Environmental Science and Pollution Research (2022) 29:1645–1676
https://doi.org/10.1007/s11356-021-16847-2

REVIEW ARTICLE

Assessment of cloth masks ability to limit Covid-19 particles spread: a systematic review

Mahshid Ataei[1,2] · Farshad M. Shirazi[3] · Samaneh Nakhaee[1] · Mohammad Abdollahi[2] · Omid Mehrpour[1,4]

Received: 14 April 2021 / Accepted: 28 September 2021 / Published online: 23 October 2021

Abstract
After the spread of Covid 19 worldwide, the use of cloth masks increased significantly due to a shortage of medical masks. Meanwhile, there were different opinions about the effectiveness of these masks and, so far, no study has been done to find the best fabric masks. This study reviews and summarizes all studies related to fabric masks' effectiveness and various fabrics against coronavirus. This systematic review is based on PRISMA rules. Two researchers separately examined three databases: PubMed, Scopus, and Web of Science. Laboratory and clinical studies were included. After extracting the articles, their quality was assessed with the Joanna Briggs Institute (JBI) tool. In addition to efficacy, other factors, including the penetration of masks, pressure drop, and quality factor, were examined to select the best fabrics. Of the 42 studies selected, 39 were laboratory studies, and 3 were clinical studies. Among the various fabrics examined, cotton quilt 120 thread per inch (TPI), copy paper (bonded), hybrid of cotton with chiffon/ silk, and flannel filtration were found to have over 90% effectiveness in the particle size range of Covid-19. The results and comparison of different factors (pressure drop, filtration efficacy, penetration, filtration quality, and fit factor have been evaluated) showed that among different fabrics, hybrid masks, 2-layered cotton quilt, 2-layered 100% cotton, cotton flannel, and hairy tea towel + fleece sweater had the best performance. Clinical studies have not explicitly examined cloth masks' effectiveness in Covid-19, so the effectiveness of these types of masks for Covid 19 is questionable, and more studies are needed.

Keywords Mask · Covid-19 · Prevention

Introduction

In early December 2019, in Wuhan's city in Hubei province, China, many people caught pneumonia. After a while, the cause of this cluster of diseases became known, which was a novel virus from the coronavirus's family. Later, the disease was named Covid-19, caused by the SARS-Cov 2 virus (Chinazzi et al. 2020). This new coronavirus had a 79% sequence similarity to SARS-Cov, which caused a significant outbreak in 2002–2003 (Lake 2020). It did not take long that Covid-19 disease became a pandemic and a global concern that killed more than 1.3 million people up to November 2020, and in most countries, the rate of Covid-19 confirmed cases was rapidly growing, according to World Health Organization (WHO) (Anonymous). Because the SARS-Cov 2 virus is so contagious and due to the lockdown removal, everyone needs to take various preventive measures, including washing their hands regularly, using various protective equipment like gloves, gowns, masks, observing social distance,

Responsible Editor: Lotfi Aleya

Omid Mehrpour
omid.mehrpour@yahoo.com.au

1 Medical Toxicology and Drug Abuse Research Center (MTDRC), Birjand University of Medical Sciences (BUMS), Birjand, Iran

2 Toxicology and Diseases Group, Pharmaceutical Sciences Research Center (PSRC), The Institute of Pharmaceutical Sciences (TIPS), and Department of Toxicology and Pharmacology, Faculty of Pharmacy, Tehran University of Medical Sciences (TUMS), Tehran, Iran

3 Arizona Poison & Drug Information Center, University of Arizona, College of Pharmacy and University of Arizona College of Medicine, Tucson, AZ, USA

4 Mel and Enid Zuckerman College of Public Health, University of Arizona, Tucson, AZ, USA

quarantining infected and suspected people to Covid-19 disease (Santos et al. 2020; Sunjaya and Morawska 2020). One type of mask is cloth masks, which are made of different materials and designs. These different materials and designs affect the mask's filtration efficacy (FE) (Howard et al. 2020). There are different types of fabric masks, of which we can mention knitted (interlocking fiber loops), woven (crossing threads are known as warp and weave), or felted (compressed, disorganized fibers). Fabric masks can partially block the transmission of respiratory droplets from people who wear them compared to those who do not wear masks. This blocking effect increases by increasing the number of fabric layers (Clase et al. 2020). Only some fabric masks and reusable respirators can be disinfected and reused among different masks without changing the filtration effectiveness (Bhattacharjee et al. 2020). Wearing cloth masks will significantly affect disease control because it can significantly control asymptomatic patients who move freely and speaking, sneezing, or cough. Viral shedding of patients with Covid-19 is higher in the time of symptom onset and before the symptom onset (Santos et al. 2020). Wiersinga et al. showed that asymptomatic carriers transmit the virus to others at a rate of 48–62% (Wiersinga et al. 2020). Therefore, cloth masks will have an advantageous effect in reducing disease transmission, especially from asymptomatic carriers. According to this, two strategies are suggested:

1) Health care practitioners)HCPs(: For Health care workers, WHO recommended that they should use medical masks and respirators (Organization 2020a, b). Macintyre's research also showed that the HCPs Chughtai AA, Seale H, Macintyre CRwho used cloth masks had a higher risk of getting influenza-like illness than those who used medical masks (MacIntyre et al. 2015b).
2) General population: To maintain medical masks and respirators for the HCPs, the CDC recommends using cloth masks for general use that are very economical and accessible (Sunjaya and Morawska 2020). WHO was initially against the use of cloth masks, so that on 19 March, WHO claimed that "Cloth (e.g., cotton or gauze) masks are not recommended under any circumstances" but, later changed its mind and on 5 June, WHO advised decision-makers to recommend all people wear masks (Clase et al. 2020). Many countries recommended the use of cloth masks for the general population based on their low price, availability, and at the same time, effectiveness. On the other hand, due to the lack of medical masks and respirators, these masks are better kept for the HCPs (Godoy et al. 2020).

Despite the extensive use of cloth masks, few studies conducted a review on their virus-blocking efficacy and summarized such studies. In the present study, we aimed to compare these masks with each other via reviewing all studies related to fabric masks' effectiveness for Covid-19.

Methodology

This systematic review follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) instructions (Moher et al. 2015). The PECO research strategy (Scells et al. 2017) was used in this study containing the following information: P = droplet and/or aerosol dispersion contamination;

E = homemade and/or commercial cloth masks; C = different cloth masks materials.

Outcome = cloth masks efficiency in reducing the transmission of contaminated droplets and aerosols through laboratory and clinical tests. We used medical subject heading (MESH) terms and combined the keywords in the title and abstract (cloth mask, fabric mask, textile mask, homemade mask, cotton mask, Covid-19, SARA-Cov-2, n-Cov-2019) while searching the main international databases, including PubMed, Scopus, Web of Science. Two researchers searched the databases mentioned above up to 5 January 2021 independently. Examples of PubMed search queries using MeSH Terms and the free-text words were as follows:

(((homemade mask*[Title/Abstract]) OR (textile mask*[Title/Abstract]) OR (((cloth mask*[Title/Abstract]) OR (fabric mask*[Title/Abstract])cotton mask*[Title/Abstract]) OR (gauze mask*[Title/Abstract])) AND ((Covid-19[Title/Abstract]) OR (COVID-19[Title/Abstract]) OR(cloth mask[MeSH Terms]) OR (fabric mask[MeSH Terms]) OR (textile mask[MeSH Terms]) OR (homemade mask[MeSH Terms]) OR (cotton mask[MeSH Terms]) OR (gauze mask[MeSH Terms]) OR (Covid 19[Title/Abstract]) OR (SARS-CoV-2[Title/Abstract]) OR (SARS-Cov-2[Title/Abstract]) OR (severe acute respiratory syndrome coronavirus 2[Title/Abstract]) OR (ncov[Title/Abstract]) OR (2019-nCoV[Title/Abstract]) OR (COVID 19[Title/Abstract]) OR (COVID-19 Virus[Title/Abstract]) OR (Coronavirus Disease 2019[Title/Abstract]) OR (SARS Coronavirus 2[Title/Abstract]OR (Coronavirus Disease-19[Title/Abstract]), OR (2019 Novel Coronavirus[Title/Abstract])))

Eligibility and selection criteria

Two authors extracted all experimental and clinical studies that met our search criteria. Additionally, the reference list of the articles included was investigated manually. No restriction was performed on the year and language of our search. After the search was completed, we removed the duplicates and screened the remaining articles. Articles that did not meet our inclusion criteria were removed from the list of references during the reading of the title, abstract and full texts. The outcomes of interest were cloth masks, filtration efficiency, penetration, pressure drop, and quality factor. Studies that refer to one or more of the above outcomes are included in our study. The inclusion criteria did not include any editorials, reviews and meta-analyses, reports and conference papers, and articles with insufficient data.

Data extraction

Data are summarized in the table (Table 1) based on a predefined checklist. The author's name, date, and place of the study, study type, sample size, identity and size of the particles, air flow rate or velocity, mask type, primary results, and risk of bias were extracted and summarized. All procedures of literature search, study selection, and data extraction were performed separately by two researchers. Any disagreement in the selection of articles has been resolved through discussion and consensus.

Quality assessment

The checklist evaluated all laboratory-based quasi-experimental studies (non-randomized experimental studies). For clinical trials, the checklist of randomized control trials (RCTs) from the Joanna Briggs Institute (JBI) was used (Tufanaru et al. 2017). The evaluated criteria were divided into nine areas for experimental studies and thirteen areas for clinical trials, categorized with "yes," "no," "unclear," or "not applicable." The checklists were analyzed for each study and classified by two authors as low, moderate, or high risk of bias. This final classification was assigned to the number of areas where "no" or "not applicable" were given as an answer. Thus, one or two domains were considered low risk in the experiment, three or four as moderate risk, and five or more as high risk of bias (Santos et al. 2020). In RCTs, one or two domains were included, while three or four were excluded, and five or more needed more information.

Results

Study selection

A total of 1163 records were primarily identified in the three electronic databases searched: PubMed, Web of Science, and two records from the reference list of other studies (Fig. 1). After the endnote manager removed 381 duplicates, 718 titles and abstracts were examined. Seventy records that satisfied the inclusion/exclusion criteria were retained for full-text assessment. Finally, forty-four articles have been selected and included in the qualitative synthesis of this systematic review. The summaries of the qualitative and quantitative data are shown in Table 1, respectively.

Study characteristics

The 44 final studies included in this systematic review consisted of three randomized control trials (RCTs) and 41 laboratory studies. The sample size, including different cloth mask models, was between 1 and 48. In three RCTs, the sample size was the number of people who participated in the trial, between 211 and 569. More than half of the studies ($n=21$) researched cloth materials, and the other half investigated commercial cloth masks. In these experiments, sodium chloride (NaCl) particles used more than all particles to examine different masks. Seventeen studies used NaCl particles in a size range of 0.009–10 µm, the flow rate was between 0.1–85 $L.min^{-1}$, and the velocity was in the range of 5.3–1650 $cm.s^{-1}$ (Bowen 2010; Clapp et al. 2020; Drewnick et al. 2021; Hao et al. 2020; Joshi et al. 2020; Konda et al. 2020a; Liu et al. 2019; Long et al. 2020; Mueller et al. 2020; O'Kelly et al. 2020; Park and Jayaraman 2020; Pei et al. 2020; Rengasamy et al. 2010; Varallyay et al. 2020; Wang et al. 2020; Zangmeister et al. 2020; Zhao et al. 2020; Guha et al. 2021). In addition to sodium chloride, three studies used another particle. One of them used 0.101 µm polystyrene latex (PSL) particles with a velocity of 10 $cm.s^{-1}$ (Lu et al. 2020). In the other one, paraffin oil aerosols were utilized with the 0.225 µm count median diameter (Jung et al. 2013). The third one used KCL + sodium fluorescein with 0–7 µm particle size range and 28.3 L/min flow rate (Lindsley et al. 2021). Nine studies used different particles that ranged in the size of 0.001–10 µm; the flow rate was between 0.9–300 $L.min^{-1}$ (Aydin et al. 2020; Chen et al. 2013; Cherrie et al. 2018; Lustig et al. 2020; Maher et al. 2020; Neupane et al. 2019; Pacitto et al. 2019; Shakya et al. 2017; Xiao et al. 2020). One study reported a velocity of 44.4 $m. s^{-1}$ (Xiao et al. 2020), and another study reported the velocity of 17.1 $m. s^{-1}$ (Aydin et al. 2020). Five studies used virus and bacteria particles to measure the efficiency of masks (Davies et al. 2013; Ma et al. 2020; Rodriguez-Palacios et al. 2020; Ueki et al. 2020; Whiley et al. 2020). These particle sizes ranged from 0.023–1000 µm. In one study, the flow rate was 30 $L.min^{-1}$ (Davies et al. 2013). Four other studies did not mention the flow rate or velocity (Ma et al. 2020; Rodriguez-Palacios et al. 2020; Ueki et al. 2020; Whiley et al. 2020). Three studies designed the experiment with respiratory particles produced by breathing, coughing, and talking that ranged from 0.01 to 20 µm and the flow rate was in the range of 5–80 $L.min^{-1}$(Asadi et al. 2020; Li et al. 2020b; van der Sande et al. 2008). Except for three studies that used human subjects (Asadi et al. 2020; Clapp et al. 2020; van der Sande

Table 1 Characteristics of included studies to investigate the relationship between cloth mask materials and their FE and pressure drop

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Maher et al. 2020)	USA	Experimental	12	1 µm Di-Ethyl-Hexyl-Sebacat (DEHS)	Flow rate 300 L/min		Masks of one, two, and three layers of cotton shower curtain vacuum bag coffee filter non-woven fabric	Average $FE_{1\ \mu m}$ was between 74.4–95.2% By increasing the layers, FE increased	Moderate
(Xiao et al. 2020)	Japan	Experimental	11	8.2 µm Starch micro-droplets 0.75 µm Latex microspheres		Velocity 4440 cm/s	6 layers cotton gauze masks Cotton T-shirts silk linen tissue paper cotton gauze	Average $FE_{0.75\ \mu m}$ was between 53.2–93.8% Average $FE_{8.2\ \mu m}$ was between 36.7–90.4% By increasing the layers, FE increased	Low
(O'Kelly et al. 2020)	UK	Experimental	31	0.02–0.1 µm NaCl		Velocity 1650 cm/s	Disposable and Washable HEPA Vacuum Bags Jeans Denim Thick felted wool Windbreaker Cotton, Heavyweight Woven 100% cotton, 100% polyester mix	Average $FE_{0.02–0.1\ \mu m}$ was between 10–62% By increasing the layers, FE increased	Moderate
(Lu et al. 2020)	China	Experimental	4	0.101 µm PSL 0.042 µm NaCl		Velocity 10 cm/s	-	Average $FE_{0.1\ \mu m}$ was between 22.9–88.3% By Increasing the filter weight, its efficacy increases Cloth masks washing have little effect on their FE	Low

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Drewnick et al. 2021)	Germany	Experimental	48	0.03, 0.05, 0.1, 0.25, 0.5, 1, 2.5, 5, and 10 μm NaCl		Velocity 5.3 cm/s 12.9 cm/s	100% cotton mixed cotton synthetic cloths PU foams triangle bandage paper towels coffee filter	FE_{min} was observed for particles between 0.05- 0.5 μm. The efficiency was higher for particles above 2.5 μm With increasing face velocity, the FE decreased for ≤ 250 nm particles and increased for ≥ 2.5 μm particles	Low
(Konda et al. 2020a)	USA	Experimental	15	0.01–10 μm NaCl	Flow rate 35 and 90 L/min		Cotton 80 & 600 TPI Chiffon Natural silk hybrids	Average $FE_{<0.3\,\mu m}$ was between 9–97% Average $FE_{>0.3\,\mu m}$ was between 12–99.5% Materials with an electrostatic charge have a better effect on smaller particles By increasing the TPI of the materials FE increase	Moderate

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Pei et al. 2020)	USA-China	Experimental	10	0.03–1 μm NaCl		Velocity 10.5 cm/s	vacuum bag common household materials	Electrically charged fabrics are recommended because they are highly effective and, at the same time, have good breathability By increasing the layers, FE increased A coffee filter is not recommended according to its low FE	Moderate
(Jung et al. 2013)	Korea	Experimental	3	CMD≈ 0.078 μm NaCl CMD≈ 0.225 μm paraffin oil aerosols	-		handkerchiefs	handkerchiefs have no protection against aerosols	Low

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Shakya et al. 2017)	USA	Experimental	3	PSL 0.03, 0.1, 0.5, 1, 2.5 µm	Flow rate 19, 8 L/min		-	The fabric mask with exhaust valve had the best FE The FE against standard particle sizes of 0.03, 0.1, 0.5, 1, and 2.5 µm was between 39–65% These masks did not provide adequate protection against diesel combustion (poly disperse) particles The FE for diesel combustion particles were between 15–57% for 0.03, 0.1, and 0.5 µm	Moderate
(Hao et al. 2020)	USA	Experimental	13	NaCl 0.3- 1 µm		Velocity 23.2, 15.3, 9.2 cm/s	Scarf Bandana pillowcases with different TPIs	These fabrics with different TPIs did not have good FE and did not have good breathability	Moderate
(Zangmeister et al. 2020)	USA	Experimental	41	NaCl 0.05-0.825 µm		Velocity 6.3 cm/s	pieces of cotton wool synthetics synthetic blends synthetic and cotton blends paper fabrics polypropylene-based fiber	Fabrics with the best FE, moderate TPI, and visible raised fibers particle charge have no effect on FE	Low

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Park and Jayaraman 2020)	USA	Experimental	9	NaCl 0.017-0.982 µm		Velocity 8.7 cm/s	Polyester Polypropylene nylon	Average $FE_{0.3\ \mu m}$ was between 9–88% The presence of a filter between the two layers increases the FE A filter with a pile on both sides is more effective than a filter with a one-way pile Increasing layers increases the FE	Moderate
(Zhao et al. 2020)	USA	Experimental	10	0.022–0.259 µm NaCl CMD≈ 0.075 µm NaCl	Flow rate 32 L/min		cotton polyester nylon silk	As quality does not change with multilayers, cotton, polyester, and polypropylene multi-layered structures can have an FE equal to or greater than medical masks	Moderate

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Teesing et al. 2020)	Netherlands	Experimental	10	0.3, 0.5, 1.0 and 5.0 µm particles	Flow rate 28.31 L/min		Cleaning cloth between quilt fabric Two layers of coffee filter between quilt fabric Felt between quilt fabric Leather Microfiber fabric One layer of Household paper towel between quilt fabric Two layers of Household paper towel between quilt fabric Quilt fabric (2,4,6 layers) Static dust cloth between quilt fabric Tea towel (1,2 layer)	Leather performed the best, and after that, a folded coffee filter or household paper towel between quilt fabric and microfiber fabric. Maximum efficacy is for microfiber material, and minimum efficacy is for tea towel material The average $FE_{0.3\ \mu m}$ was between 5 and 100% The average $FE_{0.5\ \mu m}$ was between 13 and 100% The average $FE_{1\ \mu m}$ was between 14 and 100% Average $FE_{3\ \mu m}$ was between 35 and 99% The average $FE_{5\ \mu m}$ was between 36 and 99%	Moderate
(Long et al. 2020)	USA	Experimental	9	Median diameter = NaCl 0.04 µm	Flow rate 25 L/min		Vacuum bag Cotton Paper towel	The average $FE_{0.04\ \mu m}$ was between 35 and 53%	Low

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Aydin et al. 2020)	USA	Experimental	14	100–1000 μm distilled water with 100 nm-diameter fluorescent nanoparticles (beads) act as covid-19 viruses		Face velocity 1710 cm/s	100% cotton Knitted and woven 100% polyester Cotton/polyester silk	Breathability increases strongly by fabrics porosity knit fabrics have lower FE than woven fabrics Even one layer of these fabrics has a high FE against high-velocity droplets Increasing the number of layers can increase the effectiveness of these masks	Low
(Mueller et al. 2020)	USA	Experimental	16	CMD≈ 0.009 μm CMD≈ 0.04 μm NaCl	Flow rate 0.1 L/min		Cotton quilt Cotton plain Cotton duck Cotton twill Cotton muslin Pellon Melt blown filter (BFE85) Woven nylon Massage table covering	The average $FE_{0.04\ \mu m}$ was between 28.2 and 90.7% Nylon overlayer increased the efficacy to 7% more in surgical-type masks and had the least effect on cone-shaped ones	Moderate
(Whiley et al. 2020)	Australia	Experimental	8	MS2 aerosols 6 & 2.6 μm	-		100% cotton 100% Mulberry Silk Vacuum cleaner bag	The average $FE_{6\ \mu m}$ was at least 50% The average $FE_{2.6\ \mu m}$ was 63%	Moderate
(Davies et al. 2013)	UK	Experimental	10	MS2 0.023 μm Bacillus atrophaeus 0.95–1.25 μm	Flow rate 30 L/min		100% cotton T-shirt Silk Linen Vacuum cleaner bag	The average $FE_{0.95–1.25\ \mu m}$ was at least 58- 96.35% The average $FE_{0.023\ \mu m}$ was 48.87–89.52%	Moderate

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Li et al. 2020b)	USA	Experimental	2	0.01–1 µm coughing particles	Flow rate 20.5 L/min		100% cotton 50% cotton + 50% polyester mix	Fabric masks were able to reduce cough particles by up to 77%	Low
(Pacitto et al. 2019)	Spain	Experimental	1	< 2.5 µm < 0.1 µm air pollution 0.001–0.005 µm black carbon (BC) Which can aggregate to 0.1–1 µm	Flow rate 32 42 L/min 52		A Fiber cloth mask	FE increases with breathing rates per PNC FE decreases with the increase of the breathing rate	Moderate
(Ueki et al. 2020)	Japan–USA	Experimental	1	< 3 µm 20%; 3 to 5 µm 40% > 5 to 8 µm 40% SARS-CoV-2 Virus suspension particles	-		Cotton masks Comprised a double layer of cotton, with each layer consisting of two layers of 100% cotton gauze, resulting in a total of four layers of gauze, with typical double-strap ties	Cotton masks reduced the respiration of viral particles by 20 to 40% compared to no mask In contrast, a cotton mask reduces the respiration particles of the mask used by up to 50%	Low
(Chen et al. 2013)	Taiwan	Experimental	1	< 1 µm particles of welding	Input 2 L/min Output 0.9 L/min		A cotton fabric facemask	The cotton mask had a more than 99% particle removal efficiency	Low
(Clapp et al. 2020)	USA	Experimental	7	0.05 µm median count diameter of NaCl particles	-		Woven nylon mask Cotton bandana folded once Multilayer rectangle Woven polyester and Nylon mask Non-woven polypropylene mask Woven gaiter Polyester/spandex Bandana Woven 100% cotton mask	The mean FE of face masks was between 79.0% to 26.5% The 2-layered woven nylon mask showed the highest FE	Moderate

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Li et al. 2020a)	China	Experimental	4	0.006–0.2 µm 0.3 µm particle (ASTM simulation)	-		Tissue paper folded and unfolded Tissue paper + kitchen towel	Single-layer tissue paper had the FE_{max} followed by double-layer kitchen towels (6–200 nm: 84.54%, 90–200 nm: 72.89%, and FE of > 99.9% at 3 µm)	Low
(Fischer et al. 2020)	USA	Experimental	10	-	-		Cotton-polypropylene Cotton mask Maxima AT mask One and two-layer of cotton pleated and olson style mask Polyester/spandex mask Bandana Polypropylene mask	The bandana merely reduced the droplets The FE of a cotton mask is much stronger	Low
(Varallyay et al. 2020)	Portland	Experimental	18	0.04 µm NaCl	-		Microfiber woven cloth (4,2,1 layers) 100% woven cotton tea towel (2,1 layers) polyester Knitted (4,2,1 layers) Hospital woven scrubs (2,1 layers) 100% Knitted cotton T-shirt (4,2,1 layers) 100% Knitted polyester thick and thin fleece (2,1 layers) 100% Woven silk (2,1 layers) Vacuum cleaner bag Felt, 1, 1.5, and 2 mm (4,2,1 layers) Paper kitchen towel (2,1 layers) Paper facial tissue (2,1 layers)	The average $FE_{0.04\ \mu m}$ for woven fabrics was between 27.64 and 99.66% The average $FE_{0.04\ \mu m}$ for non-woven fabrics was between 38.73 and 98.73% Polyester felt demonstrated significantly higher filtration performance On the other hand, nonelastic 100% cotton fabrics performed the worst	Low

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Neupane et al. 2019)	Nepal	Experimental	4	< 5 5–10 µm > 10 Air pollution particles	-		Cloth masks	Average FE was between 63 and 84%	Low
(Ma et al. 2020)	China	Experimental	1	3.9 µm CMD of avian influenza virus (AIV) particles	-		One layer of polyester cloth + four-layer of kitchen paper	The FE of the homemade mask was 95.15%	Low
(van der Sande et al. 2008)	Netherland	Experimental	1	0.02–1 µm Particles during breathing or speaking	Flow rate 30, 50, and 80 L/min		Tea cloths homemade mask	For all types of masks, outward protection was significantly lower than inward protection Homemade masks have very little protection These masks protect children much less than adults Activity had no significant impact on protection	Low
(Joshi et al. 2020)	India	Experimental	5	0.35, 0.55, 1.25 µm Total (> 0.3 µm) 0.06–0.14, 0.05, 0.02 µm NaCl particles	Flow rate 28.3 L/min		One layer of quilter's cotton fabric	The average $FE_{0.35\ \mu m}$ was 14.22% The average $FE_{0.55\ \mu m}$ was 26.49% The average $FE_{1.25\ \mu m}$ was 39.05% Average $FE_{>0.3\ \mu m}$ was 14.48% The FE_{min} (8.27%) was found to be in the particle size range of 0.06–0.14 µm	Low

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Wang et al. 2020)	China	Experimental	17	0.075 µm NaCl particles	Flow rate 30 L/min		T-shirt Fleece sweater Outdoor jacket Down jacket Sun-protective clothing Jeans Hairy or granular tea towel Non-woven fabrics Shopping bag Vacuum cleaner bag Diaper Sanitary pad Pillowcase air-jet down-proof fabric or jet satin	Average $FE_{0.075\,\mu m}$ was between 0- 23% The FE of the fleece sweater + hairy tea towel was > 50%	Low
(Rengasamy et al. 2010)	USA	Experimental	15	Poly disperse NaCl aerosols 0.075 µm Monodisperse NaCl aerosols (0.02, 0.03, 0.04, 0.05, 0.06, 0.08, 0.1, 0.2, 0.3, and 0.4 µm) NaCl larger particles 0.5–1 µm		Velocity 5.5 and 16.5 cm/s	Sweatshirts T-shirts Towels Scarves Cloth masks	The protection of these masks against polydisperse and monodisperse particles was highly variable With increasing face velocity to 16.5 cm s^{-1}, monodisperse particles' penetration increased, and polydisperse particles did not change Because household masks do not fit well to the face, they provide very little protection against submicron particles	Low

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Rodriguez-Palacios et al. 2020)	USA	Experimental	6	20 and 900 µm with peak at 70–100 µm 12-probiotic cultured dairy product bacterial particles	-		100% combed cotton 100% polyester 300 TPI Microfiber 100% loosely woven cotton fabrics (52,48 TPI) 100% polyester in sports jerseys	Increase the material layers to two provides 100% protection against larger particles and 97.2% protection against microparticles The least-effective textile was one layer of 100%-cotton homespun-115) with FE = 90–99 In the form of two layers showed 99.8% effectiveness	Low
(Asadi et al. 2020)	USA	Experimental	3	0.3 to 20 µm particles during breathing, talking and coughing	Flow rate 5 L/min		One layer of paper towel mask One layer of 100% cotton T-shirt mask 2 layers of 100% cotton T-shirt mask	1 layer of paper towel mask did not provide any protection Single and double layers of cotton T-shirt is increased particle penetration significantly Most penetrated particles were < 5 µm Cloth masks provide some protection against particles > 0.5 µm	Low

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Lustig et al. 2020)	USA	Experimental	14	0.01 and 0.2 µm polydisperse Rhodamine 6G nanoparticles in the PLGA matrix	Flow rate 14 L/min		Double-layer Kona cotton + Double-layer terry cloth Terry cloth towel (×2,1) Kona cotton (×4,3,2) White flannel (×2,1) Heavy T-shirt 100% cotton (×2,1) White denim + double-layer Kona cotton + white denim Double-layer Kona cotton with 1 or 2 layers of white denim between them Double-layer Kona cotton with one layer of white flannel between them Kona cotton + Pellon Double-layer Kona cotton with one layer of Pellon between them Double-layer Kona cotton with one layer of Kona 2.2 wt % Scotchgard between them Double-layer white denim with one layer of Pelon between them Double-layer blue denim (4,7,11 oz)	Masks with absorbent layers have been most effective, including terry cloth towels, quilting cotton, and flannel Some of these masks have a transmission fraction equal to N95	Low
(Bowen 2010)	Alabama	Experimental	1	1.0 to 2.5 µm NaCl	Flow rate 8.75 L/min		Bandana	The average FE of the bandana was 11.3%	Low
(Liu et al. 2019)	China	Experimental	1	0.075 µm NaCl	Flow rate 85 L/min		A reusable cloth mask	$FE_{0.075\ \mu m}$ was 20%. The airflow resistance was high (200)	Low

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Cherrie et al. 2018)	UK	Experimental	3	< 2.5 µm BC	Flow rate 40, 80 L/min		Yimeijian Gucheng Reusable cloth masks	The PN was between 0.2% -20.7%, with the lowest value being for the 'Yimeijian' mask and the highest being for the 'Gucheng mask By increasing the flow rate, penetration increased	Low
(Lindsley et al. 2021)	USA	Experimental	1	< 0.6 µm 14% KCl and 0.4% sodium fluorescein	28.3 L/min		3-ply cotton cloth face mask	$FE_{<0.6\ \mu m}$ was around 30%. The cloth masl FF was 1.3, which means that the ambient aerosol concentration is 1.3 times higher than the concentration inside the mask	Low

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Guha et al. 2021)	USA	Experimental	21	0.08–0.09 µm NaCl	3.0 L/min		100% cotton 100% polyester 100% microfiber polyester Cotton mix 100% mulberry silk Polyester + spandex 100% cellulose Acrylic + nylon + wool	Loosely knit or woven household fabrics made of cotton are breathable fabrics and low protection fabrics; however, Tightly woven cotton fabrics showed breathing resistance and at the same time better FE Combination of different fabrics revealed better FE 1000 TPI, 100% cotton tightly woven fabrics FE was above 40% for sub-micron particles	Low
(MacIntyre et al. 2015b)	Australia	Clinical trial	569 people received five cloth masks type	Clinical respiratory illness, influenza-like virus, human metapneumovirus, rhinoviruses, and influenza B	-		Double-layer cotton	The cloth mask did not provide adequate protection so that the disease rate in the control group was lower than the cloth mask group	SFI
(Yang et al. 2011)	China	Clinical trial	239 HCWs received cloth mask	Respiratory infections	-		Cotton-yarn mask	Masks/cotton Yarn masks, which are commonly used in Asia, do not fit well and therefore do not provide good protection	SFI

Table 1 (continued)

Author	country	Type of Study	Sample size (n)	Particle(s)	Flow rate (L/min)	Velocity (cm/s)	Type of Mask	Main results (Filtration Efficiency)	Risk of bias*
(Ho et al. 2020)	Taiwan	Clinical trial	211 sick people received cloth mask	0.02–1 µm influenza and Covid-19 particles		Velocity 5.5 cm/s	self-designed cotton (×3) mask	There was no significant difference between the FE of cloth masks and medical masks	SFI

FE filtration efficacy, *Q*:quality factor, *PNC* particle count number, *PM* particulate matter, *LDSA* lung deposited surface area, *SFI* seek further information

et al. 2008), all other thirty-seven experimental studies used manikin-based models. Clinical studies measured the mask's efficiency by health care workers who were infected by different respiratory viruses (Ho et al. 2020; MacIntyre et al. 2015b; Yang et al. 2011).

Systematic review

Filtration efficacy (FE)

By measuring the pre and post mask viral aerosols concentration, the FE will be calculated by this formula:$Efficiency\,(\%) = (1 - \frac{B}{A}) \times 100\%$. A: refers to the concentration of viral aerosol challenging the mask, and B is the concentration of viral aerosol after mask filtration (Wen et al. 2010). The FE in forty-one experimental studies was reported in the range of 0–100%. Four studies found FE increases by increasing the layer of clothes (Maher et al. 2020; O'Kelly et al. 2020; Xiao et al. 2020; Guha et al., 2021). One study added a nylon layer to different cloth masks and obtained the FE of surgical type masks increased but it had no effect on cone-shaped masks (Mueller et al. 2020). Guha et al. study also revealed that a combination of woven and loosely knitted fabrics can increase the FE against sub-micron particles (Guha et al. 2021). Two different studies concluded that by increasing the weight of filter material (Lu et al. 2020) and the thread per inch (TPI) (Konda et al. 2020a), FE increased. Additionally, FE depends on different parameters, including particle size, and flow rate through the filter material (Cherrie et al. 2018). Studies showed that by increasing the flow rate and/or face velocity, FE decreases (Shakya et al. 2017; O'Kelly et al. 2020). However, Lu et al. asserted that velocity increasing (from 4 to 16 cm s^{-1}) has no effect on FE (Lu et al. 2020). We have to keep this point in mind that in different studies flow rate is not constant. To be sure about the comparisons, new studies with the same situation should be done. Twelve studies calculated the filtration efficiency of different materials in the particle size range of the Covid-19, which (60–100 nm) was between 0–97% (Joshi et al. 2020; Konda et al. 2020a; Li et al. 2020a, b; O'Kelly et al. 2020; Pei et al. 2020; Shakya et al. 2017; Wang et al. 2020; Zangmeister et al. 2020; Zhao et al. 2020; Lindsley et al. 2021; Guha et al., 2021) (Table 2). According to Konda et al. study, the most effective cloth mask was a hybrid of cotton/chiffon (). They compared different fabric materials with a separate TPI and a different number of layers (Konda et al. 2020a). Then they selected some material that had a better performance to combine. Finally, between different tested materials, cotton quilt (120 TPI) (FE = 96%), and among different hybrid masks, hybrid of cotton/chiffon (FE = 97%), hybrid of cotton/silk (no gap) (FE = 94%), hybrid of cotton/flannel (FE = 95%) had the best filtration efficiency. Albeit, we have

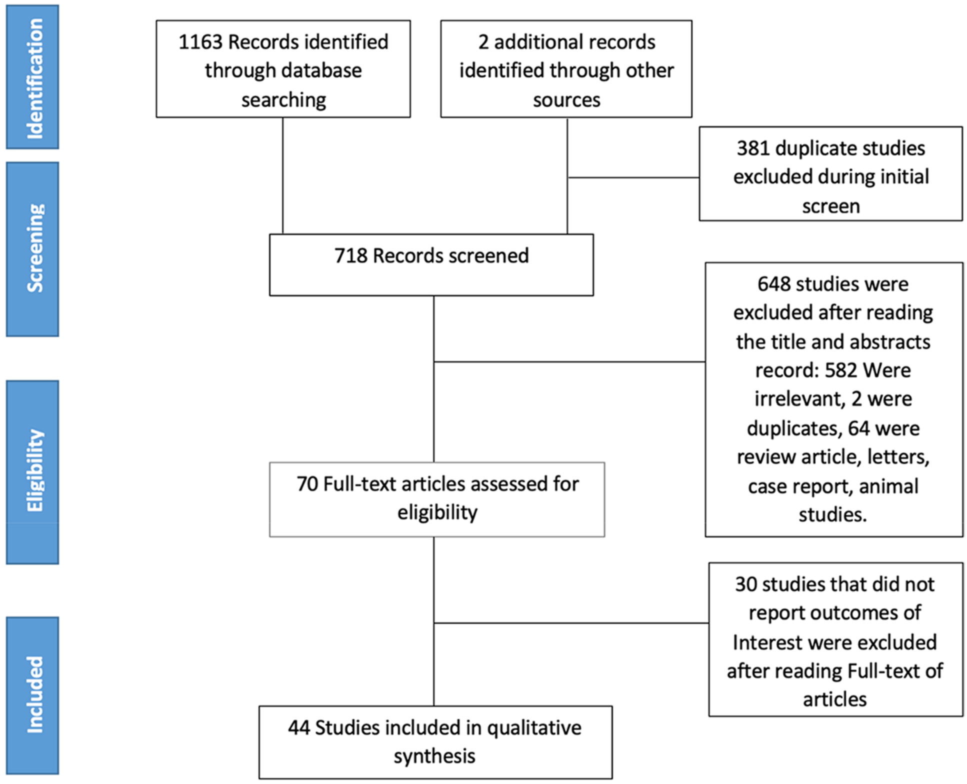

Fig. 1 PRISMA Flowchart of the literature search and strategy for the selection of relevant studies

to mention some defects of this study. Carr et al. published a letter and criticized this study methods. According to Carr et al. study the pressure drop values were significantly lower compared to similar articles (Carr et al. 2020). Furthermore, FE of N95 reported 45–70%, which was controversial. In response, Konda et al. corrected that the N95 and cloth masks capturing efficacy measured in a significantly lower pressure drop (2.5 – 13 Pa) than similar studies (Konda et al. 2020b). The Pillowcase 80 s × 60 s Jet satin had no efficacy (Wang et al. 2020). Zangmeister et al. examined different cloth materials with a different number of layers. The best-performing materials were 100% cotton fabrics, including down-proof ticking, woven hand towel, light-weight flannel, and a 4-layer 100% cotton light-weight flannel (poplin) with a FE of 48% (Zangmeister et al. 2020). By evaluating different cloth materials, Zhao et al. found that cellulose copy paper (bonded) had the best 99.85% FE (Zhao et al. 2020). Pei et al. evaluated five layers of different materials; a 5-layer shop towel with 69% FE had better performance (Pei et al. 2020). In a study by Li et al. several cloth materials have been examined and then reported a mixture of tissue paper and kitchen towels with 71.5% FE that performed the best (Li et al. 2020a). The Joshi et al. study tested just a single-layered quilter's cotton fabric (TPI = 85–100) that had an inadequate FE against particles in size range of 60–140 nm (FE = 8.27%) (Joshi et al. 2020). Wang et al. compared different materials; the results showed that all of the materials had low FE, but hairy tea towel 80% polyester/20% nylon with 23% FE was the best (Wang et al. 2020). O'Kelly et al. reported that disposable HEPA Vacuum Bags filtered more than 60% of 20–1000 nm particles (O'Kelly et al. 2020). In another study by Li et al., 2-ply 100% cotton masks showed 77% FE for 10–1000 nm particles (Li et al. 2020b). Shakya et al. compared 3 different cloth masks. One of them had an exhalation valve and, the others did not have it. In this study, the cloth mask with exhalation valve showed ≈ 90% FE for 100 nm particles (Shakya et al. 2017). Lindsley et al. study, revealed the ≈ 28% FE of 3-ply cotton face masks for particles ranged between 0–600 nm (Lindsley et al. 2021). And the Guha et al. reported the One Thousand TPI Bedsheet—1 (1000 TCBS1) with 48.9% FE was the best performing one-layered fabric which showed ≈ 5% FE increase after adding up another layer (Guha et al. 2021).

Moreover, Table 3 shows different surrogates tested which NaCl was the most used one. Among those tested NaCl particles, copy paper (bonded) indicated the highest FE. All these results can be seen in Fig. 2.

Two clinical trials reported that cloth masks' efficacy was low, and the rate of respiratory infections in the cloth mask wearers was high (MacIntyre et al. 2015b; Yang et al. 2011). The previous clinical study found no difference between the cotton mask and a medical mask (Ho et al. 2020).

Table 2 Summary of studies that evaluated cloth materials in the Covid-19 particle size range

Mask type	Filter efficiency (%)	ΔP (Pa)	QF (kPa − 1)	Particle size
100% cotton hand towel (block), 2-layers	32	61.8	6.25	50–825 nm NaCl method (Zangmeister et al. 2020)
100% cotton light weight flannel (poplin), 2-layers	24.3	106	2.62	
100% cotton light weight flannel (poplin), 4-layers	48	216	< 2.62	
100% cotton pillowcase (satin), 2-layers	20.3	128.5	1.77	
Polyester apparel fabric (Poplin), 2-layers	21.4	104	2.32	
Polyester apparel fabric (soft spun), 2-layers	20.2	177.6	1.27	
Coffee filter	34.4	-	-	
polypropylene 4 (PP-4)	6.1	1.6	16.9	22–259 nm NaCl NIOSH method (Zhao et al. 2020)
Cotton pillow cover (woven)	5.04	4.5	5.4	
Cotton T-shirt (knit)	21.62	14.5	7.4	
Cotton sweater (knit)	25.88	17.0	7.6	
Polyester toddler wrap (knit)	17.50	12.3	6.8	
Silk napkin (woven)	4.77	7.3	2.8	
Nylon exercise pants (woven)	23.33	244.0	0.4	
Paper towel (bonded)	10.41	11.0	4.3	
Tissue paper (bonded)	20.2	19.0	5.1	
Copy paper (bonded)	99.85	1883.6	1.5	
Coffee filter, 2 layers	14	153.4	-	100 nm NaCl NIOSH method (Pei et al. 2020)
Kitchen towel, 5 layers	40	158.9		
Bed sheet, 5 layers	54	433.9		
T-shirt, 5 layers	64	231.1		
Shop towel, 5 layers	69	185.8		
4-ply tissue paper	30.4	-	-	100 nm ASTM method (Li et al. 2020a)
4-ply tissue paper folded once	41.2			
Tissue paper + kitchen towel	71.5			
Disposable HEPA Vacuum Bags	60.86	2	-	20–1000 nm NaCl method (O'Kelly et al. 2020)
Windbreaker 100% Polyester	47.12	3		
Jeans Denim 100% Cotton	45.94	3		
Washable Vacuum Bag HEPA	43.64	2		
Thick felted wool 100%	35.87	0		
Cotton, Heavyweight Woven 100%	35.77	2		
Folded Sock Cotton	35.36	2		
Quilting Cotton 100%	34.54	1		
Two-Sided Minky Fabric	34.17	1		
Shirting Cotton 100%	33.59	1		
Cotton, Lightweight Woven 100%	30.2	0		
Cotton Quilt Batting 100%	29.81	0		
Cotton Flannel 100%	28.5	1		
Craft Felt Miss crafts Rayon, Acrylic, Polyester	27.72	0		
100% Nylon Woven	27.61	3		
T-shirt, Heavyweight 100% Cotton	25.21	1		
Cotton Jersey Knit 100% Cotton	24.56	0		
Lycra 82% Nylon, 18% Spandex	21.6	0		
Fusible Interfacing HTC	15	0		
T-Shirt (50% Polyester + 50% Cotton)	10.5	0		
Quilter's cotton fabric (TPI = 85–100), 1 layer	8.27	-	-	60–140 nm NaCl method (Joshi et al. 2020)

Table 2 (continued)

Mask type	Filter efficiency (%)	ΔP (Pa)	QF (kPa – 1)	Particle size
T-shirt 100% cotton	12%	15.8	-	75 nm NaCl method (Wang et al. 2020)
Fleece sweater 100% cotton	6%	5.86		
Hairy tea towel 80% polyester/20% nylon	23%	13.72		
Hairy tea towel + Fleece sweater	56%	22.84		
Fleece sweater + T-shirt	12%	20.32		
Fleece sweater, 2 layers	11%	12.4		
Granular tea towel 80% polyester/20% nylon	12%	5.72		
Fleece sweater + Granular tea towel	11%	14.08		
Non-woven shopping bag 100% polypropylene	14%	7.06		
Non-woven shopping bag + T-shirt	30%	25.26		
Non-woven shopping bag + Hairy tea towel	46%	23.64		
Non-woven shopping bag + Granular tea towel	47%	14.44		
Non-woven shopping bag + Fleece sweater	35%	14.4		
Non-woven shopping bag, 2 layers	18%	13.72		
Pillowcase 80 s × 60 s Jet satin	0%	26.86		
1000 TPI Bedsheet, 1 layer (1000 TCBS1)	48.95	272	-	80–90 nm NaCl method (Guha et al. 2021)
1000 TPI Bedsheet, 2 layers (1000 TCBS1)	53.34	314		
1000 TPI Pillowcase (1000 TCPC)	41.62	231		
Blue Jeans	40.52	197		
Microfiber pillowcase, layer (Microfiber PC1)	30.82	196		
Canvas dropcloth	18.89	58		
Silk Pillowcase	12.90	11		
200 TPI Pillowcase	9.94	11		
600 TPI Bedsheet 100	8.70	19		
Wash cloth	7.89	5		
Flannel Bedsheets	7.32	11		
Microfiber Pillowcase, 2 layers	7.12	21		
Neck tube	7.10	14		
Face tissue paper	4.57	20		
Scarf	3.79	5		
T-shirt	3.68	6		
Paper towel	3.34	12		
Cooling scarf	2.94	2		
Bandana	1.52	2		
2-ply, 100% cotton mask	77	-	-	10–1000 nm volunteer method (Li et al. 2020b)
3-ply, cotton cloth face mask	≈ 28%	-	-	< 600 nm modified Greene and Vesley method (Lindsley et al. 2021), with the cough aerosol simulator
Cloth mask 1 (exhalation valve)	≈ 90%	-	-	100 nm PSL method (Shakya et al. 2017)
Cloth mask 2	≈ 65%			
Cloth mask 3	≈ 60%			

Table 3 Comparison of different study conditions

Mask type	Filter efficiency (%)	Flow rate	Testing surrogates used	Particle size	Type of aerosols/droplets	Electrostatic charge of the particles
100% cotton hand towel (block), 2-layers	32	2.2 L/min	NaCl	50–825 nm	Solid (Zangmeister et al. 2020)	No
100% cotton light weight flannel (poplin), 2-layers	24.3					
100% cotton light weight flannel (poplin), 4-layers	48					
100% cotton pillowcase (satin), 2-layers	20.3					
Polyester apparel fabric (Poplin), 2-layers	21.4					
Polyester apparel fabric (soft spun), 2-layers	20.2					
Coffee filter	34.4					
polypropylene 4 (PP-4)	6.1	32 L/min	NaCl NIOSH method	22–259 nm	Solid (Zhao et al. 2020)	No
Cotton pillow cover (woven)	5.04					
Cotton T-shirt (knit)	21.62					
Cotton sweater (knit)	25.88					
Polyester toddler wrap (knit)	17.50					
Silk napkin (woven)	4.77					
Nylon exercise pants (woven)	23.33					
Paper towel (bonded)	10.41					
Tissue paper (bonded)	20.2					
Copy paper (bonded)	99.85					
Coffee filter, 2 layers	14	85 L/min	NaCl NIOSH method	100 nm	Solid (Pei et al. 2020)	No
Kitchen towel, 5 layers	40					
Bed sheet, 5 layers	54					
T-shirt, 5 layers	64					
Shop towel, 5 layers	69					
4-ply tissue paper	30.4	Laminar airflow	NaCl ASTM method	100 nm	Solid (Li et al. 2020a)	No
4-ply tissue paper folded once	41.2					
Tissue paper + kitchen towel	71.5					

Table 3 (continued)

Mask type	Filter efficiency (%)	Flow rate	Testing surrogates used	Particle size	Type of aerosols/droplets	Electrostatic charge of the particles
Disposable HEPA Vacuum Bags	60.86	- 16.5 m/s velocity	NaCl	20–1000 nm	Solid (O'Kelly et al. 2020)	NG
Windbreaker 100% Polyester	47.12					
Jeans Denim 100% Cotton	45.94					
Washable Vacuum Bag HEPA	43.64					
Thick felted wool 100%	35.87					
Cotton, Heavyweight Woven 100%	35.77					
Folded Sock Cotton	35.36					
Quilting Cotton 100%	34.54					
Two-Sided Minky Fabric	34.17					
Shirting Cotton 100%	33.59					
Cotton, Lightweight Woven 100%	30.2					
Cotton Quilt Batting 100%	29.81					
Cotton Flannel 100%	28.5					
Craft Felt Miss crafts Rayon, Acrylic, Polyester	27.72					
100% Nylon Woven	27.61					
T-shirt, Heavyweight 100% Cotton	25.21					
Cotton Jersey Knit 100% Cotton	24.56					
Lycra 82% Nylon, 18% Spandex	21.6					
Fusible Interfacing HTC	15					
T-Shirt (50% Polyester + 50% Cotton)	10.5					
Quilter's cotton fabric (TPI = 85–100), 1 layer	8.27	28.3 L/min	NaCl	60–140 nm	Solid (Joshi et al. 2020)	No

Table 3 (continued)

Mask type	Filter efficiency (%)	Flow rate	Testing surrogates used	Particle size	Type of aerosols/droplets	Electrostatic charge of the particles
T-shirt 100% cotton	12%	30 L/min	NaCl	75 nm	Semi-solid (Wang et al. 2020)	NG
Fleece sweater 100% cotton	6%					
Hairy tea towel 80% polyester/20% nylon	23%					
Hairy tea towel + Fleece sweater	56%					
Fleece sweater + T-shirt	12%					
Fleece sweater, 2 layers	11%					
Granular tea towel 80% polyester/20% nylon	12%					
Fleece sweater + Granular tea towel	11%					
Non-woven shopping bag 100% polypropylene	14%					
Non-woven shopping bag + T-shirt	30%					
Non-woven shopping bag + Hairy tea towel	46%					
Non-woven shopping bag + Granular tea towel	47%					
Non-woven shopping bag + Fleece sweater	35%					
Non-woven shopping bag, 2 layers	18%					
Pillowcase 80 s × 60 s Jet satin	0%					

Table 3 (continued)

Mask type	Filter efficiency (%)	Flow rate	Testing surrogates used	Particle size	Type of aerosols/droplets	Electrostatic charge of the particles
1000 TPI Bedsheet, 1 layer (1000 TCBS1)	48.95%	3.0 L/min	NaCl	80–90 nm	Solid (Guha et al., 2021)	No
1000 TPI Bedsheet, 2 layers (1000 TCBS1)	53.34%					
1000 TPI Pillowcase (1000 TCPC)	41.62%					
Blue Jeans						
Microfiber pillowcase, layer (Microfiber PC1)	30.82%					
Canvas dropcloth	18.89%					
Silk Pillowcase	12.90%					
200 TPI Pillowcase	9.94%					
600 TPI Bedsheet 100	8.70%					
Wash cloth	7.89%					
Flannel Bedsheets	7.32%					
Microfiber Pillowcase, 2 layers	7.12%					
Neck tube	7.10%					
Face tissue paper	4.57%					
Scarf	3.79%					
T-shirt	3.68%					
Paper towel						
Cooling scarf	2.94%					
Bandana	1.52%					
2-ply, 100% cotton mask	77	-	Cough particles	10–1000 nm	Liquid (Li et al. 2020b)	NG
3-ply, cotton face mask	≈ 28%	28.3 L/min	KCL + sodium fluorescein NIOSH modified method	< 600 nm	Solid (Lindsley et al. 2021)	NO
Cloth mask 1 (exhalation valve)	≈ 90%	8 L/min	PSL	100 nm	Solid (Shakya et al. 2017)	NG
Cloth mask 2	≈ 65%					
Cloth mask 3	≈ 60%					
Cloth mask 1 (exhalation valve)	≈ 90%	19 L/min				
Cloth mask 2	≈ 32%					
Cloth mask 3	≈ 28%					

NG not given

Penetration (PN)

The percent aerosol penetration (P) is defined as the ratio of the viral aerosols after filtration by maks (B) to the challenge aerosol concentration (A). Therefore, it will be calculated by this formula: $\frac{A}{B} \times 100$ (Tcharkhtchi et al. 2021). Four studies investigated the PN of particles from fabrics (Cherrie et al. 2018; Jung et al. 2013; Rengasamy et al. 2010; Shakya et al. 2017). Three of them used the hot plate method to fix the masks (Cherrie et al. 2018; Jung et al. 2013; Rengasamy et al. 2010), but one of them used maniquine based method

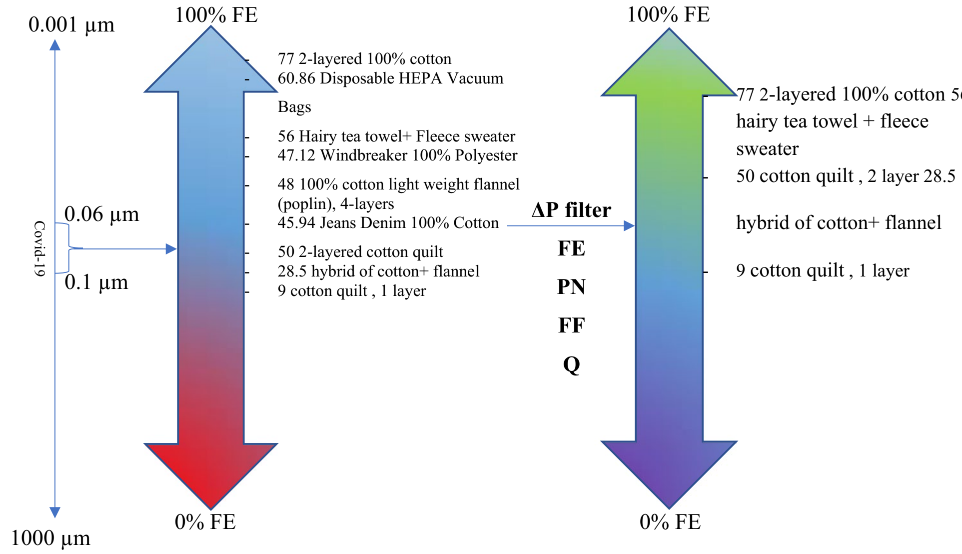

Fig. 2 Choosing the best fabrics after FE, PN, FF, Q, and ΔP filtrations

and for mask sealing used parafilm (Shakya et al. 2017). One study tested the PN of cotton and gauze handkerchiefs with the NIOSH and KFDA methods. First, they found there was no significant difference between these two methods; second, they reported that handkerchiefs, regardless of material, had no protection against 0.075 µm NaCl and paraffin oil particles (PN > 98%) (Jung et al. 2013). Another study compared the PN of three commercial cloth masks. The one with an exhaust valve and a cone or tetrahedral shape that can fit well to the face had the least PN in both flow rates (8 & 19 L.min^{-1}) (Shakya et al. 2017). The improved performance with well-fitting masks suggests that leakage may be an issue in studies that utilize mannequins to test for filter penetration. Rengasamy et al. showed variable PN rates in cloth masks and fabric materials. The cloth masks PN was between 50 and 90% for polydisperse and 70–80% for 100 nm monodisperse aerosols at 33 L.min^{-1}. The PN of fabric materials for polydisperse aerosols was between 40–89%, and for monodisperse ones was among 9–95% at 33 L.min^{-1} indicating that all of them had marginal efficacy (Rengasamy et al. 2010). The last study found that by increasing the flow rate, PN increased. In this study, PN was between 0.2 and 20.7%. The lowest value reported was for the "Yimeijian" mask, and the highest was for the "Gucheng" mask (Cherrie et al. 2018).

Pressure drop (breathability)

Seventeen studies evaluated pressure drop (ΔP) (Aydin et al. 2020; Davies et al. 2013; Drewnick et al. 2021; Hao et al. 2020; Joshi et al. 2020; Jung et al. 2013; Konda et al. 2020a; Long et al. 2020; Maher et al. 2020; Park and Jayaraman 2020; Pei et al. 2020; Teesing et al. 2020; Varallyay et al. 2020; Wang et al. 2020; Zangmeister et al. 2020; Zhao et al. 2020; Guha et al. 2021), which indicated breathability or comfort when you are breathing and face fitness of the mask or presence any leakage. ΔP has a reverse relation with breathability, which means by increasing the ΔP, breathability decreases. Also, in some studies, ΔP significantly improved by increasing the layers (Aydin et al. 2020; Davies et al. 2013; Jung et al. 2013; Wang et al. 2020). In one study, however, with increasing the layers of tightly woven fabrics, ΔP significantly declined (Guha et al. 2021). Additionally, breathability depends strongly on porosity and TPI, which means increasing the porosity increases breathability, but increased TPI has the opposite effect. (Aydin et al. 2020; Zhao et al. 2020).

Among different materials: cotton (Long et al. 2020; Maher et al. 2020), cotton-quilt (Konda et al. 2020a; Teesing et al. 2020), cotton bandana (Hao et al. 2020), cotton block hand towel (Zangmeister et al. 2020), pillowcase 100% woven cotton (Davies et al. 2013; Varallyay et al. 2020; Zhao et al. 2020), 100% cotton T-shirt (Davies et al. 2013; Varallyay et al. 2020), gauze and cotton handkerchiefs (Jung et al. 2013), fleece sweater (Wang et al. 2020), woven 100% silk scarf and thick fleece-Knitted 100% polyester (Varallyay et al. 2020), 100% polyester (Cooling scarf) and 100% microfiber polyester (bandana mask) (Guha et al. 2021), and muslin (Drewnick et al. 2021) were most breathable fabrics.

The materials with the least breathability were vacuum cleaner bag and tea towel because of their thickness and stiffness (Davies et al. 2013; Long et al. 2020; Maher et al. 2020), non-woven shopping bag + T-shirt (Wang et al. 2020), microfiber cloth—80% polyester—20% polyamide (TPI: 38) (Varallyay et al. 2020), leather (Teesing et al. 2020), cellulose copy paper and nylon (Zhao et al. 2020), coffee filter (Hao et al. 2020), plain polyester (Zangmeister et al. 2020), 5-layer bedsheet (Pei et al. 2020), poplin (Drewnick et al.

2021), one and two layers of One Thousand TPI 100% cotton Bedsheet (Guha et al. 2021), and chiffon (Konda et al. 2020a).

One study measured breathability (β), which is related to both the pressure drop (ΔP) and the changes in the flow rate, then reported that, for the same porosity, knit fabrics had higher breathability than woven fabrics (Aydin et al. 2020). Loosely knit or woven fabrics in another study considered highly breathable compared to tightly woven fabrics, which were less breathable (Guha et al. 2021). Furthermore, used knitted undershirt (75% cotton—25% polyester) showed the most breathability but, used knitted shirt (100% cotton) and used woven shirt (70% C—30% PE) were the least breathable fabrics. It has been shown that using cotton fabrics that have been washed experience shrinkage that results in pore size decrease and less breathability. Also, if various cleaning products (e.g., starch) are used for washing cloth fabrics, they can alter breathability (Aydin et al. 2020). Albeit, we have to keep in mind that cloth masks reuse will increase the risk of infection unless washing properly (Szarpak et al. 2020).

Additionally, one study tested all the fabrics after one cycle of washing with a home laundry machine. In this study, dampness has been tested. Some fabrics FE like quilting cotton, cotton flannel after dampesss has not been changed. However, some of them like denim FE substantially decreased (O'Kelly et al. 2020). Therefore, we can conclude that washing can affect some fabrics FE but not all. Another study reported no significant pressure drop indicated between different fabrics (Park and Jayaraman 2020).

Filter quality (Q)

Four studies evaluated the filter quality of different fabrics (Drewnick et al. 2021; Hao et al. 2020; Zangmeister et al. 2020; Zhao et al. 2020). Filter quality is a factor for indicating filter performance. It is related to two factors: FE and pressure drop; by increasing the FE and decreasing the pressure drop, the filter's quality increases. It will also not be affected by the number of layers of a single-layer fabric (Zangmeister et al. 2020; Zhao et al. 2020). Furthermore, a study found no correlation between filter quality and TPI (Drewnick et al. 2021). In one study, cotton sweaters and T-shirts had better filter quality, but cellulose copy paper had the worst quality (Zhao et al. 2020). The second study reported better filter quality for vacuum bags (Drewnick et al. 2021; Hao et al. 2020), and the coffee filter had the lowest quality (Hao et al. 2020). In the third study, cotton hand towels had better filter quality, and plain polyester had a low filter quality (Zangmeister et al. 2020). In the fourth study, silk had the least quality (Drewnick et al. 2021).

Fit factor (FF)

FF describes the penetration around the mask and towards the breathing zone and expresses how good the fit of a mask is on the face. FF is the ratio of time-averaged particle concentration outside and inside mask (van der Sande et al. 2008). The FE of a mask is dependent on the FF, while the FF itself could be influenced by some factors such as the type of user's activity and facial characteristics (Pacitto et al. 2019). One study done by Clapp et al. measured the fitted filtration efficiency (FFE) ranged from 26.5 to 79% by OSHA regulations. All the samples were fitted on a man face with no beard in different ways (Clapp et al. 2020).

Additionally, Teesing et al. considered a FF of 100 or higher as a good fit. In their study, none of the cotton masks report a well fit (Teesing et al. 2020). Protection factors (PF) is a similar concept to FF that is related to Portacount devices, but FF is used by OSHA (van der Sande et al. 2008). Mueller et al. found that surgical-type cloth masks had less FE because of their poor fit. Therefore, adding up a nylon layer to the cloth masks decreased gaps and increased FE (Mueller et al. 2020). Davis et al. revealed that stretchy fabrics like 100% cotton T-shirts are more fittable and preferable than non-stretch fabrics with the same FE (Davies et al. 2013). Lindsley et al. analyzed the FF of 3-ply cotton face mask which was 1.3 and showed the 50.9% FE (Lindsley et al. 2021).

Discussion

Currently, many studies have been evaluated on fabric masks, but none of them have compared the protected efficacy of fabric masks. This issue has become even more complex when one compares different types of fabrics, different layers of fabrics. In this systematic review, we attempt to compare fabric masks based on filtration efficiency, pressure drop, QF, penetration, and fit factor. different fabric masks' performance to find the best potential choice to limit the spread of respiratory particles. In two studies, single-layered cotton quilt (TPI≈80) showed FE≈9% (Joshi et al. 2020; Konda et al. 2020a). After adding another layer of the cotton quilt, its efficiency increased five times (FE = 50%). Also quilting cotton was one of the best fabrics as it showed an acceptable FE for both damp and dry particles and good breathability (O'Kelly et al. 2020). Moreover, by increasing the cotton quilt's TPI to 120, its efficiency increased by more than ten times (FE = 96%) (Joshi et al. 2020). Despite increasing the number of layers or increasing the TPI of the fabric, all samples were breathable, and that was a good point. The tighter a fabric's weave, the smaller the pores and the increase in FE as 1000 TPI 100% cotton bed sheets showed modest FE (48.9%) but high ΔP, which exceeded the limit (Guha et al. 2021). In contrast, a higher yarn count and a looser weave resulted in a lower FE (Zangmeister et al. 2020). Cotton with a higher yarn count and a looser weave showed a lower FE. Perhaps the higher yarn count causes more penetration and less FE. It should be mentioned that the best performing cloth materials have moderate yarn counts (Zangmeister et al. 2020). In addition to the cotton quilt, other 100% cotton fabrics like cotton flannel revealed well FE and tolerable ΔP (O'Kelly et al. 2020). Additionally, in the Zangmeister et al. study, 2-layers 100% cotton fabrics (TPI = 100 = 150) had 24% ≤ FE ≤ 32%. In this study, 4-layer 100% cotton light-weight flannel (poplin) had elevated FE to 48% compared with two layers (FE = 24.3%). After increasing the layers, ΔP increased, and filter quality decreased (Zangmeister et al. 2020). Hence, 100% cotton fabric like cotton flannel with one to two layers can be a good option. Also, in the Li et al. study, a 2-ply 100% cotton fabric's FE was 77% but, they reported that all tested cloth masks had less FE for particles < 1000 nm (Li et al. 2020b). We note that the efficacy of these two is different, perhaps because of the difference in the particle size range, which was greater in the Li et al. study (50–825 nm vs 10–1000 nm). To enable a better comparison, 2-layered 100% cotton should be tested in the same situation. Given this study and the previous one, it can be concluded this fabric can be a good choice. A 3-ply cotton face mask showed about 28% FE for particles < 600 nm (Lindsley et al. 2021). In Zhao et al.'s study, the copy paper, while showing high FE, also had a very high ΔP that made it of low quality. Despite having good filtration, copy paper is not a good choice for a mask (Zhao et al. 2020). O'Kelly et al., after evaluating different fabrics, stated that vacuum cleaner bags had the best efficacy. Also, Windbreaker 100% Polyester and Jeans Denim 100% Cotton had good FE, but they were not as breathable as vacuum cleaner bags (O'Kelly et al. 2020). Therefore, a vacuum cleaner HEPA bag seems a good choice as a filter layer in a cloth mask but, three studies reported it as an unbreathable fabric (Davies et al. 2013; Long et al. 2020; Maher et al. 2020). This discrepancy refers to the other materials tested in O'kellys study. As we mentioned, the vacuum cleaner bag is more breathable than jeans and a windbreakerFabrics like silk have enhanced FE because of their electrostatic properties that attract and hold particles. This is an important point that is being considered in mask design (Zhao et al. 2020). In another study, hairy tea towels alone had 23% efficacy. After it was combined with the fleece sweater, its efficacy converted to the best among other materials and became more than 50%. Its ΔP was under 49 Pa, which shows it is a breathable fabric. Fleece sweater is one of the most breathable fabrics that its FE is reported 6%. (Wang et al. 2020). Therefore, it is a good choice for combining with other fabrics to make a breathable and more effective mask. Pei et al. evaluated different fabrics against particles in the 30–1000 nm size range. For 100 nm particles, a 5-layer shop towel had the best efficacy, but the study did not report its explicit material. Furthermore, the figure of merit related to FE and ΔP did not compare the shop towel with the other materials (Pei et al. 2020). So, we cannot decide if it is a reasonable choice. In the Li et al. study, one layer of 4-ply tissue paper followed by two layers of kitchen towel showed the best efficacy (FE = 71.5% for 100 nm particles). They also reported that the most particle penetrating size was between 100 and 125 nm (Li et al. 2020a). Although the mask has the least efficacy at 100 nm, it is suitable for preparing fabric masks. However, it should be noted the mask breathability and quality factor were not reported and require further study. Considering these results, hybrid fabrics can work well as a mask. In the second step, we are going to discuss cloth mask studies. Shakya et al. compared three different cloth masks but they did not mention the cloth mask fabric materials. They recently reported the cloth mask with an exhalation valve had better filtration effectiveness and less particle penetration (Shakya et al. 2017). Thus, we are unable to fully evaluate their findings. In addition to the FE, some studies compared different cloth masks by using penetration rates. Three did not mention the details about cloth mask materials (Cherrie et al. 2018; Rengasamy et al. 2010; Shakya et al. 2017). In addition to the cloth masks, Rengasamy et al. had also examined several different fabrics: three brands of Sweatshirt, T-shirt, towel, and scarf in different materials. Penetration for mono and polydisperse aerosols was variable, and it showed marginal efficacy for these materials, especially for particles < 1000 nm (Rengasamy et al. 2010). Jung et al. investigated the penetration of cotton and gauze handkerchiefs with two KFDA and NIOSH methods. This evaluation showed that both cotton and gauze handkerchiefs had more than 98% penetration, and after folding, penetration decreased to 87%, which is still high. These results show us that handkerchiefs are not able to filter 75 nm particles well (Jung et al. 2013). Fabrics tested in penetration studies could not filter particles well. Between two RCTs tested on health care workers (HCWs), the first RCT reported that cotton yarn masks were not recommended for HCWs. The cloth mask layer count was not mentioned in this study (Yang et al. 2011). The second one used a 2-layered cotton cloth mask, but the highest rate of respiratory infections was in HCWs who wore cloth masks (MacIntyre et al. 2015b). In both studies, only one type of cloth mask was used, not different types. We recommend more clinical trials to compare cloth masks but not for HCWs, as two RCTs reported them insufficient. Another clinical study reported that a 3-layered 100% cotton mask had no significant difference from a surgical mask but did not report its exact FE (Ho et al. 2020). So, we are not able to report it as a good choice. Although our study aimed to compare just cloth masks FE. Masks of category 1 which filters > 95% of particles > 3 µm (respirators), and medical masks are more effective than cloth masks (Chughtai et al. 2020) as some countries like France banned the use of cloth masks with the outburst of new covid-19 variants (Mahase 2021).

Limitations

Our results and conclusion are based on all the studies that are done up to the present time, which are mostly experimental. Thus, there is a great need for clinical trials. In these studies, instead of using the Covid-19 particles, different surrogates (sodium chloride, cough particles, KCL + sodium fluorescein, PSL) have been used. All the studies that analyzed the FE of masks against particles in the Covid-19 particle size range with the use of different surrogates did not evaluate the FF. Because of that, we could not compare masks in this field. At the end of this study, we bring some tables that compare studies in different aspects. But because of the different situations of these studies, we could not bring a complete comparison, and some factors like the type of the surrogates and flow rate that have critical effects of FE are not mentioned.

Conclusion

Cloth masks and fabrics have provided some protection, with some variability noted. The use of cloth masks by the general population can protect them to some degree. The purpose of this study is to find the best fabrics, especially against Covid-19. We compare different materials for their filtration, efficacy, penetration, pressure drop, and filter quality. The best performing fabrics are: cotton quilt (1–2 layers), cotton flannel, 2-layered 100% cotton, hybrid of cotton + flannel, and hairy tea towel + fleece sweater. Multi-layered fabrics showed better filtrationefficacy, and breathability. One RCT reported a 3-layered 100 cotton cloth mask had equal efficacy with a surgical mask. According to two RCTs, cloth mask use is not recommended for HCWs. At the end, we have to mention that limited clinical trials showed the cloth masks or fabrics effectiveness in Covid-19; these findings are our suggestion after reviewing all articles in this area. So the use of these types of masks may not be appropriate for Covid 19.

Acknowledgements Not applicable

Author contribution MA, FMS, SN, MA, and OM contributed to conception, design, and preparation of the manuscript. MA, SN conducted literature search and contributed in article selection, MA and SN made data extraction. MA, SN, and OM contributed to acquisition, and interpretation. MA, FMS, SN, MA, and OM made substantial contributions in drafting the manuscript and revising it critically for important intellectual content. All authors have read and approved the final version of manuscript.

Data availability The datasets are available from the corresponding author on formal and logic request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Anonymous World Health Organization available at: https://covid19.who.int/ data access November 2020
Asadi S, Cappa CD, Barreda S, Wexler AS, Bouvier NM, Ristenpart WD (2020) Efficacy of masks and face coverings in controlling outward aerosol particle emission from expiratory activities. Scientific Reports 10
Aydin O, Emon B, Cheng S, Hong L, Chamorro LP, Saif MTA (2020) Performance of fabrics for home-made masks against the spread of COVID-19 through droplets: A quantitative mechanistic study. Extreme Mechanics Letters 40
Bhattacharjee S, Bahl P, Chughtai AA, Mac-Intyre CR (2020) Last-resort strategies during mask shortages: optimal design features of cloth masks and decontamination of disposable masks during the COVID-19 pandemic. BMJ Open Respir Res 7:e000698
Bowen LE (2010) Does that face mask really protect you? Appl Biosaf 15:67–71
Carr IA, Hariharan P, Guha S (2020) Letter to the Editor Regarding Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks. ACS Nano 14(9):10754–10755
Chen HL, Chung SH, Jhuo ML (2013) Efficiency of different respiratory protective devices for removal of particulate and gaseous reactive oxygen species from welding fumes. Arch Environ Occup Health 68:101–106
Cherrie JW, Apsley A, Cowie H, Steinle S, Mueller W, Lin C, Horwell CJ, Sleeuwenhoek A, Loh M (2018) Effectiveness of face masks used to protect Beijing residents against particulate air pollution. Occup Environ Med 75:446–452
Chinazzi M, Davis JT, Ajelli M, Gioannini C, Litvinova M, Merler S, y Piontti AP, Mu K, Rossi L, Sun K (2020) The effect of travel restrictions on the spread of the 2019 novel coronavirus (COVID-19) outbreak. Science 368:395–400
Chughtai AA, Seale H, Macintyre CR (2020) Effectiveness of cloth masks for protection against severe acute respiratory syndrome coronavirus 2. Emerg Infect Dis 26(10):e200948
Clapp PW, Sickbert-Bennett EE, Samet JM, Berntsen J, Zeman KL, Anderson DJ, Weber DJ, Bennett WD (2020) Evaluation of Cloth Masks and Modified Procedure Masks as Personal Protective Equipment for the Public during the COVID-19 Pandemic. JAMA Intern Med 181:463–469
Clase CM, Fu EL, Ashur A, Beale RC, Clase IA, Dolovich MB, Jardine MJ, Joseph M, Kansiime G, Mann JF (2020) Forgotten Technology in the COVID-19 Pandemic. Filtration Properties of Cloth and Cloth Masks: A Narrative Review, Mayo Clinic Proceedings. Elsevier

Davies A, Thompson KA, Giri K, Kafatos G, Walker J, Bennett A (2013) Testing the Efficacy of Homemade Masks: Would They Protect in an Influenza Pandemic? Disaster Med Public Health Prep 7:413–418

Drewnick F, Pikmann J, Fachinger F, Moormann L, Sprang F, Bormann S (2021) Aerosol filtration efficiency of household materials for homemade face masks: Influence of material properties, particle size, particle electrical charge, face velocity, and leaks. Aerosol Sci Technol 55:63–79

Fischer EP, Fischer MC, Grass D, Henrion I, Warren WS, Westman E (2020) Low-cost measurement of face mask efficacy for filtering expelled droplets during speech. Sci Adv 6(36):eabd3083

Godoy LRG, Jones AE, Anderson TN, Fisher CL, Seeley KM, Beeson EA, Zane HK, Peterson JW, Sullivan PD (2020) Facial protection for healthcare workers during pandemics: a scoping review. BMJ Glob Health 5:e002553

Guha S, Herman A, Carr IA, Porter D, Natu R, Berman S, Myers MR (2021) Comprehensive characterization of protective face coverings made from household fabrics. PloS One 16(1):e0244626

Hao W, Parasch A, Williams S, Li J, Ma H, Burken J, Wang Y (2020) Filtration performances of non-medical materials as candidates for manufacturing facemasks and respirators. Int J Hyg Environ Health 229:113582

Ho KF, Lin LY, Weng SP, Chuang KJ (2020) Medical mask versus cotton mask for preventing respiratory droplet transmission in micro environments. Sci Total Environ 735:139510

Howard J, Huang A, Li Z, Tufekci Z, Zdimal V, van der Westhuizen H-M, von Delft A, Price A, Fridman L, Tang L-H (2020) Face masks against COVID-19: an evidence review 118(4):e2014564118

Joshi M, Khan A, Sapra BK (2020) Quick laboratory methodology for determining the particle filtration efficiency of face masks/respirators in the wake of COVID-19 pandemic. J Ind Textiles

Jung H, Kim JK, Lee S, Lee J, Kim J, Tsai P, Yoon C (2013) Comparison of filtration efficiency and pressure drop in anti-yellow sand masks, quarantine masks, medical masks, general masks, and handkerchiefs. Aerosol Air Qual Res 14:991–1002

Konda A, Prakash A, Moss GA, Schmoldt M, Grant GD, Guha S (2020a) Aerosol Filtration Efficiency of Common Fabrics Used in Respiratory Cloth Masks. ACS Nano 14:6339–6347

Konda A, Prakash A, Moss G, Schmoldt M, Grant G, Guha S (2020b) Correction to aerosol filtration efficiency of common fabrics used in respiratory cloth masks. ACS Nano 14(8):10742–10743

Lake MA (2020) What we know so far: COVID-19 current clinical knowledge and research. Clin Med 20:124

Li IW, Fan JK, Lai AC, Lo CM (2020a) Home-made masks with filtration efficiency for nano-aerosols for community mitigation of COVID-19 pandemic. Public Health 188:42–50

Li L, Niu M, Zhu Y (2020b) Assessing the effectiveness of using various face coverings to mitigate the transport of airborne particles produced by coughing indoors. Aerosol Sci Technol

Lindsley WG, Blachere FM, Law BF, Beezhold DH, Noti JD (2021) Efficacy of face masks, neck gaiters and face shields for reducing the expulsion of simulated cough-generated aerosols. Aerosol Sci Technol 55:449–457

Liu Z, Yu D, Ge Y, Wang L, Zhang J, Li H, Liu F, Zhai Z (2019) Understanding the factors involved in determining the bioburdens of surgical masks. Ann Transl Med 7(23):754

Long KD, Woodburn EV, Berg IC, Chen V, Scott WS (2020) Measurement of filtration efficiencies of healthcare and consumer materials using modified respirator fit tester setup. PLoS ONE 15

Lu H, Yao D, Yip J, Kan CW, Guo H (2020) Addressing COVID-19 spread: Development of reliable testing system for mask reuse. Aerosol Air Qual Res 20:2309–2317

Lustig SR, Biswakarma JJH, Rana D, Tilford SH, Hu W, Su M, Rosenblatt MS (2020) Effectiveness of Common Fabrics to Block Aqueous Aerosols of Virus-like Nanoparticles. ACS Nano 14:7651–7658

Ma QX, Shan H, Zhang HL, Li GM, Yang RM, Chen JM (2020) Potential utilities of mask-wearing and instant hand hygiene for fighting SARS-CoV-2. J Med Virol 92:1567–1571

MacIntyre CR, Seale H, Dung TC, Hien NT, Nga PT, Chughtai AA, Rahman B, Dwyer DE, Wang Q (2015) A cluster randomised trial of cloth masks compared with medical masks in healthcare workers. BMJ Open 5:e006577

MacIntyre CR, Seale H, Dung TC, Hien NT, Nga PT, Chughtai AA, Rahman B, Dwyer DE, Wang QY (2015b) A cluster randomised trial of cloth masks compared with medical masks in healthcare workers. BMJ Open 5(4):e006577

Mahase E (2021) Covid-19: are cloth masks still effective? And other questions answered. BMJ 372:n432

Maher B, Chavez R, Tomaz GCQ, Nguyen T, Hassan Y (2020) A fluid mechanics explanation of the effectiveness of common materials for respiratory masks. Int J Infect Dis 99:505–513

Moher D, Shamseer L, Clarke M, Ghersi D, Liberati A, Petticrew M, Shekelle P, Stewart LA (2015) Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. Syst Rev 4:1

Mueller AV, Eden MJ, Oakes JM, Bellini C, Fernandez LA (2020) Quantitative Method for Comparative Assessment of Particle Removal Efficiency of Fabric Masks as Alternatives to Standard Surgical Masks for PPE. Matter 3:950–962

Neupane BB, Mainali S, Sharma A, Giri B (2019) Optical microscopic study of surface morphology and filtering efficiency of face masks. PeerJ 7:e7142

O'Kelly E, Pirog S, Ward J, Clarkson PJ (2020) Ability of fabric face mask materials to filter ultrafine particles at coughing velocity. BMJ Open 10(9):e039424

Organization WH (2020a) Advice on the use of masks in the community, during home care, and in health care settings in the context of COVID-19: interim guidance, 19 March 2020, World Health Organization

Organization WH (2020b) Advice on the use of masks in the context of COVID-19: interim guidance, 5 June 2020, World Health Organization

Pacitto A, Amato F, Salmatonidis A, Moreno T, Alastuey A, Reche C, Buonanno G, Benito C, Querol X (2019) Effectiveness of commercial face masks to reduce personal PM exposure. Sci Total Environ 650:1582–1590

Park S, Jayaraman S (2020) From containment to harm reduction from SARS-CoV-2: a fabric mask for enhanced effectiveness, comfort, and compliance. J Textile Inst 112(7):1144–1158

Pei C, Ou Q, Kim SC, Chen SC, Pui DYH (2020) Alternative face masks made of common materials for general public: Fractional filtration efficiency and breathability perspective. Aerosol Air Qual Res 20:2581–2591

Rengasamy S, Eimer B, Shaffer RE (2010) Simple respiratory protection - Evaluation of the filtration performance of cloth masks and common fabric materials against 20–1000 nm size particles. Ann Occup Hyg 54:789–798

Rodriguez-Palacios A, Cominelli F, Basson AR, Pizarro TT, Ilic S (2020) Textile masks and surface covers—a spray simulation method and a "Universal Droplet Reduction Model" against respiratory pandemics. Front Med 7:260. https://doi.org/10.3389/fmed.2020.00260

Santos M, Torres D, Cardoso PC, Pandis N, Flores-Mir C, Medeiros R, Normando AD (2020) Are cloth masks a substitute to medical masks in reducing transmission and contamination? A systematic review. Braz Oral Res 34

Scells H, Zuccon G, Koopman B, Deacon A, Azzopardi L, Geva S (2017) Integrating the framing of clinical questions via PICO into the retrieval of medical literature for systematic reviews, Proceedings of the 2017 ACM on Conference on Information and Knowledge Management, pp. 2291–2294

Shakya KM, Noyes A, Kallin R, Peltier RE (2017) Evaluating the efficacy of cloth facemasks in reducing particulate matter exposure. J Expo Sci Environ Epidemiol 27:352–357

Sunjaya AP, Morawska L (2020) Evidence Review and Practice Recommendation on the Material, Design, and Maintenance of Cloth Masks. Disaster Medicine and Public Health Preparedness, 1–5

Szarpak L, Smereka J, Filipiak KJ, Ladny JR, Jaguszewski M (2020) Cloth masks versus medical masks for COVID-19 protection. Cardiol J 27(2):218–219

Tcharkhtchi A, Abbasnezhad N, Zarbini Seydani M, Zirak N, Farzaneh S, Shirinbayan M (2021) An overview of filtration efficiency through the masks: Mechanisms of the aerosols penetration. Bioact Mater 6(1):106–122

Teesing GR, van Straten B, de Man P, Horeman-Franse T (2020) Is there an adequate alternative to commercially manufactured face masks? A comparison of various materials and forms. J Hosp Infect 106:246–253

Tufanaru C, Munn Z, Aromataris E, Campbell J, Hopp L (2020) Chapter 3: Systematic reviews of effectiveness. In: Aromataris E, Munn Z (Editors). JBI Manual for Evidence Synthesis. JBI. Available from https://synthesismanual.jbi.global. https://doi.org/10.46658/JBIMES-20-04

Ueki H, Furusawa Y, Iwatsuki-Horimoto K, Imai M, Kabata H, Nishimura H, Kawaoka Y (2020) Effectiveness of face masks in preventing airborne transmission of SARS-CoV-2. mSphere 5(5):e00637–20

van der Sande M, Teunis P, Sabel R (2008) Professional and homemade face masks reduce exposure to respiratory infections among the general population. PLoS One 3:e2618

Varallyay C, Li N, Case B, Wolf B (2020) Material suitability testing for non-medical grade community face masks to decrease viral transmission during a pandemic. Disaster Medicine and Public Health Preparedness 1–7. https://doi.org/10.1017/dmp.2020.262

Wang DJ, You YJ, Zhou XL, Zong ZY, Huang H, Zhang H, Yong X, Cheng YF, Yang L, Guo Q, Long YL, Liu Y, Huang J, Du L (2020) Selection of homemade mask materials for preventing transmission of COVID-19: a laboratory study. Plos One 15(10):e0240285

Wen Z, Lu J, Li J, Li N, Zhao J, Wang J, Yu L (2010) Yang W (2010): Determining the filtration efficiency of half-face medical protection mask (N99) against viral aerosol. Aerobiologia (bologna) 26(3):245–251

Whiley H, Keerthirathne TP, Nisar MA, White MAF, Ross KE (2020) Viral filtration efficiency of fabric masks compared with surgical and n95 masks. Pathogens 9:1–8

Wiersinga WJ, Rhodes A, Cheng AC, Peacock SJ, Prescott HC (2020) Pathophysiology, transmission, diagnosis, and treatment of coronavirus disease 2019 (COVID-19): a review. JAMA 324:782–793

Xiao L, Sakagami H, Miwa N (2020) A new method for testing filtration efficiency of mask materials under sneeze-like pressure. In Vivo 34:1637–1644

Yang P, Seale H, MacIntyre CR, Zhang H, Zhang Z, Zhang Y, Wang X, Li X, Pang X, Wang Q (2011) Mask-wearing and respiratory infection in healthcare workers in Beijing, China. Braz J Infect Dis 15:102–108

Zangmeister CD, Radney JG, Vicenzi EP, Weaver JL (2020) Filtration Efficiencies of Nanoscale Aerosol by Cloth Mask Materials Used to Slow the Spread of SARS-CoV-2. ACS Nano 14:9188–9200

Zhao M, Liao L, Xiao W, Yu X, Wang H, Wang Q, Lin YL, Kilinc-Balci FS, Price A, Chu L, Chu MC, Chu S, Cui Y (2020) Household Materials Selection for Homemade Cloth Face Coverings and Their Filtration Efficiency Enhancement with Triboelectric Charging. Nano Lett 20:5544–5552