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Face Masks to Prevent COVID-19: A Critical Appraisal of Current Evidence

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Abstract

Background: Face-masks have been one of the pillars for reducing the spread of COVID-19 by limiting exposure to SARS-CoV-2. However, the effectiveness of face-masks has frequently been the focus of debate among scientists and the general public.

Types of studies reviewed: This mini-review presents a critical analysis of factors that influence the effectiveness of face-masks on disease transmission, their benefits and side effects for adults and children, and their impact on the environment. These topics are summarized based on the most relevant research available in the literature.

Results: The mask type, fitting, behavior, and hygiene affect filtration efficiency. Cloth masks present low protection, and poor hygiene can increase the risk of infection. Surgical masks present moderate protection, with respirators such as N95 presenting the highest protection. Prolonged use of face masks and respirators can alter respiratory patterns, with the potential to cause side effects in adults and children.

Practical implications: In the context of disease transmission, surgical and cloth masks protect for minutes, and respirators for hours. The decision to wear a mask or not should consider comorbidities, well-being, and the nature of social interactions. By weighing risks and benefits, each individual should be able to make a conscious, informed decision.

Keywords

Mask wearing; COVID-19; Viral transmission; Filtration efficiency of face-masks.

Introduction

The foundation for reducing the spread of the corona virus disease has been based on limiting exposure to SARS-CoV-2 through face masks, social distancing, and hand hygiene. Similarly to other respiratory viruses, SARS-CoV-2 spreads through airborne droplets that can reach the mucosa in the oral cavity, nasal cavity, or the eyes, with the potential to infect host cells and cause disease [1]. Despite the contribution of face masks to the reduction of viral transmission in community settings, their actual effectiveness has frequently been the focus of debate among scientists and the general public [2].

According to the Centers for Disease Control (CDC), the primary function of face masks is to decrease the wearer's emission of infectious particles into the environment. At the height of the pandemic, mask mandates helped decrease the incidence of COVID-19 [3]. The uses of medical-grade masks and respirators in hospitals, and healthcare facilities have played an essential role in protecting health professionals from SARS-CoV-2. However, the efficiency of other mask types in public settings has been questioned [4]. Other mask-related issues, such as mask handling and hygiene, have often been neglected despite their potential for lowering mask effectiveness. Lack of adequate care can turn face-masks into sources of bacterial and fungal infections in the skin, respiratory and digestive tracts, which can aggravate COVID-19 [5].

As the CDC relaxed COVID-19 guidelines to promote a "live with the virus" approach, whether to wear a face mask or not is now a personal choice [6]. As of August 2022, a simple search for systematic reviews on the use of face masks for preventing COVID-19 shows forty-six results on Pubmed. The extensive literature on the topic makes it challenging to draw clear conclusions.

Many different masks are available, including homemade and manufactured cloth masks with different fabrics, bandanas, gaiters, medical surgical masks, and respirators, such as the N95 model. During the pandemic, several countries recommended wearing masks in public without distinction on mask types. The scarce supply of personal protective equipment (PPE), higher medical masks, and respirator costs likely propelled the public towards cloth masks [7]. However, the current low mortality rates, reduced pressure on healthcare systems, and sufficient supply of medical face-masks call for a data-focused questioning about mask-wearing and viral transmission [8]. The efficiency of face masks depends on multiple intrinsic factors, such as type of mask, fitting, filtration capacity, fabric microstructure, and thickness, as well extrinsic factors, such as duration of social interaction and type of environment [4].

Despite the lower disruption of daily lives by COVID-19 and the shift towards an endemic disease, it still requires vigilance. This mini-review aims to critically analyze the factors that influence the effectiveness of face mask wearing on disease transmission, their benefits and side effects for adults and children, and their impact on the environment. This article provides a scientific discussion to enable readers to make informed decisions.

Technical Principles of Face-Masks as Protective Barriers against SARS-CoV-2

A few concepts used in aerosol science are helpful to understand better the basic parameters involved in mask efficacy. SARS-CoV-2 has about 0.1 µm in diameter and it travels through the air in aerosols. Aerosols, also known as droplet nuclei, originate from larger respiratory droplets that have evaporated, with sizes up to 5 µm. These minor inhalable particles carrying the virus are the most significant transmission source, as they can stay in the air for long periods and pass through gaps and pores [9]. The filtration effectiveness of masks cannot be quantified simply by comparing the size of aerosol particles to the size of mask pores. The reasons for that include the 3D and electrostatic aspects of the fabric material and aerosol particles' route in motion [10-11]. Studies on face masks evaluate the emission of particles (protection of others) and the inhalation of particles (protection from others) [12].

Factors Affecting Face Masks Effectiveness

Cloth masks, surgical masks, and respirators constitute the most common protective barriers. Cloth masks include a variety of commercial or homemade fabric masks that considerably vary in material, construction, fit, and design. Natural or synthetic textiles with varying thread counts per inch have been used, including cotton, cotton blends, silk, flannel, polyester, spandex, nylon, and chiffon. Cloth masks are unsuitable in healthcare settings due to their lack of standardization [13].

Surgical masks are typically made of 3 layers of non-woven fabric, mostly polypropylene, and follow rigorous design standards. They can also be made from other thermoplastic polymers such as polyester, polystyrene, polyethylene, or polycarbonate. The outermost layer is leak proof, the inner layer is a high-density filter, and the inner layer is in direct contact with the skin [14].

Respirators constitute specialized filtering devices with a convex cap shape composed of 4 layers of polypropylene. The most well-known respirator in the US is the N95, whose manufacturing is controlled by the National Institute for Occupational Health and Safety (NIOSH), the CDC, and the Occupational Safety and Health Administration (OSHA). Respirators are designed to create a seal around the nose and mouth [15].

Filtration Efficiency

Filtration efficiency is defined as the protection masks offer the wearer when exposed to potentially infected people [16].

Cloth masks: Despite their popularity, cloth masks present low filtration efficiency of aerosols, varying between 2-38% due to their large pores. Cloth masks composed of three or more layers present higher filtration ability [17]. After four wash and dry cycles, their filtration efficiency can lower by up to 20%

[18]. Clapp and coworkers reported that folded cotton bandanas had about 50% filtration efficiency, while a single-layer gaiter composed mainly of polyester had about 38% filtration efficiency despite the tighter fit. Having a nose bridge and a filter increases the filtration effectiveness of cloth masks [19]. Emission of large droplets can be reduced through cloth masks; however, protection against inhalation or emission of smaller aerosol particles is limited [20]. Cloth masks are half as efficacious as N95 and 25% less effective than surgical masks [21].

The type of cloth impacts blockage of particles, with thicker fabrics presenting higher filtration efficacy, estimated at 40% for towels, 20-40% for sweatshirts, 10-20% for cotton, and 10% for t-shirts. Multi-layered masks made with cotton or tightly woven fabrics that do not allow passage of light when held up to bright light and fit adequately with no leaks can increase protection [22-23]. The bottom line is that cloth masks present low protection against aerosols, with one-layer masks being the most ineffective. Thus, when wearing a cloth mask, even a limited number of viral aerosol particles can pass through the cloth and cause infection [22].

Surgical masks: Surgical masks with elastic ear loops present a filtration efficiency of 38.1%. For those with tie strings, it increases to 71.5% due to minimized gaps. Clapp et al. recommend tying ear loops and tucking side pleats for increased protection. Surgical masks can provide moderate protection against COVID-19 given that their fit is optimized [19].

Respirators: As their name implies, N95, N99, and N100 respirators block at least 95%, 99%, and 99.97% of aerosol particles, respectively [19]. These respirators are the most efficient barriers against viral transmission, which is why the CDC recommends their use to healthcare personnel during aerosol-producing procedures [24-25].

Porosity

Cloth masks present 82% porosity. Higher porosity means air is allowed in and out, which translates into higher breathability. It also means a higher risk for the movement of particles. The pore size varies from 80 to 800 µm in textile masks, depending on fabric type [26]. Medical or surgical masks present intermediate porosity (77%) and breathability [26]. N95 masks present the lowest porosity (65%) and breathability. It presents the smallest pores (about 30 µm) and the highest fiber density. These are the main reasons for their superiority in aerosol filtration [26].

Mask Hygiene

Human saliva presents a high concentration of microorganisms, constituting a biosafety issue during prolonged use of face-masks. Furthermore, skin and upper respiratory microorganisms can also colonize face masks. They constitute fertile grounds for bacterial growth, given the high temperature and humidity conditions. Bacteria in the mask can be inhaled or colonize the skin under the mask [27]. Cotton textiles are particularly prone to microbial contamination and growth due to their ability to retain moisture. Thus, reusable masks require adequate disinfection before safe reuse; otherwise, they increase the risk of infection [28].

A microbial study of cloth and surgical masks revealed frequent accumulation of bacterial pathogens after 4 hours of mask use, including antibiotic-resistant microorganisms on surgical masks and more intensely in cotton masks. In the same study, a survey on mask hygiene reported that only 8% of surgical mask wearers used it once, and 21% of cotton mask wearers cleaned it daily [27]. The authors suggest that surgical masks are better than cotton masks if worn over four hours due to their lower bacterial counts. Furthermore, hand washing before and after handling a mask is essential. Cloth masks require daily washing at 140°F with a detergent, boiling, or ironing [27]. They should be kept moist-free and clean. Harsh chemicals and bleach should be avoided [29].

Surgical masks and respirators are intended for single use. Due to the risk of lower filtration efficacy, reprocessing, extended use, or reuse of these barriers is not recommended. In the case of supply shortage, ultraviolet germicidal irradiation and hydrogen peroxide offers the least disruptive disinfection methods.30Soap and water, microwave irradiation, and alcohol are not suggested for mask cleaning, given the risk of compromising filtration. If the surgical mask or respirator becomes soiled or damaged, or breathing becomes challenging, it should be safely discarded inside a plastic bag and replaced [31].

Type of Environment

The amount of aerosol particles in the air depends on the concentration of people and the type of environment. Crowded indoor spaces present a higher concentration of inhalable particles resulting from breathing, speaking, or singing. These particles can move through air currents and diffusion; thus, social distancing alone might not avoid disease transmission. The longer a person stays in a shared space, the more particles are likely to be inhaled. Sharing a well-ventilated space with fewer people for shorter periods decreases the concentration of particles and risk for contamination with respiratory viruses such as SARS-CoV-2 [22].

Duration of Exposure and Fitting

Brosseau et al. presented the estimated degree of protection conferred by different types of masks concerning the time needed for an uninfected person (the receiver) to reach an infectious viral dose from an infected person (Table 1). The author presents different scenarios according to the percentage of inward leakage, considering that a typical cloth mask has 75%, a typical surgical mask has 50%, non-fit-tested N95 has 20%, and fit-tested N95 has 10% inward leakage [32].

-		Receiver				
		No Mask	**Cloth Mask**	**Surgical Mask**	**N95**	**N95 fit-tested**
Source	**% Outward Leakage**	100%	75%	50%	20%	10%
No mask	100%	15 min	20 min	30 min	1.25 hr	2.5 hr
Cloth mask	75%	20 min	26 min	40 min	1.7 hr	3.3 hr
Surgical mask	50%	30 min	40 min	1 hr	2.5 hr	5 hr
N95	20%	1.25 hr	1.7 hr	2.5 hr	6.25 hr	12.5 hr
N95 fit-tested	10%	2.5 hr	3.3 hr	5 hr	12.5 hr	25 hr

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Table 1: Time to infectious dose from an infected source to an uninfected receiver according to the type of mask worn by each, presented in minutes (min) and hours (hr). Published by the Center for Infectious Disease Research and Policy (CIDRAP) in 2021, reproduced with permission from CIDRAP.

In the worst-case scenario, in the absence of facemasks, it takes 15 minutes for the receiver to get an infectious dose. If the source and the receiver wear cloth masks, the time increases to 26 minutes and to about one hour if both wear surgical masks. For the best-case scenario, if the source and the receiver wear an N95 respirator, it would take over 12 hours for the latter to reach an infectious viral dose. Fit-tested N95 for both source and receiver increases the time to infectious dose to 25 hours [32]. A fit test evaluates the comfort, fitting, and protection provided by a respirator, being required to decrease leakage and risk for infection in workplaces that involve exposure to infective agents [33].

Fit tests have highlighted the importance of fit to avoid leaks and gaps and maintain protection against viral infections. Therefore, Gandhi and Marr suggest that high-quality, tight-fitting masks are preferred in crowded indoor places. Alternatively, a tight-fitting cloth mask can be worn over a surgical mask to decrease leakage [34].

Adverse Effect of Face Mask Wearing

With COVID-19 mortality decreasing in most countries, the real question is if masks are needed. While masks are required as PPE for healthcare providers, in most instances, masks are optional for asymptomatic individuals in the US [35]. The prolonged and repeated mask use has been linked to multiple side effects [36]. Face masks cover facial expressions and muffle sounds, thus hindering interpersonal communication [37].

Pressure on the face and headaches have also been reported as side effects of prolonged mask-wearing, particularly with N95 respirators. After one and four hours of wearing a N95 mask, attention deficit, lower concentration, and headaches were reported by Ipek and colleagues [38].

Multiple studies report lower oxygen (hypoxia) and higher carbon dioxide (CO2) levels (hypercapnia) in the air under the mask and in the blood during the use of surgical masks and N95 respirators, as summarized in the review by Kisielinski [36]. When worn during physical exercise, cloth and surgical masks and N95 respirators were linked with increased heart rate, breathing difficulties, exhaustion, heat, and itchiness in the face. Hypoxia and hypercapnia can cause psychological and neurological effects, such as fatigue, disorientation, confusion, decreased thinking capacity, psychomotor abilities, and impaired cognition [36]. It has been estimated that N95 respirators lower gas exchange by 37%, possibly triggered by a 128% increase in breathing resistance and an 80% increase in dead space volume. Not all inhaled air is subjected to gas exchange. Dead space describes the volume of air that is not exchanged after inhalation. Thus, repeated use of masks over prolonged periods may lead to shifts that contribute to disease [39-40].

In patients presenting severe chronic obstructive pulmonary disease (COPD), N95 respirators can increase the risk for respiratory failure and should be removed immediately if headache, dizziness, or dyspnea develops [41-42]. Caution is also needed for patients with end-stage kidney disease and pregnant women due to their potential to influence cardiopulmonary function [43].

Dermatological conditions have also been described as a consequence of mask-wearing. The high humidity and temperature under a mask increase sebum production, altering the skin barrier function. As a result, existing skin conditions can worsen, and new conditions can develop, such as *dermatitis, acne, desquamation, rosacea, eczema,* and *urticaria* [44].

Changes to the oral mucosa have also been described as an adverse effect of mask-wearing. The most common conditions include dry mouth, *gingivitis, halitosis,* and *candidiasis* [45-48]. Those changes have been attributed to increase mouth breathing triggered by breathing resistance, which lowers salivary flow and soft tissue dehydration [36]. Frequent reuse, incorrect use, and low filtration efficiency of cloth masks increase the risk of infection due to the beneficial conditions for microbial growth, as discussed in a previous session [28].

Face masks can provide a false sense of security, leading to a disregard for other mitigation strategies. Individuals wearing masks tend to talk louder and move closer to one another during conversations due to their impact on communication, thus increasing the risk of viral transmission [49].

Benefits of Mask Wearing

There is enough evidence to suggest that respirators efficiently reduce the spread of SARS-CoV-2 and prevent infection [50]. However, this applies to a lesser degree to surgical masks and even less so to cloth masks [29]. At the current stage of COVID-19, face-masks can be beneficial to lower the chance of transmission among the elderly, immunocompromised, and high-risk patients despite the risk of adverse side effects. Patients with heart disease, diabetes, hypertension, obesity, cancer, chronic lung, liver or kidney disease, cystic fibrosis, cognitive disorders, HIV, and disabilities are more likely to develop severe COVID-19[51].

Courtney & Bax suggest that the high humidity created by face masks around the nose and the mouth might protect against COVID-19. After viral particles reach the respiratory tract, the moisture would favor mucociliary clearance and the immune response, possibly decreasing the risk of infection [52]. Nevertheless, this possible beneficial effect has only been discussed in theory.

Face-Masks and Children

While the World Health Organization (WHO) recommends mask-wearing from the age of 5, [53] and the European Centre for Disease Prevention and Control from the age of 12, [54]the US authorities recommend it for children two years and older [55]. Currently, there is a lack of research on the safety of masks for children. Thus, age-appropriate evidence-based recommendations are lacking [56].

Children are physiologically more vulnerable to the side effects of prolonged use of facemasks than adults due to their higher oxygen demand, smaller airways, and higher susceptibility of the central nervous system to hypoxia. Breathing difficulty and altered respiratory physiology are frequently reported in children wearing masks, which can cause anxiety [57]. In younger children, in particular, masks affect non-verbal communication, speech, social interactions, and emotional bonding, ultimately affecting their brain development [49].

From a filtration efficiency point of view, respirators are the only ones designed to protect against aerosols [47,50]. Nevertheless, their once-off nature, lack of fit on pediatric faces, and adverse effects make them impractical for children. Another point to consider is that young children typically cannot maintain masks correctly for long periods, such as during school hours [58]. Children with cognitive, asthma or respiratory impairment may have a lower tolerance to face-masks. For children with greater risk for COVID-19 due to immunosuppressive or chronic disease, quality masks can be required if community transmission increases [59].

Children are at lower risk of getting infected and developing severe COVID-19 than adults, possibly due to reduced expression of angiotensin-converting enzyme 2 (ACE2) receptors in their nasal cavities [60,61] Thus, the consequences of masks in children, including discomfort, social issues, impaired interpersonal communication, and physiological respiratory changes, should be carefully evaluated against their benefits [62].Children's physical, emotional, and developmental should be prioritized now that the world is learning to live with COVID-19. Asymptomatic children under 12 should not be required to wear masks [54]. However, new variants can emerge in the ever-changing COVID-19 scenario, requiring tighter community mitigation strategies. Current CDC guidelines include wearing a high-quality mask ten days after exposure to COVID-19 or a positive test. This approach suggests that, at this point, masks can help speed up the return to school for kids exposed or infected with SARS-CoV-2 [9].

Environmental Impact of Mask-Wearing

COVID-19 has undeniably impacted the environment. The disposal of face-masks is one of the environmental challenges fueled by the pandemic. It is estimated that 7,200 tons of medical waste are produced daily due to COVID-19, significantly due to disposable mask waste [63]. Most surgical masks and respirators contain polypropylene or other plastic derivatives, which are not biodegradable. Thus, globally, tons of mask plastic waste ends up in the oceans, negatively affecting the environment, global economy, and life on the planet. Furthermore, used masks can be infectious, potentially affecting public health and disease transmission. Recycling, producing effective reusable masks, and creating biodegradable disposable masks are proposed solutions to decrease the environmental toll of face masks [64].

Take Home Message

Under the current circumstances, the decision to wear a face-mask is primarily individual, as mandates are no longer in place. According to the discussion in the previous sections, the main factors related to mask-wearing are summarized below:

1. Respirators are designed to filter micro particles such as those involved in COVID-19 transmission efficiently. However, they present low breathability and high cost [24].
2. Surgical masks offer moderate filtration ability and better breathability depending on their fit [24]. Cloth masks present good breathability with varying degrees of filtration. Most commonly used single-layer cloth masks offer low protection. Reusing cloth masks without proper hygiene can increase the risk of infection [13].
3. Personal factors such as previous exposure to the virus, chronic conditions that increase the risk of severe COVID-19, and psychological well-being should be considered [32].

4. The nature (indoor or outdoor, ventilation, number of people, etc.) and duration of social interactions affect the risk of infection, with short-duration outdoor events presenting the lowest infection risk [32].
5. Loose fitting results in gaps, decreasing the filtering ability of masks and respirators.
6. Masks and respirators should cover the nose and mouth and not be touched due to their infective potential. Meticulous hand washing should take place before and after mask handling [5].
7. Prolonged use of masks and respirators can impact the body's physiology, leading to side effects [27,36].
8. Children are particularly vulnerable to the side effects of prolonged mask-wearing. For children under 12, and those under 5 in particular, poor mask behavior is expected [49].
9. Disposable masks present lower protection after decontamination and reuse. They should be worn once and recycled to decrease the environmental plastic burden [64].

Conclusion

Face-masks have become a symbol of the pandemic. How well they can reduce community transmission of COVID-19 depends on factors such as type of mask, fitting, mask behavior, and hygiene. Currently, the decision to wear a mask or not is personal. It should take into account the presence of comorbidities, physical and psychological well-being, nature, and duration of social interactions. In general, surgical and cloth masks can protect the wearer for minutes. However, used cloth masks can become a health hazard, increasing the risk of infection. While respirators can offer hours of protection, extended use of masks and respirators can raise health concerns, particularly in children. By weighing the risks against the benefits of facemask wearing, each individual should be able to make a conscious, informed decision.

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