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THE EFFICACY OF FACE MASKS AGAINST RESPIRATORY AIRBORNE PATHOGENS

ABSTRACT

The COVID-19 pandemic brought face masks back into the public eye to curtail the spread of the SARS-COV-2 virus. There were a multitude of opinions on whether face masks were the correct way to manage the pandemic. Historically, masks have been used to prevent illness from a multitude of airborne pathogens. This literature review compiles and scrutinizes peer-reviewed studies that were conducted to measure face masks' efficacy against respiratory pathogens to answer whether face masks could protect against that pathogen. In summary, this review found that face masks such as N95 and surgical/disposable masks had a high efficacy rating (>90%) against SARS-COV-2 (COVID-19), influenza (the flu), and streptococcus/staphylococcus bacteria. Cloth masks generally performed poorly (<75%) except for bacterial studies. The lowest efficacy ratings were seen in measures of rhinovirus transmission (responsible for the common cold). Given the body of evidence presented in this literature review, the idea is strongly supported that the use of face masks to prevent the spread of COVID-19 during the pandemic protected individuals from this respiratory virus. Additional research is also needed for cloth masks and rhinovirus in general, as little peer-reviewed literature has been published for these two areas. Further studies are required to further increase knowledge and awareness of all types of face masks.

INTRODUCTION

"If everybody does that, we're protecting each other," said Anthony Fauci, M.D., Director of the National Institute of Allergy and Infectious Diseases, in an interview with PBS regarding the spread of the COVID-19 in the United States of America (PBS News Hour, 2020). In this quotation, Dr. Fauci was referring to the idea of wearing face masks preemptively to protect everyone rather than situational scenarios, such as an individual being sick or entering a medical setting. The interview took place on April 3rd, 2020, and marked the shift from considering wearing a mask if an individual was sick to everyone wearing a mask, regardless of health status. This review aims to investigate whether Dr. Fauci was correct in saying face masks should be used to control and prevent the spread of COVID-19. This review also further investigates if wearing face masks could also control and prevent the spread of other common respiratory pathogens like influenza, rhinovirus, streptococcus, and staphylococcus bacteria. Results from this thesis could help the public understand the importance of face masks for not only prevention of COVID-19 but for preventing other respiratory illnesses as well.

Facial Coverings

The Merriam-Webster dictionary defines a face mask as a covering that covers the face and nose to reduce the spread of pathogens (Face mask, n.d.). By this logic, it was concluded that the first recorded mask might be the beak-like

Fig. 1: Colored-in edition of a copper engraving of Doctor Schnabel (a.k.a., Dr. Beak), a seventeenth-century plague doctor in Rome. Circa 1656 by Paul Fürst (1608-1666) (Photo source: (Matuschek et al, 2020).

masks utilized during the bubonic plague found in the Middle Ages (**Fig. 1**). Some historians have thought that plague doctors wore these masks when interacting with patients; however, there is no direct link that they were used as face masks to prevent disease, giving way to the theory that these masks were given function in retrospect.

The first official use of face masks to stop pathogens was recorded by Johannes von Mikulicz in 1897 who sterilized gauze and wore it over his mouth the way that is used in modern times in the form of a cloth mask. This mask (or "mouth bandage" as Mikulicz referred to it), was described as easily breathable (**Fig. 2**; Matuschek et al., 2020). The face mask would gain popularity within the medical community and would officially be used as a method of protection against the 1918 influenza pandemic after noticing that influenza-related deaths were decreasing when the mask was worn. Part of this reduction was attributed to the mask mandates at that time (Strasser and Schlich, 2020). However, with popularity came rejection.

Fig. 2: Hübener's mask. Photo source: Strasser and Schlich, 2020.

One of the main opponents of the use of face masks during the 1918 pandemic was the Anti-Mask League, which argued that a mask mandate violated their civil liberties. These types of groups would reappear during the COVID-19 pandemic, again echoing the notion that mandatory face mask policies inhibited one's freedom (Taylor and Asmundson, 2021). However, contrary to the most recent pandemic, masks were still a relatively new idea in the 1920s, and many leading physicians rejected them, with some acceptance by interns and nurses (Matuschek et al., 2020).

With the 1930s came more research on face masks, progressing to the 1960s with synthetic single-use surgical masks that are very similar to ones commonly used today. The main feature of these masks, when compared to other masks, was that these newer masks fit snugly on the user's face to prevent the spreading of droplets versus the loosely fitting masks that often had gaps and had to be sterilized before each use. By 1980, cloth masks were deemed inferior to synthetic face masks (Strasser and Schlich, 2020).

Mask research continued, but like in the 1918 influenza pandemic, the wearing of face masks would once again be popularized with the public with the 2020 COVID-19 pandemic. Also, as before, popularity was met with rejection, accompanied by misconceptions. Sanjay Gupta, M.D., chief medical correspondent for CNN, expressed that one of the top five misconceptions about SARS-COV-2 and COVID-19 is that masks do not protect the user from contracting the disease (CNN, 2020). During the time between July and August 2020, about 16% of American adults surveyed reported that they never or seldomly wore masks in a public setting. Akin to the 1918 influenza pandemic, anti-mask rallies popped up, but this time were widespread across America rather than limited to a few cities as was the case in 1918 (Taylor and Asmundson, 2021). The lack of trust and support in masks can be linked to social media and Republican Party political viewpoints, with mask rejecters reasoning that masks were not effective or comfortable enough to wear against a disease that they believe would not affect them (Gupta, 2020; Taylor and Asmundson, 2021).

Face Mask Types and Efficacy

The National Center for Immunization and Respiratory Diseases, part of the Center for Disease Control and Prevention (CDC) categorizes face masks into three groups: cloth, surgical/disposable, and N95 respirators (National Center for Immunization and Respiratory Diseases (U.S.), 2022). Cloth masks are made from cloth fabric and can be stacked or combined with surgical/disposable masks to increase their efficacy. These masks can be made at home, making them more accessible to the public. These masks are also reusable upon cleaning, giving them an advantage in terms of cost and reusability when compared to other mask types (**Table 1**). A major disadvantage of cloth masks, however, is that these masks have the highest potential for user error due to their ability to be produced at home and being unfitted. Many health officials have deemed cloth masks a last resort option when no other mask type is available (Das et al., 2021).

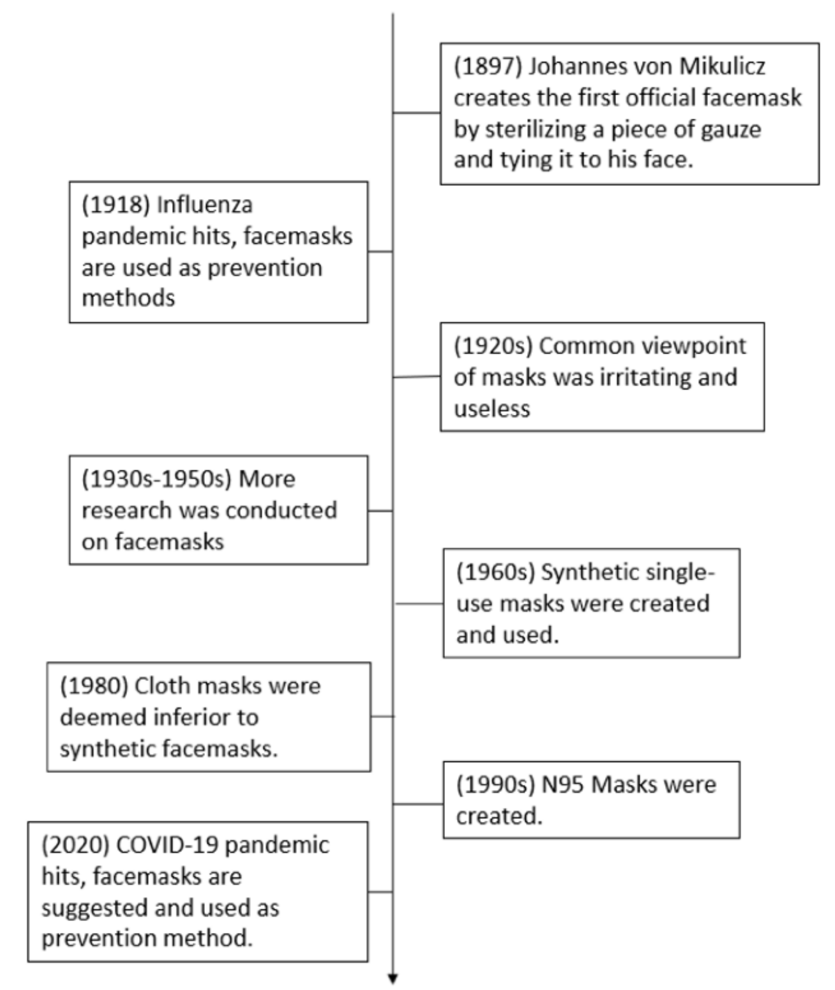

Fig. 3: A timeline containing important events pertaining to face masks such as the first official mask to the most current pandemic where masks were used as a major prevention method (Cucinotta & Vanelli, 2020; Matuschek et al., 2020; Strasser & Schlich, 2020; Tbilisi, 2022).

Surgical/disposable masks are the masks commonly used in medical settings and can be commonly found in stores in bulk, which gives this mask type an advantage over the other mask types (**Table 1**) (National Center for Immunization and Respiratory Diseases (U.S.), 2022). These masks are also fluid- and flame-resistant and regulated by the FDA (Food and Drug Administration) (Fischer et al., 2020). Arguably, their biggest advantage is that multiple studies have supported the claim that surgical/disposable masks' efficacy has little to no statistical difference to N95 masks (Randonovich, Jr. et al., 2019 and Wang et al., 2020). However, like cloth masks, surgical/disposable masks are unfitted and may not be able to create a complete seal, leaving room for pathogens to slip through gaps in between the face and the nasal and oral cavities (Ju et al., 2021). While N95 masks can protect the user from infectious aerosolized particles and droplets, surgical/disposable masks specialize mainly in only preventing aerosol/droplet spreading from the user (Fischer et al., 2020).

N95 respirators have more tightly-woven filters than the average mask and are also used in healthcare settings. N95 respirators are designed to create a seal between the nasal and oral cavities and the environment. If this is not created, then the N95 mask can malfunction and leak air from the sides (National Center of Immunization and Respiratory Diseases, 2022). N95 masks specialize in protecting the user from the environment which is the opposite specialty of surgical/disposable masks. Another advantage is that N95 respirators have four layers, as opposed to the three layers typically seen in surgical masks (**Table 1**). N95 masks also have the highest average efficacy out of the selected mask categories (Fischer et al., 2020). A major disadvantage of N95 masks is their cost, as N95 are more expensive than surgical/disposable masks while being less accessible and created to be single use (Ju et al., 2021).

	Characteristics	Advantages	Disadvantages
N95	Protects user from environment. Thickest mask type with 4 layers.	Creates total seal between nasal and oral cavity and the environment. Highest efficacy rates against all selected pathogens of the three mask types.	Most expensive of the mask types. Least accessible mask type.
Surgical/ Disposable	Protects environment from user. Has 3 layers. FDA regulated.	Cheap and flame resistant. No statistical difference when compared to N95.	Single Use Greater chance of gaps in mask due to the mask not being fitted.
Cloth	Comprised of various fabrics and cloth. Can be stacked.	Cheap and can be created at home. Most reusable of the three mask types.	Lowest efficacy rates against the selected pathogens of the three mask types. Only recommended as a last resort.

Table 1: Comparison of the three mask categories. Comparison of selected mask categories using characteristics, pros, and cons of each mask type. (Fischer et al., 2020; Ju et al., 2021; MacIntyre et al., 2011; National Center for Immunization and Respiratory Diseases (U.S.), 2022; Radonovich et al., 2019; Wang et al., 2020.)

A mask functions by blocking particles such as aerosols and droplets from getting through the mask. This is referred to as mask efficacy. If a mask has a 75% mask efficacy, then 75% of particles will be blocked by the mask. Multiple factors can contribute to a mask's efficacy rating, such as fit on the user generally, conditions the mask is worn in, and type of material that is used to construct the oral/nasal covering.

Another important aspect of face masks' ability to protect is the compliance factor, or how willingly an individual wears a mask. Face masks were already widely accepted and utilized in medical settings due to their requirement as personal protective equipment (PPE) as masks can help control the spread of various pathogens (Humphreys, 2020). However, face mask use in the public has oscillated depending on timing and location. Following Dr. Fauci's message on masks on April 3rd, 2020, the usage of masks increased nearly twelvefold in April compared to March (Richter, 2021). While there were anti-mask groups around America (Taylor and Asmundson, 2021), they were outnumbered by regular mask users, according to multiple studies. In June 2020, one survey reported that 65% of American adults wore a mask most of the time in public places, and 15% wore masks some of the time, with 16% being categorized as very rarely wearing a mask or wearing no mask (Igielnik, 2020). Another survey was concluded after this survey, taking into account the mask mandates that were put in place in late July and August to see whether the mandates increased the percentage of Americans in Wisconsin who wore a mask. In Wisconsin, 41% reported that they wore masks in early June, before any mandates. By August 1st, when the state mandate was placed, 96% reported to have worn a mask in public, more than double the number from June (Haischer et al., 2020).

The sudden increase in mask wearing during the COVID-19 pandemic is also attributed to the lower number of flu cases being reported between late 2019 and early 2021 (Gertz et al., 2023). This literature review meta-analysis aims to further elaborate on this concept, investigating how masks fare against various pathogens similar to SARS-COV-2. This paper will address whether face masks are a viable protection mechanism against not only SARS-COV-2, but other respiratory pathogens like influenza A, rhinovirus, and Streptococcus and Staphylococcus bacteria by researching the efficacy of various mask types against these respiratory pathogens.

RESPIRATORY PATHOGENS

Coronavirus

Severe Acute Respiratory Syndrome-coronavirus-2 (SARS-COV-2) is the virus responsible for the coronavirus infection, commonly known as COVID-19, and the COVID-19 pandemic. The airborne virus was first reported and isolated in December 2019 in Wuhan, China (Wang, 2020) and has an average diameter of 100 nm (Bar-On et al., 2020). The main symptoms of SARS-COV-2 infection include fever, fatigue, chills, dry cough, nausea, body aches, headache, and loss of smell or taste (Center of Disease Prevention and Control, 2022). The virus mainly travels via aerosols and/or droplets (Tang, 2020). SARS-COV-2 has an estimated basic reproductive rate (R0) of 2.5, giving it a high transmission rate between humans (Petersen et al., 2020).

Influenza

Influenza A is the virus responsible for the common flu. The airborne virus has no true origin point, though the earliest possible origin is believed to be ancient Greece (Lina, 2008). Influenza was first isolated between 1922 and 1923 (Barberis et al., 2016). The main symptoms of influenza include sudden cough, sneeze, aches, chills, fever, runny nose, and fatigue (Center of Disease Prevention and Control, 2022). The virus mainly travels via droplets and aerosols (Leung et al., 2020) and has an average diameter of 100 nm, similar to SARS-COV-2 (Louten, 2016). Influenza has a range of R0 factors from 1-5-3.0, giving it a moderate to high transmission rate from human to human (Petersen et al., 2020).

Rhinovirus

Rhinoviruses are the main virus type that causes the common cold. Rhinovirus was first isolated by Dr. Winston Price in 1956 (Kennedy et al., 2012). The common cold is not thought of to be typically lethal, instead causing mainly mild infections (Center of Disease Prevention and Control, 2023). The main symptoms of rhinovirus include cough, sneezing, runny nose, congestion, sore throat, headache, body ache, and fever (Center of Disease Prevention and Control, 2023). The virus travels via aerosols and droplets (Leung et al., 2020) and has a range of R0 factors that are >1, but ≤5, the highest of any pathogen discussed (Leung, 2021). Rhinoviruses are also the smallest pathogen of the study, having an estimated average diameter of 30 nm (Palmenberg and Gern, 2016).

Streptococcus and Staphylococcus

Streptococcus and Staphylococcus are bacteria that can cause a multitude of infections. Both bacteria can travel through the air, although they can use multiple modes of infection and cause infections like strep throat (Streptococcus) and staph infections (Staphylococcus) (Kalaiselvan et al. 2022). Streptococcus and Staphylococcus bacteria have diameters ranges of 0.5μm to 1μm and 0.5μm to 1.5μm, respectively (Patterson, 1996). Streptococcus infections can have symptoms such as fever, difficulty swallowing, swollen tonsils and lymph nodes, and sore throat (Center of Disease Prevention and

Control, 2023). Staphylococcus infections vary in severity often depending on the location. One of the main concerns is staphylococcus pneumonia as it has the potential to progress into necrotizing pneumonia or sepsis (Clark and Hicks, 2023). The bacteria can travel through the air but can also spread from direct contact from an infected surface (Park et al, 2022).

	Dia-meter (nm)	R_0 Factor	Isolation Year	Type of Pathogen	References Cited (Towards Mask Efficacy)
Corona-virus	100	≈2.5	2019	Virus	(5) Wang et al., 2020; Leung et al., 2020; Ju et al., 2021; Wei et al., 2021; Marti et al., 2021.
Influenza	100	1.5-3.0	1922-1933	Virus	(6) Leung et al., 2020; Brienen et al., 2010; Bischoff et al., 2011; Ma et al., 2020; Randonovich Jr. et al., 2019; Zhou et al., 2018.
Rhinovirus	30	≤5	1956	Virus	(2) Leung et al., 2020; Zhou et al., 2018.
Strepto-coccus/ Staphylo-coccus	500-1500	N/A	1879	Bacteria	(4) Zhou et al., 2018; Kalaiselvan et al., 2022; Park et al., 2022; MacIntyre et al., 2014.

Table 2: Basic information of selected pathogens. Comparison of basic information about each pathogen and how many references per pathogen were able to be found that related to mask efficacy. Ro factors give an estimate on how many individuals will be infected by an infectious individual. Diameters were commonly reported as averages, meaning pathogens can be greater or less than the diameter listed. Some pathogens share references and were counted accordingly. Nanometer (nm). (Bar-On et al., 2020; Barberis et al., 2016; Kalaiselvan et al., 2021; Kennedy et al., 2012; Leung, 2021; Leung et al., 2020; Lina, 2008; Louten, 2016; Palmenberg & Gern, 2014; Patterson, 1996; Petersen et al., 2020; Tang et al., 2020; Wang et al., 2020.)

METHODS

This study investigates the mask efficacy against various respiratory pathogens as reported in peer-reviewed published literature. Peer-reviewed published literature was selected from three search engines: PubMed, ProQuest, and Google Scholar. The first 150 listings for each search within each search engine were scanned for relevance to the topic of this paper. The literature was not selected if the literature was published prior to 2003. Keywords used to find literature were "SARS-COV-2", "influenza", "rhinoviruses", "Staphylococcus aureus", "Streptococcus bacteria" in combination with either "mask efficacy" or "N95". 13 papers were selected for this review using the methods listed above. Some studies counted for multiple pathogens and were only counted once for the final tally. Studies were included if they verified the existence of the pathogen or designed particles to match the pathogen being studied after the use of a face mask. After studies were selected, averages and standard deviations were calculated using Microsoft Excel (version 2041).

RESULTS

Coronavirus

The World Health Organization (WHO) declared the COVID-19 outbreak a global pandemic on March 11th, 2020 (Cucinotta and Vanelli, 2020). The COVID-19 pandemic led to a substantial increase in mask wearing in the United States despite there being a lack of peer-reviewed literature on mask efficacy against the spread of SARS-COV-2 at the time (Ju et al., 2021). For this paper, not all the chosen studies that focused on SARS-COV-2 also considered the N95 mask, with the majority basing their inquiry on ordinary surgical masks. It is also worth mentioning the details of two studies. Two studies were conducted and published prior to the COVID-19 pandemic's declaration date, with one study using SARS-COV instead of SARS-COV-2. Both viruses come from the same family and are found to be nearly identical in structure, the only changes being mutations that made SARS-COV-2 more infectious than SARS-COV (Xie et al, 2020).

Wang et al.,'s study was published in China in March 3rd, 2020, before the World Health Organization's (WHO) pandemic declaration (Cucinotta and Vanelli, 2020), but after China's issuing a mask-wearing recommendation for face masks to handle the outbreak in China (Tan et al., 2020). The importance of noting this timeline is to give an example on how different countries viewed the idea of using face masks to combat the transmission of SARS-COV-2 before it was declared a pandemic (Ju et al., 2021). The focus of the study was to identify whether face masks would protect medical staff from COVID-19. The study concluded with 0/278 of selected medical staff who wore the N95 mask being diagnosed with COVID-19 as compared to 10/213 of selected medical staff being diagnosed with COVID-19 who wore no mask. It was also noted that there was no significant difference between the two mask types (Wang et al., 2020).

Another study selected for this review focused on one mask type as well, choosing to test surgical masks instead of N95. This study uses SARS-COV instead of SARS-COV-2. The study was conducted by Leung et al. (2020) and split its interest between SARS-COV-2, influenza A, and rhinovirus. The study concluded with the finding that surgical masks had an 100% efficacy against both SARS-COV-2 droplets (>5μm) and aerosols (<5μm). These numbers were found by detecting viral loads within the droplets or aerosols located in the exhaled breath of an individual displaying symptoms caused by either coronavirus, influenza virus, or rhinovirus (Leung et al., 2020).

The study performed by Ju et al. looked at the three mask types and found that N95 masks had the highest efficacy, blocking 95% of particles larger than 0.3 μm. This is the general claim made by N95 mask manufacturers and it was supported by He et al.'s study. Surgical masks were found to have similar results to N95 (Ju et al., 2021). Cloth masks were identified as the worst mask type, being labeled with "poor filtration efficacy" (Ju et al., 2021). Poor filtration efficacy is generally <50% for cloth masks and suggests that the mask either does not properly fit or allows too many particles to flow through the mask (Sharma et al., 2020).

The next SARS-COV-2 study was Wei et al.'s study, which followed similar trends as Ju et al.'s study, determining that the N95 and surgical masks have similar efficiencies ("99.4% and 98.5% respectively" (Wei et al., 2021)). This was calculated by measuring the viral loads in the exhaled droplets from infectious individuals. The study also deemed cloth masks to have the worst efficacy at approximately 80%. Wei et al. also acknowledged that the masks become more efficient with growing particle sizes, with almost all masks reaching 100% efficacy at 3μm (Wei et al., 2021).

Finally, there was a unique study conducted by Martí et al. which looked at a face mask filter rather than the entire mask. It was concluded that this specific filter not only prevented SARS-COV-2 particles from passing through the mask, but also inactivated the virus, rendering it unable to replicate. The study used mask filters that were lined with benzalkonium chloride and measured the effects on SARS-COV-2. The mask filter could disable 99% of viral loads and was even capable of doing it against aerosols. It was also listed that this could also be used as a future method of prevention as it was 100% effective against methicillin-resistant forms of Staphylococcus aureus and Streptococcus aureus (Martí et al., 2021).

Influenza

Influenza A was the most common pathogen to attract peer-reviewed studies based on mask efficacy. Some of the selected studies would also have multiple pathogens within the same study, as is the case with Leung et al.'s study, previously noted for its SARS-COV-2 segment. Leung et al.'s study looked at how effective surgical masks were against SARS-COV-2, influenza A, and rhinovirus. Leung et al. found that surgical masks were less effective against influenza A droplets (96% efficacy) and aerosols (78% efficacy) than SARS-COV-2 droplets and aerosols (100% for both categories) (Leung et al., 2020).

Brienen et al.'s study simulated an influenza A pandemic by assuming influenza-related attributes such as transmissibility, infectivity, and how aerosols. By focusing on surgical and cloth masks, the creators of the study were able to predict the spread of an influenza pandemic, along with assessing how effective masks would be in this simulation. Following a similar trend from Leung et al.'s study, surgical and cloth masks were given a mask efficacy range of 58%-85% (Brienen et al., 2010).

Bischoff et al.'s study looked at how efficient surgical and N95 masks, paired with eye protection, would be against influenza A aerosols. This study was made possible by exposing consenting individuals with a live, asymptomatic influenza virus and set into groups based on mask type or the presence of a mask. The results were gained by measuring whether the virus was able to reach the nasopharynx of the individual. Results from the study concluded that without eye protection, surgical masks shielded 0 of 5 (0%) individuals from the virus and that N95 masks protected 3 of 5 individuals (60%) from the virus. It was noticed that the virus could have reached the nasopharynx through the nasolacrimal duct, presenting another mode of transmission (Bischoff et al., 2011) The idea of another method of transmission was also shared by a study carried out by Davies et al., which reinforces the idea that face masks can protect the individual without fully eliminating the risk of infection (Davies et al., 2013).

The next study used influenza to predict how face masks would protect against SARS-COV-2. Ma et al. used an influenza strain that was lowly pathogenic and sprayed its aerosols 100 times into a cloth mask, a surgical mask, and a N95 mask. The results showed that cloth masks blocked 95.15% of influenza particles, surgical masks prevented 97.14% of particles from passing through the mask, and the N95 mask obtained a near perfect 99.98% mask efficacy against the virus. As seen in **Table 2**, SARS-COV-2 and influenza have identical diameters, so by using influenza, the makers of the study were able to propose mask wearing as a viable method for protecting against SARS-COV-2 (Ma et al., 2020).

Radonovich Jr. et al.'s study was not a study that directly measured mask efficacy, but questioned whether the N95 or surgical masks are better at blocking influenza A. This was achieved by randomly assigning 189 groups to wear N95 masks around patients with respiratory sickness, and 191 groups to do the same, but with surgical masks instead. This process would continue for four years during the timeframe of which influenza cases would normally reach their peak. By the end of the study, 2369 individuals completed the study. Their results showed that 8.2% of the N95 group were confirmed to have been infected with influenza compared to 7.2% of the surgical mask group. The authors thought it worth mentioning that there was no significant difference between the two mask types (Radonovich Jr. et al., 2019), supporting the claims from similar studies that N95 and surgical masks produced efficacies that weren't significantly different (MacIntyre et al., 2011; Wang et al., 2020).

The final study selected for influenza focused on the N95 mask and multiple pathogens as it measured mask efficacy against influenza A, rhinovirus, and Staphylococcus aureus. Zhou et al. discovered that the N95 mask was >99% efficient against influenza A by aerosolizing influenza into the N95 mask. The same process would be used for measuring the mask efficacy of rhinovirus (Zhou et al., 2018).

Rhinovirus

Rhinovirus yielded the least number of studies, with both studies being shared with other pathogens. Leung et al.'s study makes another appearance and displays even lower efficiencies than influenza A. Rhinovirus droplets and aerosols had surgical mask efficiencies of 78% and 62%, respectively, compared to 96% and 78% for influenza droplets and aerosols, respectively (Leung et al., 2020). Zhou et al.'s study focuses on the N95 mask and its efficiency against rhinovirus, influenza, and Staphylococcus aureus. As previously stated, the process to measure the mask efficacy of N95 masks against rhinovirus was identical to the process used for influenza. Zhou et al. concluded that >99% of rhinovirus particles were contained by the N95, sharing its efficacy rating with influenza (Zhou et al., 2018).

Staphylococcus and Streptococcus

When combined, both coccus bacteria occasioned a similar number of studies to SARS-COV-2, even sharing a study with each other. As previously stated, Martí et al proposed a mask filter that could disable 100% methicillin-resistant forms of Staphylococcus aureus and Streptococcus aureus (Martí et al., 2021). As noted above, Zhou et al.'s study focused on the N95's efficacy against Staphylococcus aureus, rhinovirus, and influenza A. Like influenza A and rhinovirus, Staphylococcus aureus was aerosolized and propelled into the N95. The N95 mask's efficacy against the bacteria was >99% (Zhou et al., 2018).

Kalaiselvan et al.'s study looked at how efficient surgical masks, three-layered cloth masks, and seven-layered cloth masks were against Staphylococcus aureus. This study would be the only study to measure cloth masks with varying amounts of layers. The Staphylococcus aureus bacteria was aerosolized via speech and captured in either masks or agar plates. The results suggested that three-layered cloth masks are 98% efficient against the bacteria, and seven-layered and surgical masks are 100% effective at containing the bacteria. It was noted that masks should be replaced or thoroughly washed to prevent recontamination from bacterial colonization on the mask (Kalaiselvan et al. 2022).

Park et al.'s study followed the same trends as Kalaiselvan et al.'s study. Park et al.'s study found that surgical and cloth masks blocked 100% of the Staphylococcus aureus bacteria. This was determined by measuring the number of bacteria on either side of the face mask worn by an individual. Interestingly, it was also found that the bacteria would stick to the mask and begin to repopulate. The risk of reinfection was also present in this study, as Staphylococcus aureus colonies had an 80% chance to colonize on the mask and grow (Park et al., 2022)

MacIntyre et al.'s study in 2014 combines aspects from bacterial and viral studies. The study focused on Streptococcus pneumoniae bacteria alongside other bacteria and sought to discover the mask's ability to not only prevent the bacteria from spreading, but also the ability to prevent colonization. The mask efficacy for N95 and surgical masks were assumed to be >99%, respectively, for Streptococcus pneumoniae. The results concluded with the N95 and surgical mask filters being capable of deactivating 97.2% and 94.7% of Streptococcus pneumoniae on the mask. This study also focused on co-infection and found that mask efficacy drops by approximately 40% if there is also a viral infection occuring (MacIntyre et al., 2014).

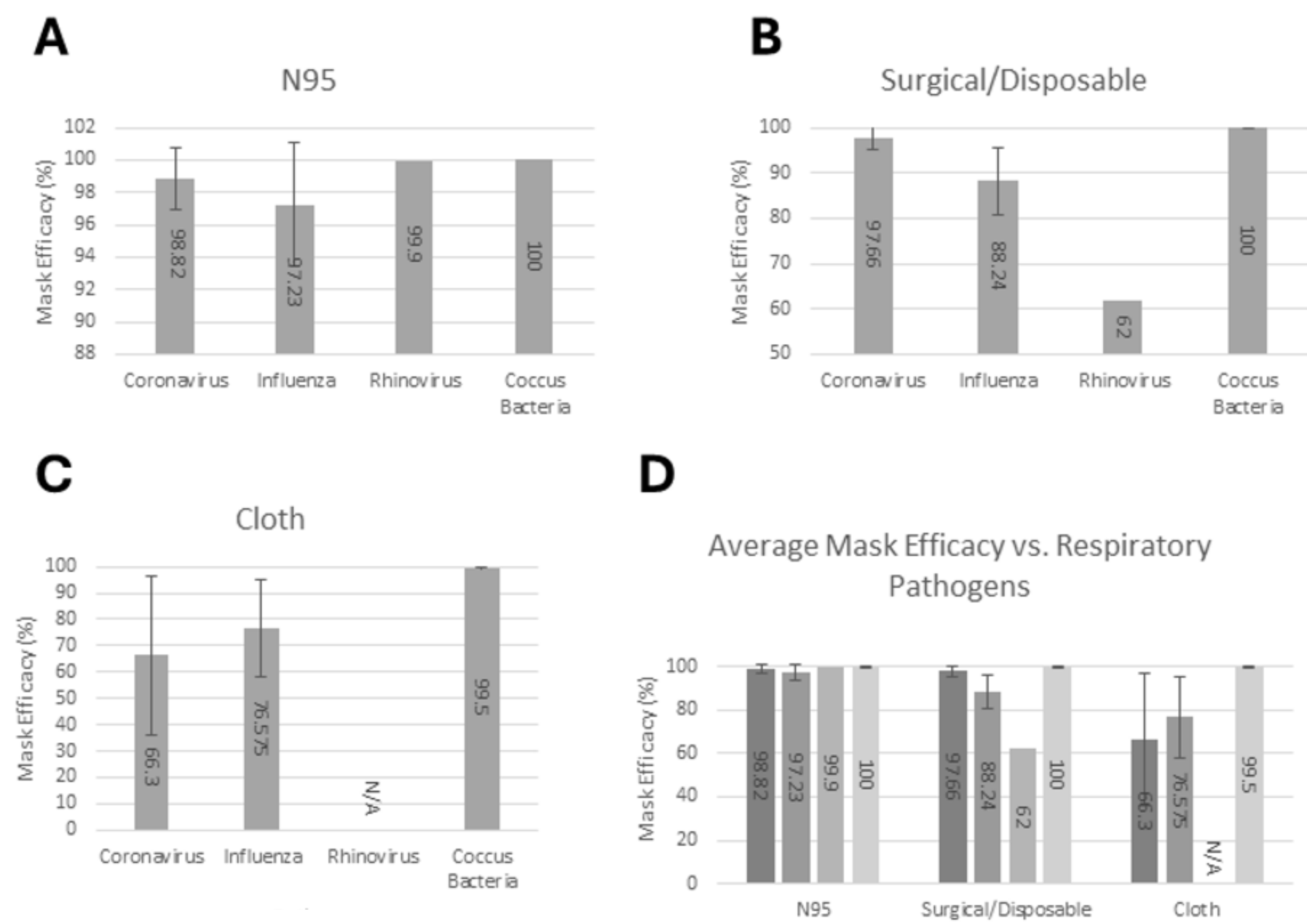

Fig. 4. Comparison of average mask efficacy for each pathogen and mask type, N95 (A), Surgical/Disposable (B), Cloth (C), and all together (D) with standard deviation bars. Averages were calculated by adding up the recorded efficacies from selected studies and divided by the number of selected studies. Rhinovirus studies did not include cloth masks in the selected studies. A N/A rating was given to show no average efficacy rating. Rhinovirus studies also provided one efficacy for N95 and surgical/disposable masks each, resulting in zero error on the average.

CONCLUSIONS

This review aims to raise interest in the efficacy of face masks against respiratory pathogens and to give a clearer viewpoint on face-mask wearing. This review compiled studies that focused on mask efficacy against a specific respiratory pathogen to determine whether face masks were efficient in preventing pathogen spread. All selected studies took appropriate measures in assuring that the tested pathogen was the chosen pathogen or that the particles used were identical to the preferred pathogen. Studies that verified the presence or characteristics of the pathogen were preferred because there is no concern that pathogens were confused for another, ruining the validity of the findings. Overall, the results of the review show that face masks provide highest efficacy rates for protection against SARS-COV-2, influenza, and bacteria and protection against these pathogens (**Fig. 4D**).

The rhinovirus had the least number of studies and did not yield a published study that solely focused on the mask efficacy against rhinovirus (**Table 2**). Both studies that included rhinovirus also focused on influenza A and Staphylococcus aureus, respectively. This could be due to fact that rhinovirus mostly causes minor respiratory infections and is thus not as serious a viral threat to human health as SARS-COV-2 or influenza (Ljubin-Sternak and Meštrović, 2023). Interestingly, the lowest efficacy rate was recorded with surgical/disposable masks against rhinovirus at 62% (**Fig. 4B**) (Leung et al., 2020). This could be attributed to the size of rhinovirus, as it is the smallest pathogen evaluated, at an average diameter of 30 nm (Mandal, 2023). For comparison, SARS-COV-2, and influenza A both have 100 nm diameter averages. N95 masks were designed to block approximately 99.8% of particles that have a diameter of 100 nm (Bar-on et al., 2020), which match the average diameters of influenza A and SARS-COV-2, but that design size would not protect against a smaller virus like rhinovirus. In contrast, bacteria like Streptococcus and

Staphylococcus have a much larger diameter of 500-1500 nm, which could be responsible in part for the near 100% ratings for all mask types (Public Health Agency of Canada, 2012). Their diameter is approximately 17 times larger than that of a rhinovirus virion's diameter. Rhinovirus was the least researched pathogen, often sharing studies with other pathogens, making the search for mask efficacy against rhinovirus difficult. This is possibly also due to the proposed lack of concern about rhinoviruses among the scientific community (Ljubin-Sternak and Meštrović, 2023).

Aside from testing for pathogenic spread, masks can also be tested against general-sized aerosols to document their efficacy. These masks have penetrating particle size ranges, giving a size range through which a pathogen could potentially flow through. The range was reported to be 30 to 100 nm for N95 masks and 200-500 nm for cloth and surgical masks (Ju et al., 2021). This would be backed by He et al.'s study, which tightened the range for N95 masks to 30-40 nm and the range for surgical masks was altered to 100-400 nm, possibly providing an alternative to look to the idea that N95 masks and surgical masks are so similar (He et al., 2019). This also supports the claim that rhinovirus has the lowest mask efficacy, as both studies found that a particle of about 30 nm could pass through the mask with relative ease compared to other viruses (He et al., 2019 and Ju et al., 2021).

The mask efficacy conclusions made by numerous studies in this review are also supported when the measured mask efficacies are averaged and compared as seen in **Figure 2**. N95 masks generally reported the highest averages in the pathogen categories between the 97th and 100th percent efficacy range with low standard deviations for coronavirus and influenza (1.92-3.83). Surgical masks and cloth masks offered more variation than the N95 masks, but surgical masks still outperformed cloth masks in their respective pathogen categories. All mask groups had their lowest efficacy against different pathogens: influenza produced the lowest average for N95 (97.23%), rhinovirus had the smallest average of the graph in surgical masks (62%), and cloth masks are the most susceptible to coronavirus (66.3%). These are only averages comprised of calculated mask efficacies from other studies, and some of which relied on results from a single study (N95 and surgical mask efficacy against rhinovirus) or did not have a documented a mask efficacy at all (such as cloth mask efficacy against rhinovirus). This variation in mask efficacies could also be attributed to the number of studies that were found for each pathogen, as shown in **Table 2**. The more studies were conducted for a pathogen, the higher the average and the lower the standard deviation.

Influenza A search resulted in six studies that fit the selection criteria for mask efficacy, the most out of any pathogen for this review (**Table 2**). Multiple reasons could contribute to the high number of studies on influenza A. Compared to rhinovirus, influenza A is bigger and has an earlier discovery than rhinovirus. As seen in **Table 2**, influenza was isolated between 1922 and 1923 (Barberis et al., 2016), whereas rhinovirus was isolated in 1956 (Kennedy et al., 2012). Influenza A also had more studies compared to SARS-COV-2 which could be attributed to the isolation year in 2019 (Wang, 2020). Although it is an identical virus in size compared to SARS-COV-2, it has been studied for a much longer timeframe (Barberis et al., 2016 & Wang, 2020). The COVID-19 pandemic is recent at the time of writing when compared to the multiple influenza pandemics, with the most recently declared influenza pandemic recorded in 2009 (Tsoucalas & Sgantzos, 2016). With influenza capable of producing multiple pandemic declarations since its isolation year, this could have resulted in a much greater interest in how masks protect individuals from influenza in anticipation for another influenza pandemic (Kilbourne, 2006).

A common message to appear with bacterial studies is the risk for reinfection. Bacteria generally had approximately 100% mask efficacy across the mask types, with cloth masks having the lowest average efficacy rating at 99.5%. This high mask efficacy rate was recorded in studies such as Kalaiselvan et al. and Park et al. studies that also warn against prolonged use of the same mask or reuse without cleaning the mask. Prolonged exposure can lead to colonization due to bacteria thriving on damp surfaces. A face mask is likely dampened by exhaled breath. Due to viruses requiring a living host to replicate themselves, a virus is far less likely to colonize and survive on a mask than bacteria. This brings another layer of concern for respiratory bacterial infections, as masks have a near 100% chance to contain the bacteria and can increase the chance of colonization, leading to possible reinfection (Kalaiselvan et al., 2022; Park et al., 2022).

Concerning Staphylococcus and Streptococcus, studies record efficacies near 100% across all masks. This connects the efficacy of the N95 mask to that against influenza A and SARS-COV-2 (**Table 2**). As stated before, the N95 mask was designed to block these smaller viruses, and as a side result, block bacteria as well. This would explain why the N95 mask's efficacy generally was high 90th percentile. The cloth mask also needs to be tested against rhinovirus, as that was the only pathogen to not have a study that involved the N95 mask. Considering that PPEs can be properly worn with both N95 masks and surgical masks, the idea that surgical masks are on similar levels in terms of mask efficacy is not far-fetched. Surgical masks were used in place of N95 masks if that type of mask was absent from the study. These masks generally stayed in the high 90th percentile, with an outlier of 62% efficacy against rhinovirus (Leung et al., 2020). Studies concluded with the idea that there is no statistically significant difference between the surgical and N95 mask, so there is more need to answer the question whether the N95 is worth the increase in price and effort, as the N95 requires precise fitting to function properly (Radonovich, Jr. et al., 2019, MacIntyre et al., 2011 & Wang et al., 2020).

A major caveat to these studies is that it assumes wearers will wear their face mask perfectly; however, N95 masks have to be fitted accordingly to the user's face (**Table 1**). As such, this opens the door for human error due to the fitted nature of N95 masks and the fact that they were not designed to be paired with other mask types. In contrast, both cloth and surgical/disposable are unfitted and can be adjusted or stacked to better suit the user (National Center for Immunization and Respiratory Diseases (U.S.), 2022.). Perhaps future studies could incorporate the potential that the individual could be wearing the mask incorrectly or proceed in a similar route as Kalaiselvan et al.'s study and perform experiments with various mask layers.

The results of this review show that wearing masks provides at least a basic level of protection against respiratory pathogens with surgical masks and that N95 masks provide a greater level of protection than cloth masks. The results also showed that wearing face masks during the COVID-19 pandemic was a beneficial way to prevent the spread of SARS-COV-2. A benefit of this review is that this knowledge can be used in the event of a future pandemic involving a respiratory pathogen. In the event of a future pandemic, global and national officials should be able to safely recommend masks quickly and efficiently in an effort to prevent the disease from progressing much further than it already has. More detailed studies can be conducted using this format to further research and our understanding of face masks and their efficacy against respiratory pathogens. ❖

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