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Review Article

Assessment of Mask Effectiveness to Prevent the Spread of SARS-Cov-2: A Review

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Abstract

Background: The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) that causes coronavirus diseases 2019 (COVID-19) is mainly spread person-to-person through droplets and aerosols. It is often recommended that healthcare workers and other people take precautionary measures to reduce their exposure to SARS-CoV-2 by wearing masks. However, the effectiveness of the masks is not well understood at the community level.

Methods: To assess the effectiveness of the masks against the SARS-CoV-2 virus, we searched electronic databases (Pubmed, Scopus, and Web of Science) for studies that assessed mask or respirator effectiveness in the prevention of SARS-CoV-2 transmission.

Results: The majority of studies reviewed suggested that all types of masks (e.g., N95 respirators, surgical masks, and cloth masks) protect the human respiratory system against airborne viral pathogens, such as SARS-CoV-2. The quality and effectiveness of the masks vary depending on the materials, structures, and methods used for construction. The data shows that both surgical masks and N95 respirators can provide similar protection against airborne respiratory infections, including SARS-CoV-2, for healthcare workers, but due to its better facial fit, N95 is recommended for high-risk environments. However, although masks reduce the spread of SARS-CoV-2, they may not entirely provide proper protection against biologic particles, which are considerably smaller than the accepted most penetrating particle size used in certification tests.

Conclusion: While all types of masks have technical pros and cons, wearing them correctly can significantly improve their effectiveness since a complete seal of respiratory particles is unlikely due to side leakage of aerosols of different sizes.

Keywords: Mask; Filter respirator; Biologic particle; COVID-19

Introduction

The coronavirus diseases 2019 (COVID-19) outbreak has had a negative impact on public health and the global economy. SARS-CoV-2 is an airborne pathogen that can be passed from person to person via droplets and aerosols [22]. SARS-CoV-2 is transmitted by presymptomatic (those who have not yet developed symptoms), symptomatic (those who develop symptoms), and asymptomatic (those who do not develop symptoms) individuals. Although the rate of SARS-CoV-2 transmission from presymptomatic and asymptomatic individuals is unknown, these individuals may be super-spreaders [26]. Evidence suggests that people infected with COVID-19 can be contagious and transmit SARS-CoV-2 to others before developing symptoms [27]. Since COVID-19 can be spread by pre-symptomatic and asymptomatic individuals, universal masking has been recommended as a low-cost and efficient means of mitigating SARS-CoV-2 virus transmission.

Airborne respiratory infections, such as SARS-CoV-2, are spread through the release of microorganism-containing aerosols and droplets during various expiratory activities such as breathing, talking, coughing, and sneezing [30]. Masks are de-

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signed to protect both the wearer and other individuals from airborne respiratory infections 1. Masks are thought to keep infected people from spreading SARS-CoV-2 to others by preventing virus-containing droplets from being exhaled into the air and protecting uninfected wearers (Figure 1) [28]. Generally, it is believed that masks can be used to block droplets and aerosols containing SARS-CoV-2 that cause COVID-19.

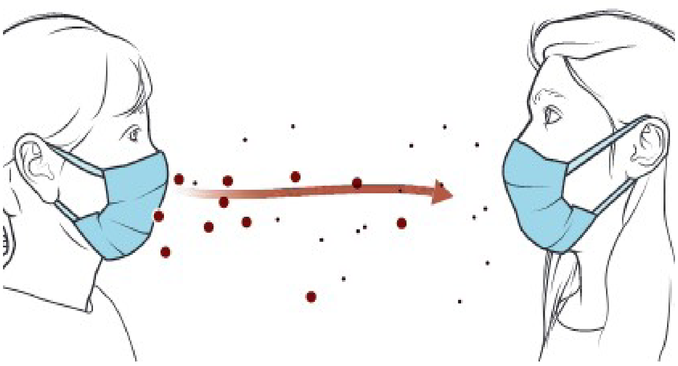

Figure 1: How masks can block droplets and aerosols containing SARS-CoV-2 [42].

Mask mandates and their efficacy in preventing SARS-CoV-2 transmission have been the subject of major debates in many countries, including South Africa. Since the outbreak of the COVID-19 pandemic, mask-wearing policies and regulations have varied in different countries. Some countries have mandated mask use in indoor public places to prevent the spread of the SARS-CoV-2 virus, while others claim there is no evidence that the masks reduce airborne infection risks among uninfected people [4]. Despite the different views and controversy surrounding the masks, there has recently been a dramatic increase in public awareness and recognition of their significant role in controlling the spread of the COVID-19 pandemic 6. However, the efficacy of different types of masks remains controversial, and compliance is low in some countries because it is not well understood whether the masks are effective enough to prevent the spread of SARS-CoV-2. In this review, we aimed to assess the effectiveness of masks, including N95 respirators, surgical masks, and cloth masks, and attribute factors to preventing the transmission of SARS-CoV-2 in healthcare and community settings.

Methods

We searched electronic databases (Pubmed, Scopus, and Web of Science) for studies that assessed mask or respirator effectiveness in the prevention of SARS-CoV-2 transmission. In the database, we searched with the keywords: "mask or respirator and effectiveness," "mask or respirator and SARS-CoV-2 or COVID-19,", "mask or respirator and leakage,", "mask or respirator and particles and penetration,", "mask or respirator and nanoparticles". Using the titles and abstracts obtained from the searches, articles were selected for inclusion in the review based on mask or respirator effectiveness, particle penetration, aerosol leakage, and respiratory protection against SARS-CoV-2.

Results

Types of Masks and Comparison

Masks are respiratory protective devices that cover a portion of the face. They are divided into three types: N95 respirators, surgical masks, and cloth masks [2]. Cloth masks are those without testing standards, including cotton masks and self-made cloth masks. Unlike N95 and surgical masks, cloth masks are not standardized or regulated by any government agency. Because they are not standardized, cloth masks are not recommended for use in healthcare facilities by healthcare workers. The N95 respirators are among the most commonly used air-filtering respirators and were in high demand during the COVID-19 pandemic. N95 is a test standard of the USA's National Institute for Occupational Safety and Health (NIOSH) air filtration rating, which provides the classification of filtering respirators 2. Unlike N95 respirators, surgical masks are not required to be fit-tested, and their efficacy is not well understood.

The main difference between surgical masks and N95 respirators is that the geometric dimensions of N95 respirators are generally fixed, but they have one more pre-filtration layer than surgical masks. This additional layer is typically used for shaping, allowing the wearer's face to be better fit [3]. Furthermore, the filtration layer of N95 respirators is denser than that of surgical masks, allowing it to block smaller particles [3]. N95 respirators are designed to reduce the inhalation of small airborne particles with clear filtration requirements. Surgical masks protect the wearer from large droplets, splashes, and sprays of fluids by establishing a physical barrier between the wearer's respiratory system and the immediate environment [41]. Furthermore, surgical masks protect others from the wearer's expelled respiratory droplets by slowing down and dispersing the small droplets produced through respiratory activities (e.g., breathing, speaking, coughing, and sneezing), there by preventing them from spreading over a large region [41]. In fact, wearing surgical masks loosely does not effectively prevent the entry of small airborne particles [37]. Unlike N95 respirators, surgical and cloth masks are not designed to be tight-fitting.

Effectiveness of the Masks

The quality and effectiveness of the masks vary depending on the materials, structures, and methods used for construction [2]. However, the effectiveness of a mask is strongly dependent upon its ability to prevent aerosol leakage through gaps between the human face and the barrier, in addition to its intrinsic penetration through the respirator's porous layers [7-9]. The N95 respirator must fit tightly to the wearer's face with limited seal leakage to be effective [37]. Leakage through gaps can be significantly reduced by performing fit testing and selecting an appropriately sized mask. However, during a public health emergency, for example, during a COVID-19 outbreak, fit-testing of respirators may not be possible, and inward leakage of aerosols through the gaps could compromise the effectiveness of the mask [10]. It is critical to quantify the impact of barrier compromise on the rate of infection spread [10]. The amount of aerosol transported through the gaps depends on the complexity of the path taken by the aerosol through the gaps and the relative flow rates through the gaps and the mask [10].

Evidence of Mask Effectiveness against SARS-CoV-2

There have been disputes about the effectiveness of different types of masks, including N95 respirators, surgical masks, and cloth masks for public usage [4,5]. However, several studies have investigated the impact of universal mask-wearing to prevent the spread of SARS-CoV-2 at the community level, and have suggested that masks are effective against airborne respiratory infections (Table 1). Mitze et al [34] investigated the impact of municipal district mask mandates in Jena, Germany, and discovered that, depending on the region, mask mandates reduced the number of newly reported SARS-CoV-2 infections by 15 to 75% within the first 20 days of implementation. The

Tables 1: Summary of the studies on the effectiveness of the mask for SARS-CoV-2 prevention.

Source	Country	Experiment/intervention	Outcome/Remark
[14]	USA	20 - 100nm test penetration for N95 respirators	The penetration threshold of 5% for N95 could be exceeded when used against nanoparticles ranging from 30 to 70nm.
[30]	USA	10 volunteers wearing masks in front of the funnel connected to an aerodynamic particle sizer	Wearing a mask can aid in the prevention of pandemics caused by respiratory diseases.
[29]	Japan	Simulated airborne transmission of infectious SARS-CoV-2 droplets or aerosols produced by human respiration and coughs	Masks provide some protection against SARS-CoV-2 droplets or aerosols. However, surgical masks and N95 masks could not completely block the transmission of virus droplets or aerosols, even when sealed.
[31]	USA	2862 health care workers used N95 respirators or medical masks in a randomized clinical trial	There was no significant difference in the incidence of laboratory-confirmed cases among health care personnel with the use of N95 respirators (8.2%) vs surgical masks (7.2%).
[32]	USA	Mask-wearing by occupants in 12 nail salons	Wearing masks reduced the airborne infection transmission risk to between 0.01% and 51.96%, depending on the salon, with an average airborne infection transmission risk of 7.30% across all salons.
[33]	China	335 participants in 124 families with at least one laboratory confirmed COVID-19 case	Masks were 79% effective in preventing SARS-CoV-2 transmission.
[34]	Germany	Six regions mandeted masks in public transportation and stores.	Masks reduced the daily growth rate of reported infections by around 47%.
[35]	Canada	Masks were mandated in 34 public health regions in Ontario	Mask mandates were associated with a 22% weekly reduction in new COVID-19 cases.
[36]	Thailand	A case-control study that included 211 cases of COVID-19 and 839 controls in Thailand	Wearing masks all the time during contact was independently associated with a 77% reduced risk of SARS-CoV-2 infection compared with not wearing masks.

study concluded that community-wide usage of masks in all public settings led to a reduction in the daily growth rate of infections by 47% [34]. Wang et al [39] assessed the impact of hospital-wide masking policies on SARS-CoV-2 infection among healthcare workers and found that implementation of universal masking policies in healthcare settings was associated with a significant decrease in the rate of SARS-CoV-2 infection among healthcare workers. Lyu et al [40] conducted a study in 15 states in the USA by examining the impacts of mask mandates in public areas on the daily growth rate, as well as the impacts of mask usage in certain work settings in comparison to community-wide mandates. The study concluded that mask mandates were associated with a lower COVID-19 daily growth rate, and that this impact increased over time after the mandates were put in place [40].

Furthermore, Karaivanov et al [35] investigated the impact of mask mandates and other non-pharmaceutical interventions on the SARS-CoV-2 virus across 34 public health regions in Ontario, as well as across Canada at the national level. The study found that within the first few weeks after the mask mandate, the average weekly number of newly diagnosed SARS-CoV-2 infections decreased by 25–31% in Ontario. On the national level, mask mandates accounted for a 36–46% reduction in weekly case numbers. The study concluded that mandating mask wear in indoor public places could be a powerful policy tool to slow the spread of SARS-CoV-2. Furthermore, Doung-ngern et al [36] conducted a case-control study that comprised 211 cases of COVID-19 and 839 controls in Thailand, and found that mask-wearing during contact with the COVID-19 positive individuals was strongly associated with a greater than 70% reduced risk of infection for those who always wore a mask, compared to those who never wore one. Ginther et al [38] discovered that counties in Kansas that implemented mask mandates had significantly lower rates of COVID-19 cases, hospitalizations, and deaths than counties that did not.

N95 Testing and Airborne Penetration

Although their use often aims at reducing exposure to biologic particles, such as the SARS-CoV-2 virus, airborne respiratory protection devices, such as N95 respirators, are usually tested using non-biologic particles as the challenge aerosols [11,14]. Although sodium chloride (NaCl) is commonly used as a standard aerosol for N95 respirator testing, biologic particle penetration through a filter may differ in workplaces or other congregated areas [15]. The standard certification tests are performed with NaCl particles of 300nm in diameter, which is assumed to be the most penetrating size. However, it is assumed that the penetration of biologic particles through N95 respirators may differ from that of their corresponding non-biologic simulations [11,14].

Since non-biologic particles, such as NaCl, have been utilized as standard aerosol for filtering respirator testing, the penetration of biologic particles through N95 respirators might be either higher or lower than that of the testing materials. This implies that the effectiveness of N95 respirators in protecting healthcare workers or other people may be controversial. The performance of N95 respirators in direct contact with biologic particles has primarily focused on airborne bacteria [11]. The penetration, P, of non-biologic particles through certified N95 respirators cannot exceed 5%; thus, the efficiency, E, of the respirator, which is calculated as E=100%-P, must be at least 95%. However, epidemiological data show that nanoparticle penetration through N95 respirators may be in excess of the 5% threshold, particularly at high respiratory flow rates [11,14]. Thus, protection against SARS-CoV-2 provided by N95 respirators may fall below 95%, especially at higher inhalation flow rates.

Inhalation Protection

The data show that both surgical masks and N95 respirators can provide similar protection against airborne respiratory infections, including SARS-CoV-2, for healthcare workers during non-aerosol generation care, but N95 is recommended for high-risk environments due to its better facial fit [12]. Due to limited access to surgical masks and N95 respirators, cloth masks have become a popular means of self-protection, particularly during the COVID-19 pandemic.

Cloth masks were tested and found to be quite effective, albeit to a lesser extent than surgical masks and N95 respirators [13]. All types of masks, including N95 respirators, surgical masks, and cloth masks, protect the human respiratory system against airborne viral pathogens such as SARS-CoV-2 [37]. However, after prolonged use of any mask type, it tends to accumulate various pathogens and become a source of infection [24]. Additionally, prolonged use of any mask, including the N95 respirators, may cause considerable facial stress, resulting in considerable discomfort. Wearing a mask may also make breathing more difficult for some people with severe chronic lung disease, though this is not due to carbon dioxide retention [3].

It is assumed that some surgical masks and N95 respirators may allow a considerable proportion of airborne respiratory viruses to pass through the filter, resulting in insignificant protection against aerosolized infectious agents in the range of 10 to 80nm [11,14]. Epidemiological evidence suggests that N95 respirators may not provide adequate protection against biologic particles that are much smaller than the accepted most penetrating particle size of 300nm used in certification tests [11]. For example, the size of the SARS-CoV-2 virus particle is approximately 100nm, indicating that N95 respirators may not completely protect wearers from the virus reaching the respiratory tract [23].

Face Seal Leakage

Face seal leakage at the interface region where the mask comes into contact with the wearer's face is a major component of inward leakage. Achieving a good fit is critical for reducing healthcare workers' exposure to SARS-CoV-2 via respiratory protection [16]. For N95 respirators that do not have a close fit to the face, aerosol leakage may be impacted more by gaps around the nose than those near the chin or the cheek gaps [10,17]. Furthermore, it is assumed that most of the leakage occurs around the nose and that the outward leakage flow is directed upward (Figure 2) [17].

Controlling the nose gap is crucial to improving the fit-factor for masks. Additionally, during a breathing cycle, air inhalation and exhalation will cyclically change the contact dynamics between the face and mask [10]. However, even N95 respirators that provide an acceptable level of fit can only reduce healthcare workers' or other people's exposure and not eliminate it completely. According to the data, there will always be some leakage as a result of gaps in the face seal interface region [16].

Evidence suggests that all types of masks, including N95 respirators, surgical masks, and cloth masks, provide protection against SARS-CoV-2 transmission, but they do not completely block the transmission of virus droplets and aerosols even when sealed [29].

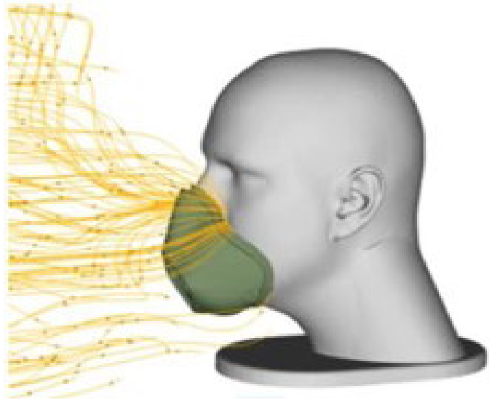

Figure 2: Leakage of the face seal occurs through the nose, chin, and cheek [10].

Discussion

We have reviewed the effectiveness of masks in preventing the spread of SARS-CoV-2, which causes COVID-19, in healthcare and community settings. Although N95 respirators are thought to be more effective than surgical masks at preventing aerosol leakage during respiratory activities, neither completely prevents side leakage. Despite the fact that surgical masks have a lower filtration efficiency than N95 respirators, studies have shown that N95 respirators have no significant advantage over surgical masks in preventing SARS-CoV-2 or other airborne respiratory infections [25,31]. Evidence suggests that surgical masks are similar to N95 respirators in reducing the spread of SARS-CoV-2, but with a better comfort level compared to N95 [20]. Surgical masks have the potential to improve source control in clinical respiratory illnesses, but they provide less protection against influenza virus infection and laboratory-confirmed viral respiratory infections [19]. In contrast, a randomized clinical trial study that involved 2862 healthcare workers found that there was no significant difference in the incidence of laboratory-confirmed influenza among healthcare workers with the use of N95 respirators (8.2%) compared to surgical masks (7.2%) [31]. Despite having a better fit for the face [21], data suggests that using surgical masks correctly is more effective than using N95 respirators. Generally, all types of masks have technical pros and cons, but wearing masks correctly can significantly improve their effectiveness since a complete seal of respiratory particles is unlikely due to side leakage of aerosols of different sizes.

Because the infectious dose of viruses, such as SARS-CoV-2 required to cause clinical infection remains unknown, it is possible that blocking most, if not all, viral particles through masks with lower filtration efficiencies of submicron particles is sufficient to prevent disease in the vast majority of cases. The question that often arises is whether nanoparticles (<100nm) are more or less likely to penetrate through gaps in the face sealing area than larger particles. Despite several studies on larger particles, there is no data on filtering respirator face seal leakage of nanoparticles [16]. Some studies suggest that penetration thresholds of 5% established for N95 respirators could be exceeded when used against nanoparticles [11,14]. It has been discovered that N95 respirators may not always provide adequate protection against biologic particles, such as SARS-CoV-2, which are much smaller than the accepted most penetrating particle size of 300nm used in certification tests [11,14].

Leakage through the nose, cheek, and chin areas of the face may be among the factors reducing the mask's effectiveness in preventing the spread of SARS-CoV-2 in healthcare and community settings. For example, the data shows that 89% of mask leakage occurs through the nose and chin of the face [10]. The data suggest that particle leakage is influenced by a variety of factors, including particle size, and that particles are less likely than gases and vapors to penetrate gaps caused by poor fit. Furthermore, nanoparticles are assumed to have lower penetration abilities than larger particles; however, the issue of particle-size-dependent leakage remains largely unanswered [16]. Some studies suggest that the aerodynamic sizes and shapes of aerosols have a great impact on particle penetration through N95 respirators [8,16]. Furthermore, flow rate and relative humidity may change the level of penetration of nanoparticles through N95 respirators. However, the correlation between airborne particle penetration through filtering respirators and the aerodynamic diameter or other physical characteristics of microorganisms remains controversial [7,8]. Generally, it is assumed that aerosol leakage may be impacted more by gaps around the nose than the cheek and chin for masks, such as N95 respirators and surgical masks, that do not have a close fit to the face.

Author Satements

Competing Interests

The authors declare no competing interests.

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