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Systematic Review

Which Type of Respiratory Mask Provides the Best Protection Against SARS-CoV-2 (COVID-19)? A Systematic Review of the Efficacy of Different Types of Respiratory Masks Against SARS-CoV-2 (surgical masks, cotton masks, N95, Kn95, FFP2, FFP3)

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Abstract

Introduction: The COVID-19 pandemic has grasped the world since late 2019. With an infectivity rate (R0) of approximately 2.5, higher than that of Influenza, SARS-CoV and MERS-CoV, and its ease of transmission through droplets, it has burdened our world with disease. COVID-19 infections produce a wide range of symptoms with the more severe symptoms presenting as complications of the disease. The increased morbidities and mortalities brought unto us by the SARS-CoV-2 virus have earned the disease the position of a public health emergency.

Aim: The purpose of this systematic review is to provide more information on the protective efficacies of cloth and surgical masks, N95, KN95, FFP2 and FFP3 respirators against SARS-CoV-2 and similar particles. A total of 8 reputable databases (PubMed, JOSTOR Journals, CINAHL, MedLINE, ERIC, ScienceDirect, Google Scholar and The Directory of Open Access Journals) have been searched for articles as guided by a set inclusion and exclusion criteria. A program was utilized to maintain a detailed record of the articles. A total of 10 articles were included in this review.

Results: Masks have been proven to reduce infection rates of COVID-19 to an extent. Cloth masks composed of different blends of fabrics, in addition to numerous layers provide the wearer with a higher level of protection as compared to a cloth mask made of one material and one layer. Surgical masks provide better protection; however, this level of protection is significantly affected by the fit of the mask, and the masks' certification of validity (NIOSH-approved, EN 14683). N95, KN95, FFP2 and FFP3 respirators all exceed the levels of protection provided by cloth and surgical masks. These respirators provide the highest levels of protection against SARS-CoV-2.

Conclusion: Cloth masks provide some protection against SARS-CoV-2, followed by the surgical mask then by respirators. Respirators in particular have been proven to reduce the transmission of SARS-CoV-2 in high-risk healthcare settings. Despite these promising conclusions, research targeting the understanding of proper mask fit, design, quantitative fit testing for cloth and surgical masks are areas that will re-shape our understanding of mask FE.

Keywords: *Systematic Review; Efficacy; Efficiency; Respiratory Protection; SARS-Cov-2; COVID-19; Cloth, Fabric; Surgical; Mask; Respirator; N95; Kn95; Ffp2; Ffp3; Filtering Face Piece*

Abbreviations

AGPs: Aerosol Generating Procedures

ASTM: American Society for Testing and Materials

BFE: Bacterial FE

CASP: Critical Appraisal Skills Programme

CDC: Centre for Disease Control and Prevention

CI: Confidence Intervals

Cm: Centimetre

CUHNFT: Cambridge University Hospitals NHS Foundation Trust

COVID-19: Coronavirus Disease 2019

EUA: Emergency Use Authorization

FDA: Food and Drug Administration

FFP: Filtering Face Piece

FE: Filtration Efficiency / Efficacy

GOU: Government of Uganda

JBI: Joanna Briggs Institute

L: Litre

m/s: Metre per Second

Mg/m: Milligram per Metre

Min: Minute

Ml: Millilitre

mm: Millimetre

mmHg: Millimetre Mercury

µm: Micrometre

NDA: Uganda National Drug Authority

NHS: National Health Service

NIOSH: National Institute for Occupational Safety and Health

nm: Nanometre

PCR: Polymerase Chain Reaction

PFE: Submicron Particle Filtration Efficiency

PICO: Population, Intervention, Comparison, Outcome

PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analysis

RCT: Randomized Control Trial

RPE: Respiratory Protection Equipment

RT-PCR: Reverse Transcriptase Polymerase Chain Reaction

SARS-COV: Severe Acute Respiratory Syndrome Coronavirus

SD: Standard Deviation

U. K: United Kingdom

U.S. A: United States of America

VFE: Viral FE

WHO: World Health Organization

OR: Odds Ratio

RR: Relative Risk

Introduction

COVID-19 was discovered in late 2019 in Wuhan, China, when a surge of unexplained cases of pneumonia were observed [1]. The virus was isolated and revealed that a strain of the *Coronaviridae* family was the culprit. The novel, positive-stranded RNA virus was given the name Severe Acute Respiratory Syndrome Coronavirus -2 (SARS-CoV-2). SARS-CoV-2 had demonstrated a higher infectivity rate ($R_0 = 2.5$) than its relatives (SARS-CoV, MERS-CoV) [1,2]. Furthermore, it has a broad tissue tropism and affects the endothelial lining of blood vessels, thus causing hypercoagulability and affecting the majority of the body's organs, specifically those that deal with the angiotensin-converting enzyme 2. The incubation period of SARS-CoV-2 starts a few days before the onset of symptoms and continues throughout the symptomatic stage. However, some individuals have been shown to be infected but exhibit no symptoms [3]. The presence of asymptomatic cases can lead to an unnoticed transmission of COVID-19, thereby hindering our attempts to gain control over the spread of this disease [1].

COVID-19 affects most of the body's systems, causing symptoms such as fever, chills, cough, dyspnoea, fatigue, headache, sore throat, nausea, diarrhoea, conjunctivitis, altered levels of consciousness and skin discolorations [4,5]. According to a variety of studies, COVID-19 infections are also associated with multiple complications. In general, respiratory infections are linked to up to a six-fold increase in risk of severe cardiovascular complications [6]. COVID-19 is not exempt from this trend, as it has been associated with severe cardiovascular complications as well as respiratory, neurological and gastrointestinal complications [7]. Among the most severe are myocarditis, acute myocardial infarction, heart failure exacerbation, encephalitis and Guillain-Barré syndrome (GBS) [7,8]. Data collected in the U.S.A had observed a fluctuation in hospitalization rates due to COVID-19 since March of 2020, with an increase throughout the months of November 2020 to February 2021. Moreover, the majority of hospitalizations indicate that approximately 53% of the patients had hypertension, 49.8% were obese, and 42.9% had a metabolic disease [9]. Approximately 614,531 deaths had occurred due to COVID-19 from the 8th to the 14th of August 2021. 65.7% of deaths had occurred in a healthcare facility, and 79% in older age groups (> 65) [10]. As of April 2021, (2nd to the 6th of April) an average of 108,118 occupied beds in the U.K had been observed, of which an average of 2,680 occupancies were due to COVID-19 infections. 16% of COVID-19 hospitalizations were mechanically ventilated. Furthermore, the average number of absences of healthcare staff due to COVID-19 was approximately 14,112 throughout the UK [11]. Hence, it is clear that COVID-19 infections have led to significant increases in morbidity and mortality. In addition, COVID-19 has provided additional risks to older age groups, individuals with comorbidities and healthcare workers. Affected healthcare workers would affect the workflow of healthcare facilities [12].

As of the 7th of July, 2022, a total of 550,218,992 COVID-19 cases have occurred globally, with 6,343,783 deaths [13]. Medications such as ivermectin have been proven to be safe and effective against COVID-19. In general, medications such as these could be used to relieve the burden of COVID-19 particularly in low and middle socioeconomic countries [14,15]. When paired with COVID-19 vaccinations and respiratory protection, the immense burden of COVID-19 has decreased and become more manageable [16]. Nevertheless, vaccinations have not completely prevented COVID-19 infections from occurring. Factors such as human behaviour and evolving COVID-19 variants may contribute to the continuous risk we face during this pandemic. Hence, infection prevention and control measures remain to be a vital cornerstone in protecting one-self from COVID-19 [17-20].

The aim of this review was to focus on providing better clarification on the most effective mask against SARS-CoV-2. A better understanding of the most effective mask would reduce transmission of COVID-19 and subsequent morbidities and mortalities. The most efficient mask, a mask with better protective levels, easily accessible, comfortable and re-usable would shield individuals, specifically those at high risk against COVID-19, more efficiently. It would also reduce subsequent wastes brought unto us by the pandemic. Healthcare workers and healthcare facilities would have a better accessibility to masks in general, specifically more protective masks, thus ensuring the continuous flow of medical care.

Transmission routes of SARS-CoV-2

Droplets are tiny secretions, usually 5 - 10 microns in diameter, which are expelled from a person by coughing or sneezing. Microorganisms use this respiratory droplet as a gateway to leave the infected host, thereby spreading the disease [4,21]. The infected person and the susceptible host must be in close proximity for droplet or contact transmission to occur [22]. Aerosols are usually < 5μm in diameter, and due to their small size, they can float in the air for longer periods of time and travel more than one meter [4,21,23]. Additional precautions are required for this transmission route, such as the use of a respirator in addition to environmental interventions. According to research, the smaller the aerosol, the easier it penetrates the alveolar space [23].

SARS-CoV-2 can cause illness by entering the human body through several routes including contact, droplet, airborne, fomite, fecal-oral and blood-borne [4]. The main transmission route has been concluded to be via droplets, either directly or indirectly via contact with respiratory secretions. Hence, SARS-CoV-2 can travel from an individual in respiratory droplets, generated during sneezing or coughing, that are present within one metre of a susceptible host. The respiratory droplet can enter the respiratory system or the eyes of the host either directly-by inhalation- or indirectly -by touching the contaminated surface and then their nose, mouth or eyes [4].

Positive pressure ventilation, endotracheal intubation, airway suctioning, tracheostomy, sputum induction, bronchoscopy, and nebulizer treatment can all result in airborne transmission of SARS-CoV-2 [4,24]. The WHO in conjunction with the scientific community have debated on whether SARS-CoV-2 can transmit through aerosols, to which a number of theories were generated. The theories suggests that (a) respiratory droplets may evaporate thereby creating an aerosol, and (b) normal breathing and talking generate aerosols. The inhalation of an aerosol carrying the SARS-CoV-2 virus could lead to an infection if the aerosols contained a sufficient amount of the virus. The threshold of the number of infectious aerosols and the ability of respiratory droplets to evaporate into aerosols has not yet been studied in the case of SARS-CoV-2 [4].

In conclusion, in the case of respiratory transmission, SARS-CoV-2 can be transmitted mainly through droplets generated from respiratory secretions. Airborne transmission routes are limited to AGPs.

Respiratory protection items

Respiratory protection items provide protection to the wearer by removing contaminants from the air entering the respiratory tract [25]. An item of respiratory protection is usually one that has been certified by the CDC, WHO, FDA, EN, or NIOSH as offering some sort of protection against respiratory-based infections [25,26]. Non-powered respirators are more commonly utilized for healthcare purposes due to their availability, ease of usage and the abundance of oxygen in the surrounding air [27]. The type of RPE to be worn by an individual is determined by the (a) the wearer's health, (b) the task at hand and (c) the surrounding environment.

The CDC's recommendation to wear masks in public during the pandemic had popularized cloth masks. The public was informed that these masks should be constructed of two or more layers of washable, breathable cloth, in addition to other specifications. A cloth mask is considered less protective if it is not made with at least two layers, is not worn appropriately, is not washed frequently, and/or is not adequately sealed around the face [25]. Furthermore, studies conducted after the emergence of COVID-19 have indicated that when compared to other masks, cloth masks provide the least amount of protection against viral respiratory illnesses. Protection varies depending on the number of layers and how well the cloth mask is worn and fit. Nonetheless, its efficacy is thought to be lower than that of any other masks [25,28].

Surgical masks are disposable masks that filter out small particles and act as a fluid barrier. These masks are usually used in healthcare settings and are comprised of three layers -an outer hydrophobic, a middle filtering and an inner absorbent layer [29]. The filtering layer is usually composed of microfiber material that can be electrostatically charged. The microfiber material alone has been shown to have a high FE and a low resistance due to its porous structure. When combined with an electrostatic charge, the FE of this material can increase to up to 20 times without altering the resistance of the material itself [30]. Qualitative testing of surgical masks include the ASTM F2100 and the EN1468:2019. The ASTM F2100 states that a surgical mask must have a BFE of ≥95%, a PFE of ≥95% and a resistance to blood efficiency of ≥80mmHg [31]. A tiny metal strip secures the mask to the nose, allowing less air to pass to the individual without passing through the mask [29].

N95, KN95, and FFPs are high-filtration masks that filter at least 95% of airborne particles [32]. When compared to a surgical mask, these masks can filter incredibly minute particles. These respirators are made to form a tight seal around the wearer's face, offering further protection.

N95 respirators are certified by NIOSH and are one of the most commonly used type of respirators in healthcare. These respirators are not resistant to oil and have a FE of ≥ 95%, hence the name N95. In comparison to a surgical mask, the N95 respirator has a more efficient filtering layer and a tighter fit and seal [30]. The filter layer is 3 times thicker than the inner and outer layers and comprises of approximately 50% of the thickness of the respirator. It is composed of electrostatically charged nylon, cotton, polyester and polypropylene. The combination of these materials allows for this respirator to have better durability and filtration as compared to other RPEs. Polyester and polypropylene fibres are acid, alkaline and heat resistant (up to 150^{0}C). Additionally, the polypropylene fibres are tightly wound in a random fashion to provide a more efficient trap for the inhaled particles [30,33]. The overall design of the N95 respirator reduces the amount of air that may pass to the individual without passing through the respirator itself. Furthermore, it provides a highly efficient barrier from infectious inhaled particles thus increasing protection [30].

FFPs, particularly FFP2 and FFP3, are types of high-filtering respirators that provide up to 16 times more protection than surgical masks. They have been proven to provide protection from very minute particles such as asbestos. FFPs are required to meet the European standard EN 149:2001, in which case the FFP2 must have a minimum FE of 94% and a maximum internal leakage limit of 11%, and the FFP3 99% and 5% respectfully [34,35]. The N95 and the FFP2 are similar in their FEs and are the most recommended when performing AGPs [34].

KN95 respirators are a more recently introduced high-filtration respirator and are required to meet specifications as per Chinese standards. EUA-approved, and FDA approved KN95 respirators have been shown to have FEs similar to that of the N95 respirator. The KN95 respirator is made up of 4 layers- an outer, filter, cotton, and inner layers. Approximately less than 20% of the thickness of the respirator is due to the filter layer alone and 70% is due to the cotton layer. Despite the thinner filter layer as compared to the N95, the KN95 respirators have 10 times smaller pore-sizes than the N95s, thereby compensating for the lack of mass [33].

At least 95% of hazardous particles would be filtered out by a properly worn respirator. According to studies, even a poorly worn respirator can give up to 90% protection from airborne particles [36]. Non-certified respirators carry the risk of not providing sufficient protection as compared to their certified counterparts [33]. Nevertheless, it is undeniable that respirators are superior to surgical masks in regard to protection. The overall designs of the N95, FFP2 and FFP3 respirators provide better protection partially due to their tight fit. This is achieved by performing a fit test to ensure the most appropriate fit for each individual. Thereby, the use of these particular respirators is limited to certain settings in which (a) high-risk circumstances are involved, (b) an appropriate fit test kit and tester are available [37].

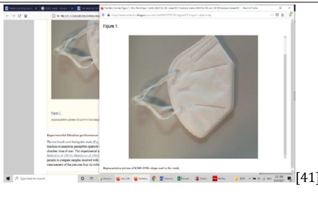
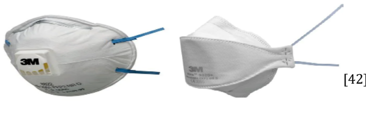
Type	Design	Image
Cloth Mask	Washable, permeable fabric masks ≥2 layers that can be reused [25] [38].	 [39]
Surgical Mask	Three-layered disposable masks (an outer hydrophobic, a middle filtering, electrostatically charged MB fabric, and an inner absorbent layer). Secured via a thin metal strip [29][30]	 [40]
N95 Respirator	High-filtering respirators that are made of multiple layers (middle electrostatically charged MB fabric). They are meant to tightly seal around the wearer's face and filter at least 95% of airborne particulates [30][32]	 [29]
KN95 Respirator	Composed of 4 layers- an outer one, a filter, a cotton layer, and an inner layer [33] .	 [41]
FFP2	A high-filtering, light-weight respirator that is designed to provide comfort and protection from dust and mists [42] .	 [42][43]
FFP3	A light-weight respirator, designed to accommodate a wide variety of facial movements while providing respiratory protection against higher levels of fine dust, mists and metal fumes. Can be valved [44][45] .	 [44][45]

Table 1.0: *Types of Masks.*

Methods

Which respiratory protection mask offers the most protection against SARS-CoV-2?

This question was formulated by using the PICO framework. The PICO framework is a recognised strategy utilized to create a focused research question. It consists of 4 selected components that assist in clarifying the proposed question [46]. These components allow the researcher to identify the clients affected, the interventions required and the important outcomes. Additionally, it aids in the identification of key terms and inclusion and exclusion criteria [47]. These components are explained further in table 2.0.

P: Population	Individuals above the age of 18 and healthcare providers all over the world.
I: Intervention	The use of either a cloth mask, surgical mask, N95 respirator, Kn95 respirator, FFP2 respirator, or FFP3 respirator in the presence of SARS-CoV-2/similar particles.
C: Comparison	Comparison of FEs between cloth masks, surgical masks, N95 respirators, Kn95 respirators, FFP2 respirators, FFP3 respirators against SARS-CoV-2/ Similar particles.
O: Outcome	The reduction of SARS-CoV-2 transmission as based on mask type and risk level.

Table 2.0: *PICO Framework in Detail.*

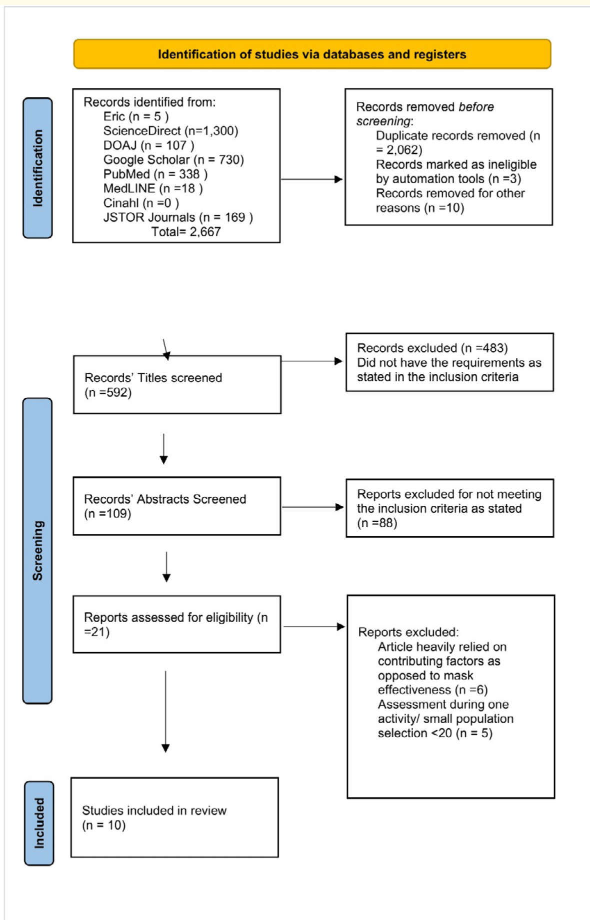
The proposed question and framework aim to identify the mask with the highest protection against SARS-CoV-2 and as based on risk levels. The included masks in this review are a) cloth masks, b) surgical masks, c) N95 respirators, d) KN95 respirators, e) FFP2 and f) FFP3. These masks will be assessed for their protective efficacies against SARS-CoV-2 or similar particles. The effect of each mask will be compared to the other in the presence of SARS-CoV-2. As discussed above, certain groups are at a higher risk either due to their proximity to infectious cases (healthcare workers) or due to co-morbidities or old age. Thereby the outcome of this review is to identify the levels of protection provided by respiratory masks to each of these groups and the general public as based on the level of risk of COVID-19 infection.

As part of a systematic review an inclusion and exclusion criterion have been set to provide a more structured paper that would answer the research question [48]. Table 3.0 clarifies the criteria for inclusion and exclusion.

Inclusion
1. Any papers published from 2011-2021. 2. Papers published in the English language. 3. Randomised control trials, observational studies (case-control, cohort), experimental studies and mixed method studies. 4. Papers discussing the filtration performance and/or the effectiveness of surgical/ cloth masks / N95 / Kn95 / FFP2 /FFP3 respirators against SARS-CoV-2 or similarly sized particles. 5. Papers discussing the prevention of droplet or airborne transmission of SARS-CoV-2 /similarly sized particles via the included masks only. 6. Open access articles.
Exclusion
1. Papers that address or describe policies related to respiratory protection programmes, fit testing, extended use or re-use of masks, plans/interims, outbreak management, shortages, financing, or evaluating a facility's readiness. 2. Papers that discuss respiratory metabolism or respiratory protective mechanisms other than the use of masks (i.e., enzymes, disinfection, hand hygiene). 3. Papers that discuss/compare other transmission routes (i.e., contact, fecal-oral), other methods for disease prevention, ventilation, vaccination/other pharmaceutical interventions. and/or papers comparing COVID-19 to other diseases. 4. Papers that discuss disinfection processes of used masks, level of contamination of used masks, compliance/ challenges of PPE during the pandemic, detection/cleaning processes associated with COVID-19, and/or medical services given to COVID-19 patients. 5. Environmental or artificial/man-made factors that contribute to the masks' increased or decreased efficacy. 6. Papers that highlight effective respiratory protection donning and doffing techniques, as well as approaches to improve the wear of respiratory protection devices. 7. Papers addressing the usage of masks in sectors other than building, renovation, and/or firefighting. 8. Papers discussing the impact of the pandemic, the burden of face masks and/or subsequent waste on our environment, and/or the rationale for universal masking. 9. Papers that discuss the efficiency of masks other than those included in the review and/or against diseases other than COVID-19/ SARS-CoV-2 particles (or similar particles). 10. Papers discussing the transmission/inactivation/shedding of the SARS-CoV-2 virus and/or asymptomatic COVID-19 patients. 11. Papers discussing the effect mask wearing on bodily functions (speech, breathing, life-saving procedures). 12. Papers discussing the emergence/efficacy of new masks and/or the protective effect of isolation rooms.

Table 3.0: *Inclusion and Exclusion Criteria.*

A total of 8 databases- Google scholar, PubMed, MedLINE, JSTOR Journals, CINAHL, ERIC, ScienceDirect and The Directory of Open Access Journals were searched for relevant articles. Appropriate search terms and Boolean operators had been used to produce results in the databases (e.g.: "Surgical mask efficacy AND SARS-CoV-2", "Cloth mask efficacy AND COVID-19, "N95 respirator effectiveness AND SARS-CoV-2", "Kn95 respirator effectiveness AND COVID-19"). were. The search yielded a total of 269,603 results. Of the 269,603 results only 2,667 articles were entered into a software for proper management, control and search. Articles were reduced by initially removing duplicates then screening the articles as per the inclusion and exclusion criteria. A final collection of 10 articles were included in this review. 8 of the included articles were experimental studies and only two were observational studies. This is explained thoroughly in figure 1 below.



*Consider, if feasible to do so, reporting the number of records identified from each database or register searched (rather than the total number across all databases/registers).

**If automation tools were used, indicate how many records were excluded by a human and how many were excluded by automation tools.

Figure 1.0: *PRISMA Flowchart- Demonstrating the process of inclusion and exclusion [51].*

Ethical Considerations

A systematic review would provide us with evidence to choose the most appropriate mask to protect ourselves against COVID-19. In addition, it would assist in discovering new ideas and illuminating other theories [49]. Systematic reviews do not collect sensitive or confidential information, and the idea of test subjects is not included. These reviews collect relevant matters and emphasize connections, difficulties, and/or limitations by searching through publicly accessible papers, publications and experiments. Institutional ethics should be considered when creating a systematic review, such as that required by universities and facilities [50].

Results

The data selected from the included articles will be extracted to involve only the relevant data to the aim of this review. This review will not analyse statistical data from any of the included studies as it is a systematic review rather than a meta-analysis. Furthermore, the quality of the included articles will be highly scrutinized via the appropriate tools (i.e., CASP checklists, JBI checklists) as seen in the Critical Appraisal section and discussed thoroughly in the Discussion section below. The following table 4.0 features summarized data from the included articles.

				FE (Inward Protection)				**Level of Outward Protection**
Mask	**Aydin., *et al.***	**Darby., *et al.***	**Ferris., *et al.***	**Hill., *et al.***	**Maurer., *et al.***	**Sterr., *et al.***	**Mboowa., *et al.***	**Tanisali., *et al.***
Surgical mask	Median droplet blocking efficacy: *high momentum droplet* 98.5%(1.83 ± 0.15) *low momentum droplet* = 99.7%	**EN14683 certified** = no detectable penetration, some leakage.	-------------	*60nm droplet* = 88% filtration, *125nm droplet* = 88% filtration.	------------	**Certified** *worn FE* = 41.2 ± 4%, **Non-certified** = *Material FE* = 63.4 ± 18.7%, *Worn FE* = 14.2 ± 2.8%	****NDA and GOU approved** FE *Not decontaminated/70% ethanol* = ≥99.9%. ****Not NDA/GOU approved**: FE *Not decontaminated/ 70% ethanol* = ≥ 99.9%.	**Single Surgical mask** level of contamination = 61cm^2, **double surgical mask** level of contamination = 67cm^2.
FFP2	----------------------	----------------	-------------	----------------	--------------	**Material FE = 98.2% ± 1%** **Worn FE** = 65% ± 27%	------------------------	-----------------
FFP3	----------------------	----------------	31-100% protective against SARS-CoV-2.	----------------	--------------	----------------	--------------------------	--------------------

Eterna FFP (single layer)	------------------------	----------------	-------------	---------------	FE = 99.8% ± 0.13	----------------	----------------------------	------------------
N95	------------------------	----------------	-------------	---------------	--------------	----------------	----------------------------	Level of contamina-tion: **Valved** : 113cm² / **Valveless**: 52cm²
N95 1 layer	------------------------	----------------	-------------	*60nm and 125 nm droplets* = 90%. (SD = 0)	--------------	----------------	----------------------------	------------------
N96 2 layers	------------------------	----------------	-------------	*60nm and 125 nm droplets* = 90%. (SD = 0)	--------------	----------------	----------------------------	------------------
KN95	------------------------	----------------	-------------	*60nm and 125 nm droplets* = 98%. (SD = 0)	--------------	*Material FE* = 93.8% ± 3.9% ; *Worn FE* = 41.2% ± 4%	****NDA & GOU approved** = FE *Not de-contaminated /70% ethanol* = ≥99.9%	------------------
Valved N95 (3M 8511)	------------------------	----------------	-------------	*60nm droplet* = 95% filtration and *125 nm droplet* = 98%. (SD = 90-100)	--------------	----------------	----------------------------	------------------
Cloth	------------------------	----------------	-------------	---------------	--------------	*Material FE* = 27.8% ± 25.4% ; *Worn FE* = 11.3% ± 3.1%	----------------------------	Level of contami-nation = 63cm²

FE Per material type / number of layers	
Aydin et al. (median droplet blocking efficiency)	
Used shirt, knit, 100% cotton	96.8% (1.37 ± 0.06)
New undershirt,knit,100% cotton	81.9% (10.70 ± 0.66)
New quilt cloth, woven, 100% Cotton	71.7% (8.67 ± 0.12)
Used undershirt, knit, 75% Cotton, 25% polyester	72.5% (11.97 ± 0.25)
Used shirt, woven, 70% Cotton, 30% Polyester	93.6% (1.8)
New T-shirt, knit, 60% Cotton, 40% Polyester	83.1% (7.23 ± 0.5)
New quilt cloth, woven, 35% Cotton,65% Polyester	81.8% (5.07 ± 0.21)

New bedsheet, woven, 100% Polyester	94.8% (3.23 ± 0.36)
New dishcloth, napped, 80% Polyester,20% Polyamide	98.2% (6.53 ± 0.21)
Used shirt, woven, 100% Silk	92.9% (3.9 ± 0.36)
Used shirt, woven, 100% Silk	98.7% (2.1 ± 0.61)
New undershirt, knit, 100% Cotton (2 Layers)	94.1% (5.53 ± 0.35)
New undershirt, knit, 100% Cotton (3 Layers)	98.9% (3.77 ± 0.06)
New T-shirt, knit, 60% Cotton,40% Polyester (2 Layers)	98.1% (3.87 ± 0.06)
New T-shirt, knit, 60% Cotton, 40% Polyester (3 Layers)	>98.1% (2.63 ± 0.06)
Darby et al.	
3 layer cloth (2 layers = 0.4nm thick, 80% polyester, 20% elastane +1 filter layer 1mm thick, 100% polypropylene)	Minimal penetration, some leakage.
1 layer cloth (1 mm thick)	High penetration, some leakage.
Bandana (0.3 mm folded 3x)	High penetration, low leakage.
Hill., *et al.*	
Cotton 1 layer	60nm = 26% filtration, 125nm = 15% filtration (SD = 10-35)
Dust mask	60nm = 60% filtration, 125nm = 35% filtration (SD = 3-5)
Coffee filter	60nm = 26% filtration, 125nm = 38% filtration (SD = 20-42)
Cotton 2 layer	60nm = 22% filtration, 125nm = 45% filtration (SD = 8-55)
Shop Towel	60nm = 38% filtration, 125nm = 50% filtration (SD = 5-8)
Filtrete 1500	60nm = 78% filtration, 125nm = 70% filtration (SD = 60-88)
Surgical Wrap	60nm = 90% filtration, 125nm = 75% filtration (SD = 5-10).
ShopVac	60nm and 125 nm = 90% filtration (SD = 0)
FTR	60nm and 125nm = 98% filtration (SD = 0)
Maurer et al.	
Hermko 9920 (100% polyester, 1 layer)	FE = 34.9% ± 1.25
Devetex (72% viscose, 28% polyester, multifilament yarn, 1 layer)	FE = 41.3% ± 2.39
HB Protective (98% polyester, 2% carbon, 1 layer)	FE = 44.3% ± 1.69
Wegerich (out 100% polyester, in fleece 100%, propylene, 3 layers)	FE = 44.9% ± 0.32
Wolford (91% polyamide, 9% elastane, 2 layers)	FE = 45.3% ± 2.18
Trigema/Armedangels (50% cotton, 50% polyester, 2 layers)	FE = 50.1% ± 0.72 / FE = 59.8% ± 1.8
UYN (synthetic fiber, texlyte nano, 1 layer)	FE = 59.7% ± 1.48
Van Laack (100% cotton, 3 layers)	FE = 61.3% ± 1.6
Cotonea (100% bio-cotton)	FE = 62.5% ± 0.85
Falke 44802 (Out = knitted 65% polypropylene, 35% polyamide, midlayer = microfilament fleece, in = 70% polyester, 30% polyamide, 2 layers)	FE = 86.4% ± 0.81

Falke 44801 (Out = knitted 65% polypropylene, 35% polyamide, midlayer = microfilament fleece, in = 70% polyester, 30% polyamide, 3 layers)	FE = 88.7% ± 0.18
Eterna and Jungfeld (1 layer cotton)	Eterna = FE = 37.2% ± 0.85 / Jungfeld = FE = 46.7% ± 1.38
Medima and Mey (2 layer cotton)	Medima = FE = 46.8% ± 2.60, Mey = FE = 55% ± 1.67
Mboowa., *et al.*	
Single layer polypropylene	FE Not decontaminated/ 70% ethanol/ washed sundried = ≥99.9%
Single layer thick material with thick elastic straps	FE Not decontaminated/ 70% ethanol/ washed sundried / washed ironed = ≥99.9%
Single layer thick material single elastic straps	FE Not decontaminated/ 70% ethanol/ washed sundried/ washed ironed = ≥99.9%
Double layer with kitenge out and cotton in	FE Not decontaminated/ 70% ethanol/ washed sundried/ washed ironed = ≥99.9%
Single kitenge with elastic straps	FE Not decontaminated/ 70% ethanol/ washed sundried/ washed ironed = ≥99.9%
Double layer non elastic straps	FE Not decontaminated/ 70% ethanol/ washed sundried/ washed ironed = ≥99.9%
Face scrub cloth with elastic straps	FE Not decontaminated/ 70% ethanol/ washed sundried/ washed ironed = ≥99.9%
Thick material with single elastic strap	FE Not decontaminated/ 70% ethanol/ washed sundried/ washed ironed = ≥99.9%
FE Based on Mask Type and Wearer/s	
Ueki., *et al.*	

No mask for the receiver and the spreader	At **25 cm** from each other: Viral Titer = 100 (5X10^{5}PFU) , Viral mRNA = 100(5X10^{5}PFU)		At **50 cm** from each other: Viral Titer = 45 (5X10^{5}PFU) , Viral mRNA = 38(5X10^{5}PFU)	At **100 cm** from each other: Viral Titer = 31 (5X10^{5}PFU) , Viral mRNA = 23(5X10^{5}PFU)
	No mask	**Cotton**	**Surgical**	**N95**
Receiver wearing and 50cm away from spreader	Viral Titer = 100 (5X10^{5}PFU) , Viral mRNA = 100(5X10^{5}PFU)	Viral Titer = 83 (5X10^{5}PFU) , Viral mRNA = 63(5X10^{5}PFU)	Viral Titer = 53 (5X10^{5}PFU) , Viral mRNA = 50(5X10^{5}PFU)	Viral Titer = 43 (5X10^{5}PFU) , Viral mRNA = 14(5X10^{5}PFU)
Spreader wearing and 50cm away from receiver	Viral Titer = 100 (5X10^{5}PFU) , Viral mRNA = 100(5X10^{5}PFU)	Viral Titer = 24 (5X10^{5}PFU) , Viral mRNA = 43(5X10^{5}PFU)	Viral Titer = 27 (5X10^{5}PFU) , Viral mRNA = 42(5X10^{5}PFU)	Viral Titer = 5 (5X10^{5}PFU) , Viral mRNA = 4(5X10^{5}PFU)

Receiver wearing and 50cm away from spreader. Spreader wearing cotton only.	Viral Titer = 100 (5X10^5PFU) , Viral mRNA = 100(5X10^5PFU)	Viral Titer = 32 (5X10^5PFU) , Viral mRNA = 33(5X10^5PFU)	Viral Titer = 26 (5X10^5PFU) , Viral mRNA = 31(5X10^5PFU)	Viral Titer = 18 (5X10^5PFU) , Viral mRNA = 11(5X10^5PFU)	
	Spreader = Viral Titer = 45 (5X10^5PFU) , Viral mRNA = 43(5X10^5PFU)				
Receiver wearing and 50cm away from spreader. Spreader wearing surgical mask only.	Viral Titer = 100 (5X10^5PFU) , Viral mRNA = 100(5X10^5PFU)	Viral Titer = 40 (5X10^5PFU) , Viral mRNA = 31(5X10^5PFU)	Viral Titer = 29 (5X10^5PFU) , Viral mRNA = 24(5X10^5PFU)	Viral Titer = 31 (5X10^5PFU) , Viral mRNA = 12(5X10^5PFU)	
	Spreader = Viral Titer = 43 (5X10^5PFU) , Viral mRNA = 57(5X10^5PFU)				

Table 4.0: *Summary of Findings.*

A total of 10 studies were included in this review. 7 out of 10 studies discussed the FEs of surgical masks (including leakages). 8 discussed FEs of cloth masks and FEs of different material types. 3 studies had analysed the FEs of KN95s, and 2 studies for the N95. FEs of FFP2 and FFP3 had been discussed in one study for each. 1 study had discussed the effectiveness of masking in general in reducing SARS-CoV-2 transmission.

Masking in general

Wang., *et al.* assesses the level of reduction of secondary transmission of SARS-CoV-2 provided by face masks, amongst other measures, in households in Beijing, China. In this retrospective cohort study, Wang., *et al.* selects 335 people in 124 different families with at least one laboratory confirmed COVID-19 infection, between the 28th of February to the 27th of March 2020. "Family members" were those who had lived with the infected case 4 days prior and 24 hours after the onset of symptoms. Those identified as family members with secondary transmission were those members who had become infected within the incubation period of the virus (2 weeks). Of the 124 households, 41 had exhibited secondary transmission of COVID-19. The overall secondary attack rate in families was 23%, with the 69.9% of the infections occurring in adults. In conclusion, the highest risk of house-hold transmission was that prior to the onset of symptoms, as those households who had a better adherence to masking had not exhibited secondary transmission [52].

FFP3

A prospective cohort study was conducted in the CUHNFT tertiary hospital with a 1,000-bed capacity. The study was conducted from the 2nd of November 2020 to the 15th of January 2021. COVID-19 infection rates were observed in healthcare workers working in a RED ward (COVID-19) and GREEN wards (non-COVID-19). Before implementing a change of RPEs, COVID-19 infection rates were significantly higher in the RED ward as compared to the GREEN ward ($p = 0.016$). After the surgical masks were replaced with FFP3 on the 22nd of December 2020, the infection rate in both the wards was similar ($p = 0.5$). Furthermore, an obvious association between the COVID-19 community curve and the GREEN wards was observed ($R^2 = 0.88$). However, this association was not observed in the RED wards ($R^2 = 0.01$). Hence, the source of COVID-19 infections in the GREEN ward were linked to the community curve of the disease, while on the RED ward, they were linked to both community-acquired and hospital-acquired COVID-19 infections, with the majority being hospital-acquired. The risk of hospital-acquired SARS-CoV-2 infections in the RED ward was significantly higher than that of community-acquired risk of infection (47x greater than the risk on the GREEN wards [CI: 7.92,?]). Nevertheless, the introduction of FFP3 respirators provided 100% protection against hospital-acquired COVID-19 infections [CI 31.3%, 100%] [53].

Critical appraisal

No.	Checklist Items / Study	Cause and Effect Clear	Similarity between Participants	Participants included in other exposures	Control Group	Multiple Measurements (pre/ post intervention)	Follow-up Completed	Outcome Measured in the Same Way	Outcomes Measured Reliably	Statistical Analysis Used
1	**Aydin *et al.*,2021**	✓	✗	✗	✓	N/A	✓	✓	✓	Unclear
2	**Darby *et al.*, 2021**	✓	✗	✗	✗	✗	✓	✓	✗	✗
3	**Hill *et al.*, 2020**	✓	✗	✗	✗	✓	✓	✓	✓	Unclear
4	**Maurer *et al.* ,2021**	✓	✓	✗	✗	✗	✗	✓	✓	✓
5	**Sterr *et al.*, 2021**	✓	✗	✗	✗	✓	✓	✓	✓	✗
6	**Mboowa *et al.*, 2021**	✓	✗	✗	✓	✓	✓	✓	Unclear	✗
7	**Tanisali *et al.*, 2021**	✓	✗	✗	✓	✓	✓	✓	✓	Unclear
8	**Ueki *et al.*, 2020**	✓	✗	✗	✓	✓	✓	✓	✓	✓

Table 5.0: *Critical Appraisal Using JBI Quasi-Experimental Checklist Summary for Experimental Studies.*

No	Checklist Items / Study	Clear issue?	Recruited in an acceptable way?	Exposure accurately measured?	Outcomes measured reliably?	Confounding factors identified?	Account for confounding factors taken?	Follow-ups complete enough?	Follow-up long enough?	Results?	Precision of results?	Believe the results?	Apply to local population?	Fit with other available evidence?	Implications for practice?
1	**Ferris., *et al.*, 2021**	✓	✗	✗	✗	✗	✗	✓	✓	Table 4.0	Table 4.0	✓	✓	✓	✓
2	**Wang., *et al.*, 2020**	✓	✓	✗	✓	✓	✓	✓	Unclear	Table 4.0	Table 4.0	✓	✓	✓	✓

Table 6.0: *CASP Checklist for Cohort Studies.*

Discussion

Filtration efficacies of 6 commonly used masks against SARS-CoV-2 were examined in a variety of situations. 4 in laboratory settings, 1 in households of infected individuals, and 1 in a COVID-19 ward. The results of each study, despite the study design, have attempted to close the gap of misinformation regarding the 6 masks in general. However, due to the lack of other more realistic study designs, the full and precise understanding of the effectiveness of masks against COVID-19 infections can only be estimated. For instance, Hill., *et al.* and Sterr., *et al.* had concluded the lack of correlation between the FE of the material and FE when worn [54,55]. Moreover, Darby., *et al.*, Hill., *et al*., Maurer., *et al*. and Tanisali., *et al.* had stressed on the importance of proper mask fit. A better fitting mask in general would increase FE [54,56,57,58]. Hence, the results of these studies could be altered by ensuring a proper fit of the mask itself on individuals. The assessment of FE of materials is undeniably beneficial. These studies narrow down the wide selection of possibilities given to us by mask materials and designs. Furthermore, these studies pave the way for the use of high-filtering materials in masks and may subsequently affect mask designs in the future.

4 of the included studies are laboratory-based in design. Laboratory-based studies, in general, can control variables that may negatively influence the results of the study, hence representing a truly experimental and artificial design. However, some variables may be necessary to replicate real-life scenarios, such as environment, humidity, velocities, human breathing fluctuations and so on. Many of the studies included cannot replicate real-life scenarios due to the control required throughout the experiment. To reduce the levels of control throughout the experiment would be quite difficult and may impact the study design in a negative way. Thus, these experiments can make the research and subsequent outcomes less realistic. A combination of experimental studies and real-life studies would collectively yield a more reliable conclusion [59]. Thus, this review attempts to compare the results of laboratory-based study designs with the observational studies included.

The observational study conducted by Wang., *et al.* in Beijing, China had indirectly assessed the protective efficacy of masks in general on household members of an infected individual. Approximately 23% of secondary transmission of COVID-19 was concluded. This study provides evidence that masks are a key factor in eliminating the risk of transmission of SARS-CoV-2. This study had identified cases by applying the local guidelines, thus identifying individuals based on epidemiologically related risk factors, clinical presentation, and RT-PCR. Univariable analysis of primary cases concluded that 96% of cases were mild in severity and 74.2% of cases took more than 2 days to isolate after the onset of symptoms. After 1ry cases were confirmed to have COVID-19, 33.1% had never worn the mask at home, and 36.3% had not isolated. These factors and others were the most significant in associating secondary transmission within the families. The study had ensured complete follow-up with included groups thus providing an accurate estimation of secondary transmission. Wang., *et al.* had concluded that the efficacy of masks can increase when combing proper mask use with other infection control practices such as good hand hygiene, cough etiquette and isolation [52].

The study had not mentioned the masks used throughout the study- whether they were cloth, surgical or respirators. Moreover, approximately 40.5% of confirmed COVID-19 cases can be asymptomatic according to studies [60]. Thereby, it can be confidently assumed that not all those who had not exhibited symptoms did not contract COVID-19. In addition, certain mask types may have led to a higher risk to secondary transmission than other mask types (i.e., cloth masks). Failure to identify the types of masks may have provided an obscure and unclear outcome. Wang., *et al.* clarified the importance of early suspicion, early detection and subsequent timely isolation of individuals suspected/confirmed to have COVID-19. Incompliance to proper isolation and lack of early detection was mentioned in the study. Individuals who had known of their health status had not isolated properly, as discussed above had potentially infected their family members. Moreover, Wang., *et al*. indirectly concluded that the isolation of these individuals before the onset of symptoms could hinder the chain of transmission of SARS-CoV-2 significantly [52]. Studies have shown that the transmission rate of asymptomatic individuals may account for approximately 24% of COVID-19 transmission [61].

Aydin., *et al*. had conducted a laboratory-based study assessing the FE of surgical masks and 11 different household materials for use in a cloth mask. They had assessed the efficacies at different velocities mimicking cough, sneeze, and speech. They had not mentioned the status of the surgical masks included in their study (whether certified or not). However, the structure of cloth masks, including material type, porosity and thread counts were made clear. Aydin., *et al.* had not mentioned stitch type of the cloth masks included in the study. In the case of cloth masks, Aydin., *et al.* concluded the lack of correlation between filtration performance and material porosity. Porosity ranged from 4.5 % to 1.1 % in the better-performing materials. Similarly, the number of threads in a material did not always correlate with FE. The material with the best performance had a thread count of 111.5 threads/inch. Meanwhile, the material with the highest thread count did not have a higher FE. Thus, fabric construction and fabric type/blend had no discernible effect on filtration performance. However, new materials with multiple layers (3 > 2) outperformed those with only one layer and/or used materials [62].

Droplet sizes used throughout the study were adjusted to imitate SARS-CoV-2 virus-containing droplets. This is beneficial when assuming that SARS-CoV-2 can transmit only through droplets. However, as discussed above, SARS-CoV-2 can also be transmitted through aerosols when performing AGPs. Thus, this study only assesses the ability of the masks to block droplets of SARS-CoV-2 and not aerosols. Despite this, Aydin., *et al.* argues that SARS-CoV-2 virus particles are usually excreted in saliva and are therefore more viscous. The increased viscosity would then require more energy to penetrate the mask. Therefore, the results provided would probably increase if this theory is correct. Aydin., *et al*. had concluded that mask breathability does not correlate with its droplet-blocking efficacy, as the better the efficacy the lower the breathability of the mask [62].

Darby., *et al*. was the one of only two studies that argued the absence of a validated outward leakage tests for masks, specifically surgical masks. Validated tests for inward leakage of surgical masks exist, such as the previously discussed ASTM and EN14683 tests. Thus, their use of the curved laser sheet was innovative and aimed to address an important issue of respiratory protection- outward leakage of masks. They assessed the FE and leakages of surgical masks, a bandana, a 3-layered and a 1-layered cloth mask. The aerosols used in the study had a mass median diameter of 3μm, with 10% of them being larger than 10μm. Thus, the level of self-protection provided by the masks could only be towards particles ejected during speech and not necessarily infectious particles. The EN 14683 surgical mask had an overall excellent level of inward (self) protection, followed by the 3-layered cloth mask. The 1-layer cloth mask and the bandana had not performed well and had exhibited a high penetration rate. Leakages were evident in all cloth mask samples in the study. However, the overall structure of the study (i.e., use of a curved laser sheet) had not provided a comprehensive overview of the outward protectiveness of the included masks. The laser sheet did not provide accurate results in the case of leakages, specifically leakages around the chin, as the position of the laser sheet was difficult to manipulate throughout the study. Additionally, the lack of statistical data obscures the confidence in the findings of this study. Darby., *et al.* had stated that the lack of statistical evidence was due to the absence of a control- the control placed in the study could not be properly assessed due to the overall design of the experiment. The placement of the laser sheet was limited in some areas; thus, some important pieces of data were not included. The dummy head used in the study was concluded to be 95% larger than the average adult male head, thereby the mask fit on the dummy could not be compared to the fit on an average human. In conclusion, Darby *et al*. stressed on the importance of mask fit and urged inventors to revise the design of masks [56].

Hill., *et al*. had argued that the ASTM F2299:2017 validation test only highlights limitations in material properties and fit without assessing the effectiveness of the mask to prevent inward leakage of harmful particles. They had assessed various materials to be used as inserts for the cotton, 600-thread count, double-layered cloth mask used in the study. Of those inserts, a single-layer, and a double-layer N95 respirator non-woven material was assessed. Base FE and worn FE were assessed for the majority of inserts. The only exception being the single-layered N95. The inserts had exhibited a sharp decline in FE when worn, thus Hill., *et al*. had concluded that material FE does not correlate with worn FE. The base FE of a valved N95 respirator (3M 8511) also assessed and had exhibited promising results [53].

Assessing only a portion of the N95 respirator cannot adequately assess the efficacy provided by the N95. As previously mentioned, the presence of multiple layers, in addition to the overall structure of the mask provides possible additional layers of protection. The presence of electrostatically charged layers and a tighter fit present in the design of the N95 is lacking in this study [30,32]. Nevertheless, the results are informative. The material of the N95 respirator may in itself be designed to filter out contaminants [54]. Thus, the inclusion of multiple layers, electrostatic charge and a proper fit may enhance the FE provided by the N95 respirator.

The use of a soft headform, without proper adjustment of the headform's size, composition and/or feel may have altered their results. The headform was not compared to a human head size or feel. Thus, the fit of the masks on the headform cannot be compared to the fit on an individual. Nevertheless, the use of a thermoplastic adhesive to improve the fit of the KN95 on the headform had not deviated from the base FE of the respirator (base FE = 98% (± 1.6%), worn FE = 96.7% (± 0.2%)). Cloth and surgical mask fit were assessed qualitatively only [54].

The majority of nanoaerosols generated were sized at around 40nm in diameter, significantly smaller than the average size of SARS-CoV-2 aerosols. Attempts were made to focus on FE toward 60 to 125 nm aerosols. Despite this, the results can be viewed as being more restricted than needed. In conclusion, Hill., *et al*. had deduced that surgical and cloth masks are poorly fitted, in general, and thus have a high amount of leakage specifically around the nose, chin, and jawline. This had highlighted the importance of mask fit once again [54].

The material inserts performed similarly to a double-layered cotton mask alone and did not provide any additional protection. Materials with better pliability and less permeability can play a strong role in improving FE of masks in general, particularly cloth masks. The less pliable and/or the higher the permeability of a material, the higher the penetration and the presence of more leakages due to an improper fit. Hill., *et al.* had advised face mask designers to reconsider the mask designs and to include fit and penetration testing as important factors. Moreover, he advised mask wearers to perform a quantitative fit whenever possible [54].

Sterr., *et al*. was the other study that argued the lack of a validated outward protection test. Despite this, they aimed to evaluate the masks' protective efficacies against airborne particles. 3 separate tests were used to compare the FEs of the masks. 3 samples of each mask type were included in the study to rule out material defects and provide a reliable average. Only 2 samples of some cloth masks were included due to their unavailability. Surgical and cloth mask and KN95 and FFP2 respirators were assessed for self-protective efficiency [54].

The assessment of filtration efficacies against only 0.5μm-sized aerosols limit the study as SARS-CoV-2 aerosols range from 60 to 140 nm [54,55]. However, they argue that SARS-CoV-2 droplets usually aggregate, thus the aggregated droplet collection would be of a similar size to that utilized in the study. The placement of the particle counter inside the artificial trachea may not have been the best place to assess the penetration of particles. Studies have shown that viral shedding is observed in a more concentrated amount in nasal swabs as opposed to throat swabs [63]. Additionally, placing the particle counter further away from the point of entry may reduce the number of particles counted due to dispersal in the upper portion of the dummy. The use of a 3D printed dummy head with an average head size of the US population limited the results of the study to those with similar head sizes. The coating of the dummy head with liquid gum to simulate the feel of human skin had perhaps provided the study a more realistic sense. Nevertheless, no substance can achieve the exact same feel of human skin. Human skin varies from one person to another; the presence of moles, excess hair follicles, excess sweat glands and overall facial contour is not standardized and cannot easily be represented in a laboratory-based setting [55,64]. Sterr., *et al.* had concluded that material FE and worn FE did not correlate with each other, similarly to Hill., *et al.* The differences in material FE and worn FE were exceptionally significant, this indicated the importance of a proper fit on FE [55].

The overall lack of information on the types of cloth masks included in the study (material types, layers, thread counts) may lead to misinterpretation of results if not assessed well. The cloth masks were not categorized into any category, neither were there designs elaborated on in the study. As previously mentioned, the CDC recommends at least 2 layers for a cloth mask to be effective in preventing transmission of disease. They had also informed the public on the need for regular decontamination of cloth masks [25]. Studies have shown that certain materials such as silk have a higher filtration performance than others. Blends of different fabrics have also been shown to effect filtration performance of cloth masks. Decontamination processes (i.e., washing, drying) have been shown to affect filtration performance as well [57,62,66]. Thereby, the results of the filtration performance of cloth masks produced by this study are obscured by the lack of detail. To conclude, cloth masks had the least worn FE (11.3% (± 3.1%)), followed by the non-approved surgical mask (14.2% (± 2.8%)), then KN95 respirators and certified surgical masks (41.2% (± 4%) and finally the FFP2 (65% (± 27%)). Sterr., *et al.* concluded that certified surgical masks are highly recommended to protect the wearer from airborne particles in low-risk settings [55].

In Mboowa., *et al.*'s study, the FE of surgical and cloth masks and a KN95 respirator were assessed. A hand-held sprayer containing *Mycobacterium smegmatis* was used to spray aerosols of unknown diameters at a mask sample. The mask sample was placed in front of a petri dish. A petri dish without a mask was used as a control. The use of a hand-held sprayer did not allow for better control of droplet or aerosol sizes as compared to an automated one. Moreover, the use of *Mycobacterium smegmatis*, which is 3 to 5 µm long, cannot replicate SARS-CoV-2 as it is significantly larger than the virus (60 to140 nm) [54,55,66].

The standards of certification and approval by the NDA/GOU was not mentioned clearly throughout the study, hence the certified surgical mask cannot be easily compared to ASTM or EN14683 certified surgical masks unless further information is provided. The assessment of the filtration efficacies of the included masks after different decontamination methods was the highlight of the study, as none of the included studies had assessed the efficiency of masks after decontamination. The FE after decontamination can conclude the overall re-usability of the mask [66]. This is of particular interest during shortages of RPEs.

The FE of the masks was assessed at different distances and after different decontamination methods, perspectives unique to this study. A semiquantitative fit test (saccharin reagent) was modified twice: once to include the number of squeezes until the 4 volunteers tasted the reagent, and another to include the number of squeezes until the reagent was tasted at different distances. Despite this modification, the use of a fit test on various masks may not accurately assess the FE. The application and fit of masks such as surgical and/or cloth vary from face to face [67]. Furthermore, the presence of gaps due to facial structure could alter the FE of the masks. In regard to decontamination methods, the assessment of the effect of commonly used decontamination methods in Kampala, Uganda was included. Decontamination by using 70% ethanol was performed on all masks including the surgical mask and the KN95 respirator. Washing with a non-bacterial soap and drying the masks under the sun and/or ironing them were performed for all the cloth masks included in the study. Mboowa., *et al.* had concluded that NDA/GOU certified surgical masks and KN95 respirators, non-certified surgical masks and all the samples of cloth masks have a high filtration efficacy even after decontamination methods (≥ 99.9%). However, the distance-dependant tests proved that the FE of masks declines after decontamination in general. Additionally, the further the volunteer was to the source of the saccharin reagent, the less they had tasted it. Despite this, most masks had failed this portion of the experiment, with the exceptions being the surgical masks, the KN95 respirator and 2 samples of the cloth masks [66].

It is unclear how this decontamination was achieved. 70% ethanol could be sprayed onto, or used to soak the mask sample, washing the masks could be manually washed or placed in a washing machine. The methods of decontamination here would significantly alter the validity of the conclusion. For instance, as previously mentioned, a surgical mask is made of 3 layers (hydrophobic, filter and absorbent layers) in addition to having an electrostatically charged filter, hence the spraying of 70% ethanol could potentially disrupt the filter layer. Soaking the surgical mask in ethanol for up to 2 hours has been proven to reduce FE to approximately 58.4% from an estimated average of 75.25% [68]. Thus, proper clarification on the exact method of decontamination in this article would play a vital role in understanding the effect of decontamination processes on FE.

Lastly, the results of this experiment are beneficial when the material, including its composition, are clarified in the study. However, this is not the case with some of the materials assessed. For instance, the exact material of the face scrub cloth is not elaborated on in the study [66]. This elaboration would have provided a foundation on which researchers could compare the results to results of their own experiments. Hence, the results of this study cannot be easily compared to other studies to justify the findings and solidify the evidence.

Ferris., *et al.* was the second observational study included in the review, and the only study that had assessed the FE of FFP3 masks. As previously discussed, Ferris., *et al.* had observed the COVID-19 infections in healthcare workers in RED and GREEN wards during a 12-week period- 8 weeks before the change to FFP3 and 4 weeks after. The results had concluded that FFP3 provides 100% protection from COVID-19 infections in the RED wards [CI 31.3%, 100%]. Appropriate ethical considerations were taken before the initiation of the study [53].

Due to the overall small sample of included healthcare workers in this study- only 27.8% - the results may not be conclusive [53]. Studies involving small samples of a population may not allow proper data from being extrapolated. Furthermore, the inclusion of a small selection may enhance an incorrect/false result [69]. In addition to the results obtained from a small sample size, factors such as hand hygiene, standard precautions amongst others, were not considered. The CDC recommends the integration of infection control practices to reduce the rates of disease transmission, particularly COVID-19 [25]. In conclusion, the small sample size and the lack of consideration of the effect of commonly used infection control practices in healthcare settings on hospital-acquired transmission of COVID-19, have reduced the confidence in the results to an extent.

Tanisali., *et al.* had been one of the few studies to assess the level of protection offered to others surround the wearer of a mask. Their experiment depended highly on refractive index and wavefronts of a generated cough by 5 consenting volunteers. The cough had generated an area of contamination that was detected and measured by the Schlieren method. The mask with the larges area of contamination was the valved N95 respirator (113 cm^2). This suggests that the valved respirators do not provide sufficient protection to others besides the wearer [58]. This finding coincides with studies that conclude that valved respirators are not to be used in healthcare/high-risk settings [71]. The double-surgical mask followed the valved N95 with an area of contamination measuring 67cm^2. A single surgical mask had an area measuring 61 cm^2. Tanisali., *et al.* had concluded that the leakages present while wearing a surgical mask had contributed to this area of contamination, which were more pronounced while wearing 2 surgical masks [58]. This suggests that while double masking may provide better filtration, it does not necessarily protect others from infection as it increases the leakage of the surgical mask.

The use of the Schlieren technique was innovative and had aided in understanding the propagation of a cough through the air. In this particular study, it had provided us with a foundation in understanding how leakages affect the protective efficacy of masks in general. Despite this, the Schlieren technique can only "sense" the propagation of coughed air. It cannot assess the propagation of droplets or aerosols, a vital factor in assessing efficacies against diseases such as COVID-19 [58]. Nevertheless, the experiment provided clarification on the importance of outward protection, which is often an overlooked topic.

Ueki., *et al.*'s study assessed the FE of surgical and cloth masks, and N95 respirators (fitted and non-fitted). They had specified a mannequin head as the spreader (attached to the nebulizer) and the other the receiver (attached to the mechanical ventilator). They consistently alternated the mask type and the "wearer" throughout the study, in addition to testing the FE of at different distances. No mask on both the spreader and the receiver was considered the control throughout the study. The no mask phase proved that the SARS-CoV-2 viral load decreased as distance between the 2 mannequin heads increased. Hence, proving that distance plays a significant role in the transmission of SARS-CoV-2. As masks were placed on the receiver head, which was placed 50 cm away from the spreader, FE was assessed as appropriate. The least protective mask was the cloth mask, while the best was the fitted N95 respirator. These results are similar to masks placed only on the spreader, in which case the least protective being the cloth mask and the best being the fitted N95 once more. When the receiver and the spreader wore masks, the protective efficacy had increased, indicating a synergistic effect. In conclusion, cotton, and surgical masks and N95 respirators reduce the transmission of SARS-CoV-2 more effectively when worn by the "spreader" [72].

The use of surgical masks and N95 respirators did not completely block the transmission despite the control of fit, specifically in the case of the N95 respirator. This could partially be due to the use of a high-dose of SARS-CoV-2, in addition to the improved particle stability throughout the experiment. In a realistic setting, the stability of the particle would depend on factors such as temperature and the presence of other particles. This is eliminated in a laboratory setting, as these factors were controlled to an unrealistic extent. Hence, the results of this experiment could have been under-interpreted since the efficacies of the masks may have been over-tested [72]. This under-interpretation could prove to be beneficial in assessing mask/ respirator use in high-risk settings, such as performing AGPs on COVID-19 patients. The aerosols produced whilst performing these procedures may pass through surgical masks easily. Moreover, the risk of different types of AGPs vary according to the proximity of the healthcare worker to the patient. Studies have shown that healthcare workers inserting an endotracheal tube for intubation were associated with an increased risk in SARS-CoV-2 transmission (OR 8.8%

[95%CI 5.3% - 14.4%]) [73]. Hence, the excess scrutiny of the protective effect of the N95 respirator in particular could highlight the need for additional protective measurements during high-risk procedures.

Ueki., *et al*. argued that the unfiltered SARS-CoV-2 that had passed the N95 respirator specifically may not be sufficient enough to obvious illness [72]. Studies have concluded that the viral load of SARS-CoV-2 is not an adequate predictor of illness, as high viral loads were not necessarily linked to higher severity of the disease. Furthermore, some high viral loads have been observed in asymptomatic individuals [74].

Strengths

In regard to strengths, this systematic review had formulated a research question focusing on a world-wide population, specifically adults and healthcare workers. This would widen the implications of this review's results. Furthermore, comparing the efficacies of various masks against each other in the presence of SARS-CoV-2 would result in a more extensive understanding of FE of masks.

Appropriate research methodologies were performed and had resulted in the inclusion of relevant studies. 7 out of 10 studies had discussed the FE of surgical and cloth masks. The abundance of studies regarding these 2 mask types provides a fuller overview of the FEs. 6 of these studies had focused on assessing the FE of different materials for cloth masks. Cloth masks are abundant, and variable as based on material types and layers. Hence, the analysis of the FE of various materials in this review had broadened the evaluation of cloth masks as appropriate.

Another strength of this review is the inclusion of 2 observational studies. The inclusion of these studies would support the results of the experimental studies in a more realistic setting.

Limitations

The inclusion of 8 experimental study designs and the scarcity of research on the FE of some mask types (i.e., N95, FFP2, FFP3, KN95) in the presence of SARS-CoV-2 had limited the review extensively. Due to the overall shortage of information, FEs of all included masks could not be done on a wider scale as intended. Moreover, as previously discussed, experimental studies are limited in their results due to the lack of realism throughout the study [59].

Some studies would have benefited from the statistical analysis provided by a meta-analysis study design. Critical appraisal tools, specifically standardized tools for the assessment of experimental studies, are quite scarce, and thus the reliability of experimental studies could only be assessed using one tool. The lack of inclusion of unpublished articles may hinder this review as having publication bias. Other limitations include the absence of age groups below 18 years old in the research question and the exclusion of other mask types (i.e., FFP1, N99, N100, P95).

Conclusion

The question proposed at the beginning of this review aimed to provide clarification on the best protective mask against the dreaded SARS-CoV-2 virus. The objective of this review was to draw attention to overlooked aspects of respiratory protection, namely outward protection [56,58,72]. For masks to provide better respiratory protection and to aid in the reduction of SARS-CoV-2 infections, the chain of transmission must be broken. The assessment of both self and outward protective efficacies play a significant role in understanding mask FEs.

The idea that masks in general reduce the transmission of SARS-CoV-2 is not to be doubted [52]. The levels of reduction differ from mask to mask, person to person and so on. Multiple factors play roles in mask FE and thus interfere with the transmission routes of the virus in different ways. The CDC's recommendation to enforce public mask wearing throughout the pandemic was a strategized manoeuvre in attempt to halt the spread of the virus [25]. Cloth masks reduce the transmission of SARS-CoV-2 less efficiently than other masks. Research had illuminated the potential of cloth masks by reviewing the FEs of various materials and blends of fabrics. The integration of multiple layers and possible fabrics such as silk and fleece can improve the FE of the humble mask [54,55,57,62]. Surgical masks have been the optimum choice for individuals, specifically healthcare workers. This is due to the overall level of protection offered by these masks, their accessibility and comfort [54,55,62,75]. Respirators have been proven to provide the best FE amongst the masks included in this review. Mask fit has been proven to intimately correlate with mask FE, the better the fit, the higher the FE and the lower the leakage. In short, cloth masks have the least FEs followed by surgical masks and then by respirators. The overall assessment of FEs had targeted the second objective of this review. Nevertheless, in the case of respirators, the studies included did not yield sufficient data to reach this conclusion. Moreover, the effect of leakages on mask protective efficacies were not assessed in full due to the scarcity of studies.

Recommendations

Further research is recommended to understand the FE of respirators against SARS-CoV-2. In addition, research discussing the overall design of masks may allow the discovery of a mask with a more controllable fit on various face shapes and sizes. Research on the blends of material and the effect of various decontamination methods on fabrics are also paths that must be embarked upon to improve our understanding of cloth mask FE and can eventually reduce the impact of mask manufacturing and subsequent wastes.

Respirators should be reserved for high-risk areas in healthcare settings, as they require subsequent quantitative testing which may be expensive and may produce false results if not done properly and annually [76]. Moreover, special care must be taken into consideration when attempting to fit an individual with facial hair, as the respirator cannot provide sufficient FE to individuals with facial hair [77]. This can impact an individual emotionally, psychologically, and spiritually, as some religions advise men to grow facial hair [78]. Therefore, for the time being, we can rely on masks to reduce transmission of a disease, specifically COVID-19. However, the level of protection that a mask can offer relies on our understanding of proper mask wearing, hand hygiene and mask fit.

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