloth mask 2	89%	15%	91%	62%
				Cloth mask 3	54%	26%	NA	NA
				Cloth mask 2	57%	32%	94%	70%
				Cloth mask 3	57%	27%	NA	NA

Continued on next page

TABLE 4. Continued

					Cloth mask		Medical mask	
					flow rate (L/min)		flow rate (L/min)	
					8	19	8	19
			500 nm	Cloth mask 2	47%	57%	92%	65%
				Cloth mask 3	45%	31%	NA	NA
			1 μm	Cloth mask 2	69%	54%	99%	96%
				Cloth mask 3	85%	49%	NA	NA
					Cloth mask		Medical mask	
					Short term	After 3 h	Short term	After 3 h
van der Sande et al, ³² 2008	Cloth mask, homemade, made of TD Cerise Multi tea cloths (tea towel) (Blokker); 1-layer mask	Volunteers	PortaCount, 0.02-1 μm	Sitting quietly	60%	69%	76%	77%
				Nodding	55%	63%	79%	78%
				Shaking head	55%	66%	80%	76%
				Reading	69%	77%	81%	83%
				Walking	58%	66%	76%	74%

^aNA = not available.

^bWhen a medical mask was included as a comparator, we have also provided the data for the medical mask.

^cWe excluded cloth mask 1 because it had an exhalation valve that may have improved its performance. We included the latex particle data because they are comparable with other experiments but not the data obtained with diesel combustion particles (these data are provided in the [Supplemental Table](http://www.mayoclinicproceedings.org), available online at <http://www.mayoclinicproceedings.org>).

DOES WEARING A CLOTH MASK PREVENT INHALATION OF COARSE AND FINE PARTICLES (INWARD PROTECTION OR PERSONAL PROTECTION)?

Table 4 summarizes studies of cloth masks worn by volunteers or on a manikin **Figure**. In one study, the 3 authors made personalized cloth masks from heavy-duty T-shirt material, including 3 sets of ties and 8 layers of material at the front.¹³ Filtration efficiency, measured using a PortaCount (0.02 to 1 μm), was 99%, 92%, and 94% for the 3 individuals tested. (On this test, a respirator performing at 99% or greater would be considered a good fit.)

In a study using healthy volunteers and a PortaCount (0.02 to 1 μm), a 2-layer homemade T-shirt mask provided 50% inward filtration efficiency during a range of activities, compared with 80% to 86% from a medical mask.^{14,49}

In the study by Shakya et al,³⁰ 3 cloth masks and 1 medical mask purchased from street vendors in Kathmandu, Nepal, and 2 N95 masks were tested using a manikin. Test particles were polystyrene latex and diesel combustion particles. Cloth mask 1, which had a conical shape and an exhalation valve, performed as well as the 2 N95 masks: all 3 masks had approximately equal to 80% filtration efficiency for polystyrene latex particles across the range of particle sizes, from 30 nm to 2.5 μm . Cloth masks 2 and 3, simple rectangles with ear loops, had filtration efficiency of 1% to 65% for 30-nm particles and 65% to 75% efficiency for 2.5- μm particles. For diesel particles between 30 and 500 nm in diameter, filtration efficiency was 25% to 85%, 10% to 70%, and 10% to 25% for cloth masks 1, 2, and 3, respectively, and 55% to 85% for the surgical mask.

Similar results, filtration efficiencies of 55% to 77%, tested with aerosols (0.02 to 1.0 μm) were reported for a 1-layer tea towel mask (**Table 3**).³²

In experiments using a manikin to identify leakage around the interface between mask and face, leakage was reduced by taping or by holding material in place with pantyhose.¹²

These studies found that one specific cloth mask performed as well as an N95 in excluding aerosols from the wearer,³⁰ that complex,

multilayer homemade masks can perform above 90%,¹³ and that simple 1-layer masks can perform similarly to medical masks.³² The poorest-performing masks had some inward filtration efficacy for aerosols.

DOES WEARING A CLOTH MASK PREVENT DISEASE IN ANIMAL EXPERIMENTS?

In rabbits exposed to aerosolized tubercle bacilli, tightly fitting 3- or 6-layer, 40 \times 44 (84 TPI) gauze masks reduced the number of tubercles per rabbit from 28.5 in unmasked and 1.4 in masked rabbits, representing filtration efficacy of 95% ($P=.003$, our calculations).²⁵ This controlled animal experiment reveals significant reduction in aerosol transmission of tuberculosis, usually considered an airborne organism, by multilayered cloth masks.

HAVE RCTS BEEN CONDUCTED ON THE EFFECTIVENESS OF CLOTH MASKS IN ANY SETTING?

We identified a single RCT that compared continuous wear of a cloth mask with continuous and with as-needed wear of medical masks.²⁶ The cloth masks used were tested on an industry-standard TSI device according to the standards used for N95-type mask material and were found to be unusually inefficient at 3%. Although data are not exactly comparable between studies, the observed filtration efficiency of 3% for this particular cloth mask material is the lowest for commercial cloth mask that we identified in any study (**Table 1**).^{16,20,26,29} The medical mask comparator, assessed at 56% filtration efficiency (as flat material), performed substantially better.²⁶ Unsurprisingly given these properties, continuous cloth mask use, compared with continuous medical mask use, was associated with increased incidence of influenzalike illness (relative risk [RR], 13.3; 95% CI, 1.74 to 101). Participants in this study were health care workers on high-risk medical wards. The comparator groups were continuous medical mask use and medical mask use where indicated by the patient's isolation status. The use of a cloth mask continuously meant that health care workers caring for patients requiring

respiratory isolation wore a cloth mask in this context instead of a medical mask. This study has been widely discussed in the press and has not always been accurately represented. One report summarizes it as “actually increased the rate of infections among health care workers compared to those who wore surgical masks,” which could be interpreted as cloth masks actually causing harm.⁵⁰ A 2015 article on this study carries the title, “Cloth Masks: Dangerous to Your Health?” and refers to “harm caused by cloth masks.”⁵¹ The study leaves us unable to draw conclusions about the efficacy or harms of wearing a cloth mask, compared with no mask, because there is no “no mask” comparison group. What we can infer from this study, however, is that in a health care setting, a device with 56% filtration efficiency prevents clinical illness compared with one with 3% filtration efficiency.

There is absence of evidence, then, rather than evidence of absence or evidence of harm, on whether cloth masks prevent transmission of clinical illness.

DOES WEARING A MEDICAL MASK IN A COMMUNITY CONTEXT PROTECT ONESELF OR OTHERS?

On April 9, 2020, Greenhalgh et al⁵² identified 5 peer-reviewed systematic reviews on public mask wearing to prevent transmission of a wide range of respiratory pathogens and summarized them as absence of evidence; citing the precautionary principle, the authors advocated for public mask wearing. Using the framework of evidence-based medicine and the concept of risk-based decision making under uncertainty (ie, the absence of clear clinical evidence of benefit), we supported this position.⁵³ Subsequently, in a meta-analysis of observational studies of risk of infection from the coronaviruses SARS-CoV-1, Middle East respiratory syndrome, and SARS-CoV-2, use of masks (respirators, medical masks, or 12- to 16-layer cloth masks) compared with no mask was protective in both health care settings (RR, 0.30; 95% CI, 0.22 to 0.41; $I^2 = 50%$) and non-health care settings (RR, 0.56; 95% CI, 0.40 to 0.79; $I^2 = 48%$).⁵⁴

DOES WEARING A CLOTH MASK IN A COMMUNITY CONTEXT PROTECT ONESELF OR OTHERS?

The meta-analysis by Chu et al⁵⁴ identified 3 observational studies of mask use in the community. The primary studies, reports of SARS-CoV-1 transmission in Hong Kong, Beijing, and Vietnam, did not identify the mask type used.⁵⁵⁻⁵⁷ One of these reports included only 9 participants wearing masks.⁵⁵ In another of these reports, the odds ratio for infection associated with visiting an infected individual while wearing a mask compared with not visiting the infected individual was 1.8 (95% CI, 0.8 to 4.0) for one person wearing a mask, 1.9 (95% CI, 0.9 to 4.0) for both persons wearing a mask, and 4.2 (95% CI, 2.4 to 7.3) for neither wearing a mask.⁵⁶ The third study reported an odds ratio for infection of 0.5 (95% CI, 0.2 to 0.9) for sometimes wearing a mask when going out and 0.3 (95% CI, 0.2 to 0.5) for always wearing a mask when going out compared with the referent of never wearing a mask when going out.⁵⁷

The meta-analysis and detailed review of the primary studies advance our understanding from “absence of evidence” to the point where we have somewhat consistent observational evidence of a protective effect from mask wearing in the community, with a large effect size. It is plausible that masks protect people, and there is coherence between the data on community mask wearing and mask wearing in health care settings.⁵⁸ However, the evidence is somewhat indirect: SARS-CoV-1 transmission may differ from SARS-CoV-2. Randomized controlled trials have not been conducted.

Symptomatic people should follow public health guidance and self-isolate. The point of community mask wearing is to prevent presymptomatic and asymptomatic transmission. Although asymptomatic transmission undoubtedly occurs,⁵⁹⁻⁶² the proportion of transmission that occurs from asymptomatic individuals is the subject of controversy.^{63,64} However, evidence from transmission pairs suggests that in individuals who will eventually develop symptoms, peak infectivity may occur before the onset of symptoms and that the highest levels of

viral shedding may occur 2 to 3 days before the appearance of symptoms and 1 day after.⁶⁵ Data on viral load in the days after symptom onset are congruent with this hypothesis,⁶⁶ and presymptomatic transmission has been documented.^{62,67} Modeling studies reveal that face mask use depresses the effective basic reproductive rate over a range of plausible values for mask use and cloth mask effectiveness and that in conjunction with periods of lockdown, even 50% adherence to a 50%-effective cloth mask dramatically alters the total number of individuals affected.⁶⁸

WHAT MATERIALS AND DESIGNS SHOULD BE USED? AN EVIDENCE-INFORMED CLOTH MASK

A pleated mask design based on the common pleated design for ASTM International level 1 masks results in a mask with subjectively good fit that is relatively simple to make. Paper fasteners, florists' or electricians' wire, or pipe cleaners can be inserted across the top to improve fit at the nose. Although data are not available that conform with any modern standard method, from the studies available, cotton, muslin (a type of unfinished cotton), and flannel are the best supported and are our suggestions for an evidence-informed cloth mask. Successful masks have used muslin at a TPI of approximately 100 in 3 to 4 layers (4-layer muslin²⁸ or a muslin-flannel-muslin sandwich¹⁷), tea towels (also known as dish towels)—studied as 1 layer³² and 2 layers expected to be better^{12,14,15,18-24,27,34}—and good-quality cotton T-shirts in 2 layers^{14,46,49}; in flat cloth experiments, linen tea towel in 2 layers^{14,46} cotton 600 TPI in 2 layers²³ or cotton 600 TPI with flannel 90 TPI²³ performed well. (Two-layer cotton 80 TPI did not perform well.²³) Multiple layers should be used, at least 2 and preferably 3 or 4. With fabric that stretches, such as T-shirt fabric, it may be important to use a design with edge stitching to prevent transmission of tension to the cloth, which will increase the size of gaps in the material and affect filtration. There is a trade-off with increased layers: they provide increased filtration efficiency

but also increase the resistance to breathing, which increases the work of breathing and may lead to discomfort and even to reduced adherence. Increased resistance with increased layers also leads to increased edge leak, decreasing the efficiency of the mask. People making masks for sale should specify the materials (composition, weave, weight, thread count) for each layer and the number of layers (eg, cotton 100%, plain weave, 150 g/m², 150 TPI; 3 layers). People making their own masks or choosing a mask should consider these same factors and also their planned activities while wearing a mask. It might be sensible, for example, to choose a higher number of layers for quietly sitting at a desk in a shared workspace for the duration of a working day than for grocery shopping in a ventilated environment with physical distancing. Based on expert opinion, the WHO guidance published June 5, 2020,⁹ recommends a 3-layer mask, the outer layer and middle layers hydrophobic (eg, polypropylene, polyester, and their blends) and the inner layer hydrophilic (eg, cotton or cotton blends).

Our previously mentioned recommendations for materials are the same if using a bandana or scarf-type design, although we would anticipate that it would be less efficient. Optimally, this mask will include a prefolded shape and a clear differentiation of outside and inside, such as the multilayered suggestion demonstrated on YouTube.⁶⁹ Evidence on household filters is limited. The one study of tissue paper and paper towel masks did not report high efficiencies³⁵; we believe that a third or fourth layer of cloth is preferable to a disposable filter. Information on materials, designs, and correct use intended for the general public and for mask manufacturers can be found at clothmasks.ca. We will update this site as new information is published.

WHAT ARE THE RESEARCH PRIORITIES? AN EVIDENCE-BASED CLOTH MASK

Reproducibly described cloth and cloth masks should be tested in aerosol laboratories. The effects of activity, time, and moisture^{18,24} on effectiveness should be studied. The trade-

off with higher thread counts and additional layers between increased protection on the one hand and decreased tolerability and increased leak on the other should be explicitly explored.⁷⁰ Women, children, people with facial hair, people who wear turbans or hijabs, people who are deaf and people who wear glasses require special consideration. Optimal methods of laundering (home and industrial) and the effect of laundering on mask properties should be studied.

Human trials should focus on best-performing cloth masks, should include health care workers, other essential workers, and clients of essential services who can tolerate mask wearing, and should study both inward and outward protection. Considerations are multifaceted—educational interventions, measures of unintended consequences (eg, incorrect mask use, complacency about physical distancing and hand hygiene, mitigation of effects on people who do not hear well), and the impact of adherence on outcomes.

If reproducible designs of cloth masks that meet ASTM International standards can be identified, it will have direct and immediate impact in low- and middle-income countries. Widespread adoption in any setting, including high-income countries, of reusable evidence-based cloth masks that meet the standards of PPE would reduce the environmental impact of PPE and mitigate supply problems in this and future pandemics.

Standards for cloth masks have been developed by the French standardization association Association Française de Normalisation (AFNOR): testing flat cloth using 3- μ m particles, 70% to less than 90% filtration efficiency is designated as category 2 (for use by the general public in a group of mask wearers), and 90% to less than 95% is designated as category 1 (for use by non—health care professionals in contact with the public, eg, police).⁷¹⁻⁷³ At the time of this writing, a database of more than 1200 tested mask material combinations (many of them including nonwoven synthetic materials such spunbond and meltbond that are used in formal PPE) has been compiled.^{73,74}

Businesses and academics in textiles, design, and fashion are critical in embracing

evolving information on evidence-informed and evidence-based masks and in using their specific knowledge and skills to create a variety of masks that are not only functional but comfortable and stylish to maximize the acceptability of mask wearing, particularly for young people.

CONCLUSION

Cloth masks can offer substantial filtration, in some cases equivalent to some medical masks. This knowledge can be used to create evidence-informed cloth masks to mitigate transmissibility of viruses such as COVID-19. Aerosol laboratory testing of these masks may lead to the design of evidence-based cloth masks, reproducibly described so as to be manufactured in diverse settings. Currently, no direct data with clinically important outcomes are available.

Advocating for the public to wear cloth masks shifts the cost of a public health intervention from society to the individual. In low-resource areas and for people living in poverty, this burden may be unacceptable and could be mitigated by public health interventions with local manufacture and distribution of evidence-informed and evidence-based cloth masks.

ACKNOWLEDGMENTS

This work was created, in part, on the traditional territory shared between the Haudenosaunee confederacy and the Anishinaabe nations, which was acknowledged in the Dish With One Spoon wampum belt.

We thank Melanie Chiarot, librarian, for her assistance in retrieving articles during a holiday period and Robinson Healthcare Limited in the United Kingdom, who volunteered details of materials and methods for and photographs of the commercial 4-layer muslin mask. We thank the authors who responded promptly for additional details of their studies and the editors and anonymous reviewers whose suggestions greatly improved this work. We thank Dr Zain Chagla, infectious diseases consultant, McMaster University, for his peer review of the cloth-masks.ca website. We dedicate this article

to Esta H. McNett and Charlotte Johnson, nurses who made important contributions to the field of mask design but who were not acknowledged as authors in the manuscripts that included descriptions of their work. We recognize the animals that suffered and died.

Author contributions: The concept for the manuscript originated with Drs Clase, Jardine, Mann, Pecoits-Filho, Winkelmayr, and Carrero. Dr Clase and Mr Fu performed the original literature review, and Dr Clase wrote the first draft. Mr Fu, Mr Ashur, Ms Clase, Dr Kansime, and Dr Joseph reviewed citations and performed data extraction. Dr Carrero and Mr Fu collated discrepancies and, with Dr Clase, resolved them by consensus. Mr Fu performed statistical analysis on reported data and created graphs and tables. Prof Dolovich provided input on aerosol science and Dr Beale on virology and relevance to COVID-19. All authors contributed references and important revisions of content and meaning. Dr Clase is the guarantor for the work.

SUPPLEMENTAL ONLINE MATERIAL

Supplemental material can be found online at <http://www.mayoclinicproceedings.org>. Supplemental material attached to journal articles has not been edited, and the authors take responsibility for the accuracy of all data.

Abbreviations and Acronyms: COVID-19 = coronavirus disease 2019; PPE = personal protective equipment; RCT = randomized controlled trial; RR = relative risk; SARS-CoV-2 = severe acute respiratory syndrome coronavirus 2; TPI = threads per inch, the sum of the warp plus weft thread count per inch; WHO = World Health Organization

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Potential Competing Interests: Dr Clase has received consultancy fees from Amgen Inc, Astellas Pharma Inc, Baxter, Boehringer Ingelheim International GmbH, Janssen Pharmaceuticals, Inc, Johnson & Johnson Services, Inc, LEO Pharma Inc, and Pfizer Inc and speaker honoraria from Sanofi. Dr Jardine is responsible for research projects that have received unrestricted funding from Gambro, Baxter, CSL Limited, Amgen, Eli Lilly and Company, and Merck Sharp & Dohme Corp; has served on advisory boards sponsored by Akebia Therapeutics, Inc, AstraZeneca, Baxter, Boehringer Ingelheim International GmbH, and Vifor Pharma Management Ltd; serves on steering committees for trials sponsored by Janssen and CSL; and has spoken at scientific meetings sponsored by Janssen Pharmaceuticals, Inc, Amgen, F. Hoffmann-La Roche Ltd, and Vifor Pharma Management Ltd. (all funds paid to her institution). Dr Mann has received speaker honoraria from AstraZeneca, Bayer AG, Boehringer Ingelheim International GmbH, Fresenius Medical Care, MEDICE, Novartis Pharmaceuticals Corporation, Novo Nordisk A/S, and Roche Ltd; has received research support from Celgene Corporation, Novo Nordisk A/S, Roche Ltd, and Sandoz International GmbH; and has been a consultant for AstraZeneca, Bayer AG, Boehringer Ingelheim International GmbH, Celgene Corporation, and Novo Nordisk A/S. Dr Pecoits-Filho has received consultancy fees from Akebia Therapeutics, Inc, AstraZeneca, Fresenius Medical Care, and Novo Nordisk A/S; has received speaker honoraria from AstraZeneca and Novo Nordisk A/S; and has received research support from Fresenius Medical Care. Dr Winkelmayr has received consultancy fees from Akebia Therapeutics, Inc, Amgen Inc, AstraZeneca, Bayer AG, Daichi-Sankyo Company, Limited, Janssen Pharmaceuticals, Inc, Merck & Co, Inc, Relypsa Inc, Vifor Pharma Management Ltd, and Fresenius Medical Care Renal Pharma and speaker honoraria from FibroGen, Inc. Dr Carrero has received consultancy fees from AstraZeneca and Baxter; has received speaker honoraria from AstraZeneca and Vifor Pharma Management Ltd; and has received research support from the AstraZeneca, Vifor Pharma Management Ltd., and Astellas Pharma Inc. The other authors report no competing interests.

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