Public use of face masks to control the coronavirus (SARS-Cov-2) pandemic: a review of theory and evidence

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Abstract. The current Coronavirus Disease 19 (COVID-19) pandemic, caused by the SARS-CoV-2 virus, is unprecedented in recent history and threatens the lives and livelihoods of billions worldwide. The rapid spread and lack of modern parallels have left governments, health agencies, and the public racing to understand how to best mitigate and ultimately suppress the pandemic, but we are still working to understand the strengths and weaknesses of various interventions at our disposal. Few issues have been as contentious as the public use of face masks to control the pandemic's spread. There is ongoing debate about their effectiveness, but an increasing body of evidence suggests that masks could be a useful in preventing the spread of coronavirus, leading several governments and health agencies to review and revise their policies. Here, we review the theory and evidence behind use of masks. The theory behind masks is that they prevent the spread of viral particles by infected persons, and inhalation of viral particles by uninfected persons. Even assuming masks are not 100% effective in preventing infection, they may reduce severity of infection by reducing viral dosing. Laboratory studies suggest masks may be effective in stopping both exhalation and inhalation of viral particles. However, real-world studies provided limited evidence for the use of masks in controlling influenza transmission and highlight potential problems associated with their misuse, such as poor compliance or improper use. Evidence for efficacy of face masks against the first SARS virus, SARS-CoV-1, implies that they may be effective against the current outbreak of SARS-Cov-2 virus. This is important as mathematical modeling suggests that even small reductions of in transmission rates can make a large difference over time, potentially slowing the pace of viral pandemics and limiting their spread. Perhaps the strongest argument for the use of masks is that countries with early adoption of masks have tended to see flatter pandemic curves, even without strict nationwide lockdowns. There is little evidence that respirators are more effective than surgical masks, but this may be due to misuse or poor compliance. Studies suggest some non-medical masks perform on par with medical masks. Improvised masks are less effective than medical masks, but may provide better protection than nothing at all. While many governments now encourage the use of improvised face coverings, more will need to be known about material, design, and who needs to wear masks, and when, to ensure effectiveness. Proper use of masks will also be important; if masks are used improperly or infrequently they may provide limited protection. It is important that public health policy makers consider the debate and the potential of masks as part of multi-faceted coronavirus control strategies.

Through history, new diseases have repeatedly emerged and spread through civilizations, causing pandemic outbreaks [1]. Pandemics are the result of concentrating people in cities, then linking them by ships, roads [1], rail, and aircraft [2] [3] [4]. The discovery of antibiotics against bacterial diseases and vaccines against bacteria and viruses seemed to mark an end to millennia of pandemics [1], but they provide no defense against a novel virus.

This is the world a new SARS strain, SARS-Cov-2, emerged into, in December 2019 [5]: one with almost 8 billion people, intimately connected by air travel, with few defenses. Countries have had to adapt rapidly, implementing measures such as quarantines, social distancing, isolation, and travel bans. Because few countries have faced such an outbreak in modern times, we have limited evidence to draw on. The result is, unsurprisingly, intense controversy over the most appropriate measures to use, and the benefits, risks, and costs of different interventions. Few issues have been as contentious as the public use of facemasks. Face masks were initially introduced around the turn of the century to control infection [6] and transmission by pathogens in hospital settings [7] and their use became widespread to combat the 1918-1919 flu pandemic [8]. Even in that time their use was controversial. Face masks had limited effect on flattening the pandemic curve and it was unclear whether the issue lay in the ineffectiveness of face masks, or their application [8].

Following the SARS outbreaks, two distinct approaches were taken with respect to the public use of face masks. In some countries, especially eastern Asia, policies officially or in practice have encourage the use of facemasks. Such countries and territories included China, Hong Kong, Taiwan, South Korea, Thailand, Vietnam, Mongolia, and Japan, and non-Asian countries such as Kuwait, Czechia, and Slovakia. Some countries, such as China, encourage or require mask use. Others, such as Taiwan, don't officially encourage mask use, but have taken steps to ensure public availability— increased production, restricted export, controlled distribution, price controls, rationing.

The other approach, followed until recently by the World Health Organization, the US, Canada, the UK and Western Europe, discouraged public use of facemasks except for infected individuals. The argument was made that medical masks such as N-95 respirators and surgical masks were required for health care workers, and of no proven benefit for the public. This decision led to questioning and criticism by China's CDC [9], scientists [10], journalists, and social media campaigns. Several countries, including Austria and India, encouraged public adoption of facemasks. In the United States, the cities of LA and New York and the states of Alaska and Colorado broke with the CDC, before the CDC reversed its position and encouraged the public to use improvised masks. Other countries, including Indonesia, Bangladesh, and Morocco, have recently followed suit. The WHO continues to advise that masks are only needed by infected individuals or those caring for them.

The debate surrounding masks is ongoing. Many important questions need to be better understood, and sooner rather than later. How exactly do masks work? How effective are masks when used by the public? Should they be integrated into a broader pandemic strategy? If so, who needs to wear them, and when?

Unlike some other interventions such as vaccines, masks would likely to require consistent use by a large number of people to be effective. Therefore a strong rationale for their use will be necessary if governments and health agencies choose to employ them as a strategy. Here we review the rationale and science behind mask use, what is known and unknown. The goal of this paper is to help inform scientific debate and discussion about further developing rational and evidence-based public policies.

The Theory: Masks may protect you from others, and others from you

It seems sensible to assume that any barrier between two people's airways reduces the chance of an air-borne virus being transmitted between them. Masks worn by infected people catch some fraction of virus-laden respiratory droplets that are released by breathing and coughing. Perhaps just as important, breathing through a mask slows and deflects air as it is exhaled, potentially reducing the distance that viral droplets travel as aerosols.

As a simple flow-visualization experiment, one can hold some flour in one's hand, then give it a hard puff of air, or a cough: it flies everywhere. When the same is done with a cotton T-shirt over the mouth, no matter how hard you try, it's difficult to move more than a tiny fraction of that flour. Particularly in light of the ability of coughs, sneezes, and breaths to expel jets of droplet-laden air [11], this implies that masks could limit a person's ability to spread particles by slowing the air released from the mouth.

Meanwhile, masks worn by uninfected people catch some fraction of the virus that they would otherwise inhale. If both infected and uninfected people wear masks, then these effects should multiply. For example, if, hypothetically, an infected person's mask reduces the amount of virus spread by 75%, and the uninfected person's mask reduces it by another 75%, then the total reduction of virus spread would be 94%.

It is still possible that the reduction in the amount of virus spread is not enough to prevent an infection. However, masks may still protect people, because dosage matters. Lower dosing of virus means infection takes longer to build up, giving the immune system time to mount a response. Higher viral dosage gives the virus a head-start in its race against the immune system, leading to a more dangerous, rapid course of infection. We see this in laboratory studies of animals. For example, mice exposed to lower doses of influenza virus become less ill [12] than those exposed to high doses – which became more ill and suffered more lung damage. In chickens exposed to avian influenza, the higher the initial dose of virus, the faster the birds became sick and died [13]. It follows that by lowering the initial dose, the use of a mask could conceivably make the difference between mild symptom,s and a more severe course of illness resulting in hospitalization, or death.

The practice. Evidence on the effect of masks on viral spreading from experimental and real world studies

Experimental studies suggest that surgical masks can greatly reduce the exhalation of virus particles [14]. A recent study found that wearing of surgical masks by patients with respiratory infections resulted in a statistically significant decrease in coronavirus RNA detected in aerosols. Reduction of virus detected in droplets was also found, but not statistically significant, perhaps because of the small number of patients with coronavirus [14]. Strikingly, the pattern in shed influenza virus was very different. Masks resulted in a decrease in influenza RNA in droplets, but a small and non-significant reduction in viruses detected in aerosols [14]. This is important because it suggests that masks affect different viruses in different ways, and so results from studies of influenza cannot automatically be assumed to apply to coronaviruses, or vice versa.

The only study of exhalation of SARS-Cov-2 virus looked at how masks affected shedding. They found that those coughing while wearing either surgical or cotton masks were able to transfer virus to a petri dish placed 20 cm [15], and found that virus was able to either penetrate the mask or flow around the edges to contaminate the outer surface. This is perhaps not a realistic setting, in that people typically stand 20 cm apart when interacting, but it does raise cautions about how effective masks would be to control the spread of virus by infected persons, either among the general public or in a hospital setting. There is also the issue of low sample size, particularly given that it is difficult to induce patients to cough in a uniform fashion [8].

However, as discussed above, masks may function not only to filter air leaving the lungs, but to slow the jets of air released by exhalation or coughing; in this case a mask might still be effective in reducing spread of virus even if it performs relatively poorly in filtering exhaled air. Experimental studies confirm that masks are able to reduce the distance that exhaled air travels [16]. During coughing, expelled air traveled 68 cm, 30 cm, and 15 cm (Fig. 1), depending on whether the person wore no mask, a surgical mask, or an N95 respirator [16]. This suggests that even with limited filtration efficiency, masks could effectively reduce viral dispersion by infected people.

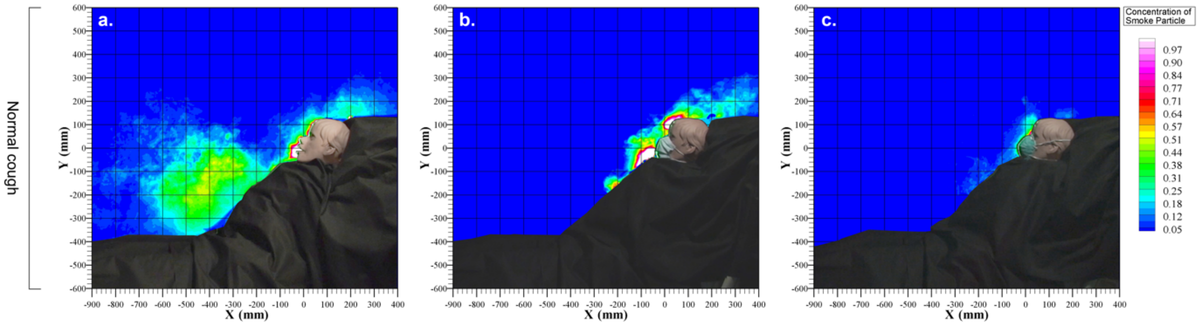

Figure 1. Flow visualization using smoke to show dispersal of exhaled air using (a) no mask, (b) surgical mask, (c) N95 respirator during a cough. From [16].

Other studies have examined the effectiveness of masks in reducing the inhalation of virus particles. The effectiveness of surgical masks varied greatly, some providing less protection and some more [17]. Surgical masks tested reduced particles inhaled by a factor of anywhere from 1.3 to 20, and influenza virus particles by a factor ranging from 1.1 to 55; the average mask reduced the amount of virus particles breathed in by an average of tenfold [17]. Importantly, there was a strong correlation between the reduction of particles inhaled and virus inhaled, which suggests that tests using inert particles rather than viruses can still provide useful information on mask effectiveness.

In real world settings, several studies suggest masks provide at least some protection against spreading and catching airborne infections. Again, studies for influenza and coronaviruses show different patterns. A number of studies focus on influenza. For example, a study of a hospital in Germany found that once staff began wearing masks continuously, the number of patients contracting influenza in the hospital declined by half [18]. The hospital study is not a controlled study, and so it is difficult to reject the possibility that the influenza outbreak abated naturally, or as a result of staff becoming immune, rather than the use of masks. In a study of German households, use of masks or masks plus hand-washing were found to significantly reduce the spread of influenza between family members, but only if implemented with 36 hours of symptoms [19]. A study of university students found that masks plus hand sanitizer could reduce the spread of influenza by up to 75% [20] but did not find that masks alone were effective. A study of Japanese schoolchildren found that those wearing masks had a small but significant reduction of 14% in their risk of catching influenza, with a 14% reduction [21]

Overall, evidence for efficacy of masks in controlling influenza spread found by these and other studies is surprisingly limited, which conforms to real-world experience in a pandemic setting in 1918-1919[8]. A systematic review [22] confirmed that there is relatively limited evidence for efficacy of masks in preventing the spread of influenza virus. That review found evidence that face masks prevented influenza from spreading from infected people, but there was less evidence that they protected uninfected people [22].

Studies of the first Severe Acute Respiratory Syndrome (SARS) [23] outbreak provide a different picture. Within a hospital setting, consistent and proper mask use was shown to prevent transmission of the SARS-Cov-1 coronavirus to hospital personnel [24]. Importantly, two separate studies found that frequent mask use in public spaces during the SARS epidemic was associated with a lower risk of infection by the public [25] [26], with one study concluding that masks were “strongly protective.” [26] The authors wrote the finding that “mask use lowered the risk for disease supports the community’s use of this strategy” [26]. This study found that sometimes using a mask was associated with a 60% reduction in risk, while always wearing a mask was associated with a 70% reduction in risk of acquiring SARS-Cov-1 [26]. A systematic review of all retrospective studies of the SARS-Cov-1 epidemic concluded masks were effective in preventing acquisition of SARS-Cov-1 [27] and suggested that masks reduced the risk of contracting SARS-Cov-1 by 68%.

No studies have yet been conducted on the use of masks to prevent the spread of COVID-19, caused by SARS-Cov-2 virus, among the general public. However, a study of health care personnel in Zhongnan Hospital in Wuhan University [28] found that N-95 respirators, combined with hand washing and disinfection, were 100% effective at preventing COVID-19 infection. Those using respirators were exposed to infected patients at a far higher rate than those not using protection, but did not catch the virus.

The differing results for influenza viruses and SARS-1 and SARS-2 are striking and puzzling: there appears to be relatively good evidence for efficacy of face masks against SARS-Cov-1 coronavirus and SARS-Cov-2 / COVID-19, but weaker and more ambiguous evidence for their effectiveness in controlling influenza.

Such results might make more sense interpreted in an evolutionary context. The SARS-Cov-2 virus causing COVID 19 disease and SARS-Cov-1 are closely related bat-derived coronaviruses [29] [30] [31]. They share a broadly similar epidemiology, as well as evolutionary history. The SARS-Cov-2 virus is not closely related to influenza. It is part of a distinct evolutionary family, the coronaviruses, classified as family Coronaviridae, order Nidovirales. Influenza is classified as family Orthomyxoviridae, order Articulavirales.

A possible and admittedly speculative explanation for these differing results is coronavirus transmission relies more heavily larger droplets [32] [33] which are presumably easier to filter out, rather than smaller aerosol particles, which will pose more of a challenge to filter. In the case of H1N1 influenza, about half of infections appear to derive from aerosol transmission, i.e. fine droplets [34]. These might be more likely to penetrate through masks or leak around the edges. This hypothesis is speculative, but the differing results for coronaviruses and influenza viruses recently reported Leung, 2020 #4325} seem to support the idea that slightly different mechanisms of transmission in the viruses result in differing efficacy of masks against influenza and coronaviruses.

A mistake that has been made initially in dealing with SARS-Cov-2 / COVID-19 is assuming that it is "just like the flu." The pathology of the disease and potential for harm caused by the virus are clearly more dangerous than the flu, it seems reasonable to consider- and increasingly, evidence suggests- that it is unlike the flu in how it spreads, as well, and inferences made from studies of influenza might be misleading. Remarkably, these issues were first brought up over a century ago, when it was written, "if, as we believed, the gauze mask is useful as a protection against certain infections, it would be unfortunate if its uncontrolled application in influenza should result in prejudicing critical and scientific minds against it" [8].

Models suggest masks may have potential to control pandemics

It is difficult to overstate the implications of the findings for SARS coronavirus and COVID-19 for the current pandemic. The reproductive number of the virus, R, determines an epidemic's course. When R falls below 1, that is, each infected person passes the virus on to less than one other person on average, the epidemic slows, then dies out. Many estimates have been published for COVID-19s basic reproductive rate, R0, with a mean of 3.28 and a median of 2.79 [35]. If its rate of spread could be reduced by 70% (as found in one study of SARS-Cov-1), the virus' reproductive rate would become 0.837-0.984. Therefore the effective reproductive rate would drop below zero, and the epidemic would cease. This is a simplistic scenario, because in the case of masks, if they work they would reduce not only the rate at which people catch the virus but also the rate of onward transmission.

Of course, it is possible that masks might have only limited benefit in stopping the spread of COVID-19— for any number of reasons. Masks might provide limited protection, because they are less effective than suggested by some studies. People misuse them or wear them inconsistently. Shortages of effective masks such as surgical masks and N-95s could limit their effectiveness. All of these could be true. Yet counterintuitively, it appears that interventions with small effects on transmission, especially if applied early, can have a large effect on total number of cases. To understand how a limited effect could still make a substantial difference, we have to consider masks in the context of small reductions in viral transmission rates.

Consider how epidemics grow, i.e., exponentially. Allowed to spread unchecked, one case of Covid-19 becomes 2.5 (assuming for this model an R0 of 2.5), each case causing 2.5 more, and so on. Over the course of 15 reproductive cycles, each taking 7 days, or about 3 months in total, one case becomes 2.5 x 2.5 x 25… or 2.5^15 = 931,323 cases (Fig. 1).

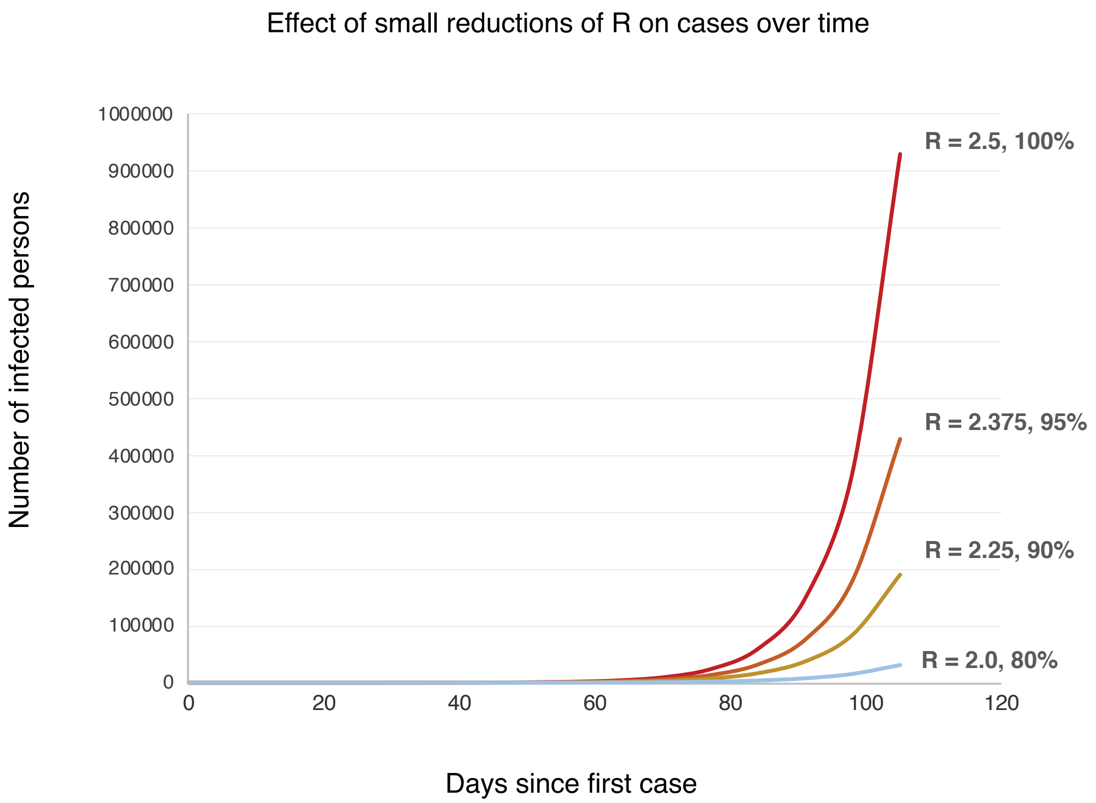

Figure 2. A simple model showing exponential growth in an uncontained outbreak over time (generation time = 7 days, R0 = 2.5) and with small reductions in the reproductive rate R.

Now, let us suppose widespread use of masks cuts the growth rate by just 10%. Each person now infects 2.25 others, who infect 2.25 others, and so on. Over 15 cycles, 2.25^15 = 191,751 cases. An 80% reduction. Understanding this exponential growth explains how the pandemic caught the world by surprise even as it was monitored in real time. Exponential growth doesn't make sense, until you do the numbers, and even, they're hard to believe. But another counterintuitive aspect of exponential growth is that small decreases in the exponent greatly slow growth. A 10% increase in the exponent can have a massive effect, but even a limited intervention, with a 10% decrease over time, pays large dividends (Fig. 2).

These are basic models, simply to illustrate a point rather than provide any sort of detailed policy guidance. But more sophisticated modeling suggests that large scale use of masks could slow, or even stop, pandemics. A 2010 study found that above a certain threshold, widespread use of effective masks can reduce the reproductive number (R) of an influenza virus below 1, and the pandemic stops [36]. If face masks were highly effective (well-designed, used properly and consistently), then public use of masks could stop a flu pandemic if used by just 50% of people. If masks were less effective, more than half the population would have to wear them to stop the pandemic. If masks had limited efficacy, they may flatten the curve of the epidemic, but wouldn't stop it [36]. We don't know which model is most accurate. But in the context of the current pandemic, any of these scenarios would be highly advantageous.

A second study [37] found similar results modeling pandemic influenza. The model found that the pandemic was highly sensitive to the number of people wearing masks. Even if 50% or 25% of people wore masks, the number of cases drops greatly [37], flattening the curve. Critically, masks are far more effective implemented early in the course of an epidemic, than implemented late [37]. This study also found it was important for both infected and uninfected people to wear masks [37]. Both studies support the results of simple calculations: use of masks can make a major difference.

Production of masks costs money. Obviously, reduction of suffering and mortality is the current priority, but with finite resources we must think strategically about the economic costs of interventions. One modeling study found that depending on the coverage of masks, the use of masks in the US might save almost $600 billion [38]. Given the unprecedented economic disruption caused by the pandemic, which has caused record numbers of jobless claims and declines in purchasing [39], it is entirely possible that this is an underestimate. Therefore, if masks are proven to be effective, they may be an inexpensive way to reduce spread.

Finally, a systematic review offers a note of caution for any one advocating for public use of masks. A systematic review of pandemic modeling looked at different studies that included a variety of pandemic responses. These included social distancing, quarantines, air travel restrictions, case isolation, antiviral drugs, vaccination, and masks [40]. They found that strategies using a combination of multiple interventions were far more effective than those that used a single approach to fighting the pandemic.

The implications are clear. Even assuming, for the sake of argument, that masks were the single most effective intervention available, the current pandemic would be brought under control more quickly, with less damage by employing a wide range of interventions [40]. There is probably no magic bullet against coronavirus, no single tool that will stop the pandemic [40]. Controlling the pandemic will require many different tools, each of which cut down on transmission to some degree, a death by a thousand cuts.

Obviously these are models. What works in theory needs to be tested in the real world. However, the remarkable success of China in suppressing a large outbreak, using a multi-faceted approach, one that includes the public use of face masks, suggests that in this respect, the computer models may be broadly accurate.

Real world experience suggests masks work in pandemics

Perhaps the most compelling evidence for the potential effectiveness of masks in the fight against COVID-19 comes from their use in the real world. Many of the countries and territories that have controlled their coronavirus epidemics most effectively - China, South Korea, Hong Kong, Taiwan, Vietnam, Singapore, Kuwait, Czechia, Slovakia, Japan, Mongolia- adopted masks early (Fig. 3). Aside from China, which was the epicenter of the pandemic and was therefore caught off guard, virtually all of the worst outbreaks are in Western countries that officially advise against mask use, and where there is little culture or practice of mask wearing.

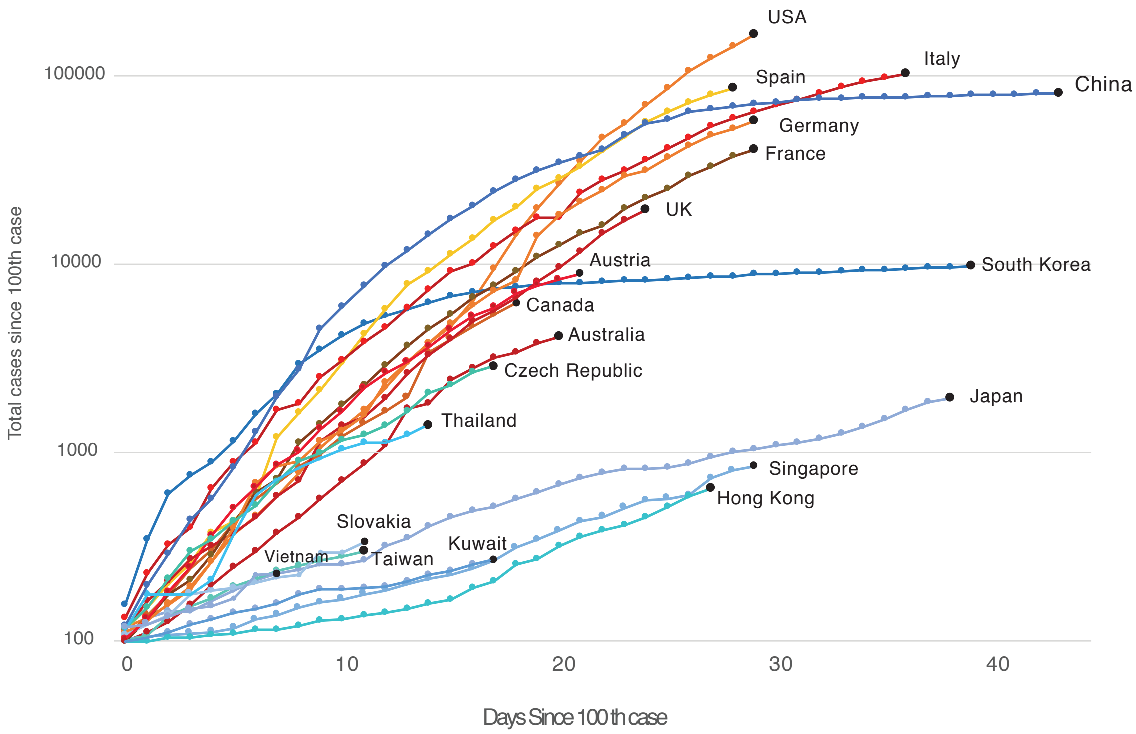

Figure 3. Western countries (US, Canada, Australia, UK, Western Europe) with late mask adoption or no use of masks, versus countries and territories with early use of masks as part of official government or in practice policy (China, South Korea, Japan, Hong Kong, Taiwan, Vietnam, Thailand, Kuwait, Slovakia, Czech Republic, in blues and greens). Countries with early mask usage tend to have flatter curves, even without the use of lockdowns.

Correlation is not causation. In theory, masks could be a signal of an effective pandemic response- an aggressive willingness by the government and public to do everything possible to control the outbreak- rather than a direct cause of suppression. By analogy, the number of luxury cars on the road in a country is a signal of economic prosperity, rather than a direct cause of it.

But the diversity of these countries, and their responses, suggests against such an interpretation. Places like China, South Korea, Taiwan, Vietnam, Kuwait, Czechia and Singapore differ greatly in political organization, ranging from communism to democracies, and also in their level of economic development and population density. And strikingly, these countries also differ in their suppression strategies. China implemented a lockdown of Wuhan, shut down industry nationwide, implemented temperature checks and social distancing, tested extensively, and employed masks. Korea responded with an aggressive testing and contact tracing, and masks. Japan has done far less extensive testing than Korea, but shut down schools and large gatherings, and used masks. The pandemic management strategies used by these countries more diverse than has been appreciated. Perhaps one of the few things all these successes share is widespread wearing of masks. And on the other hand, one common factor shared by the pandemic suppression strategies of the US, Canada, the UK and Western Europe has been the decision to discourage the use of masks by the public until recently. This does not prove, but does imply that masks could be an important part of these countries' successful suppression strategies. Critically, the different suppression strategies used by different countries can act as real-world experiments. By watching countries like Austria and the United States that have recently revised their policies, we can test this idea.

What kind of mask? Surgical masks as good as N95s.

If face masks can help control the spread of respiratory disease, then which work best? The commonly used medical masks are surgical masks, and N95 respirators. Surgical masks are loose-fitting, disposable masks that cover the nose and mouth, and are typically made out of nonwoven fabric, with a layer of melt-blown polyethylene to act as a filter. They are designed to protect against large droplets, sprays, and bodily fluids, not to filter fine particles. N95 respirators are speecifically designed to filter small particles from the air breathed by the users. The designation signifies that they remove at least 95% of particles .3 microns in diameter or more. They are tight fitting, with the aim to limit leakage around the edge of the mask, as more virus may pass through gaps in the seal with the face than through the mask itself [41]. In theory, because the N95 and similar masks are designed specifically to filter small airborne particles whereas surgical masks are not, and N95s should be more effective in preventing the exhalation or inhalation of virus.

Surprisingly, there is limited evidence that surgical masks are superior to N95 respirators in preventing respiratory disease transmission. One study randomly assigned surgical masks or N95 respirators to nurses [42], both groups acquired influenza infections at similar rates. Study of a hospital in Singapore during the 2009 H1N1 influenza outbreak found the same pattern [43]. Another study tried to isolate influenza virus from infected patients wearing a surgical mask or N95; both were equally effective at stopping viruses [44]. One recent study assigned health care personnel to wear respirators or surgical masks. Those using respirators fell ill at approxiately the same rate as those using surgical masks [45].

Three different systematics reviews, synthesizing these and other results, suggest that surgical masks were comparable to respirators in effectiveness. Two found that both were equally effective against influenza [22 46]. Another found that surgical masks and N95 respirators were equally effective, measured in terms of preventing lab confirmed respiratory infections, influenza-like illness, or absenteesm [47]. Again, caution may be required in extrapolating from studies of influenza to coronaviruses. However, a systematic review found "limited evidence" that respirators were superior to surgical masks during the SARS epidemic [27].

The reasons for these results are unclear. It could be that N-95 respirators, which are more difficult and less comfortable to wear, are misused or used less frequently. Or it may be that our understanding of how masks protect against viral transmission is inadequate and that the theoretical advantages of the N-95 and similar masks do not translate to real world benefits. This has important implications given current shortages. Respirators and surgical masks are both in short supply. But surgical masks are cheaper and simpler, making it easier to accelerate production. Surgical masks are easier to use and more people might wear them [22].

Non-medical masks

If simpler masks are about as effective as more complicated masks, this raises the possibility of whether readily available alternatives to N-95s and surgical masks exist.

Although not specifically studied for their ability to stop viruses, studies of non-medical masks showed that dust respirators were better than surgical masks in filtering fine airborne particles, and two of the three cycling masks compared well to surgical masks in performance [48]. Mass production of such masks by the private sector might conceivably be able to provide protection.

Cloth masks

Improvised cloth masks, made in factories or at home, are another possibility. Such masks were originally used to combat the 1918 influenza pandemic [6], but with the advent of inexpensive, disposable medical masks [7], their use has largely been abandoned in the west. However, improvised cloth face coverings have now recently been recommended by the US CDC and other countries, such as India and the Czech republic. Research into the effectiveness of cloth masks is limited [7]. Existing research shows homemade masks tend to be inferior to surgical masks, but are better than nothing all. One laboratory study found homemade masks were half as effective as surgical masks in filtering particles [49]. Another study found homemade masks made from various materials stopped virus aerosols (Fig. 4), but not as effectively surgical masks [50]. A surgical mask stopped 90% of viral aerosol particles, a dish towel, 72%, linen, 62%, and a cotton T-shirt, 51% [50]. Finer weaves like bedding or denser weaves like the towel tended to perform better than coarse weaves like the T- shirt, in agreement with early experiments conducted a century ago [8 51].

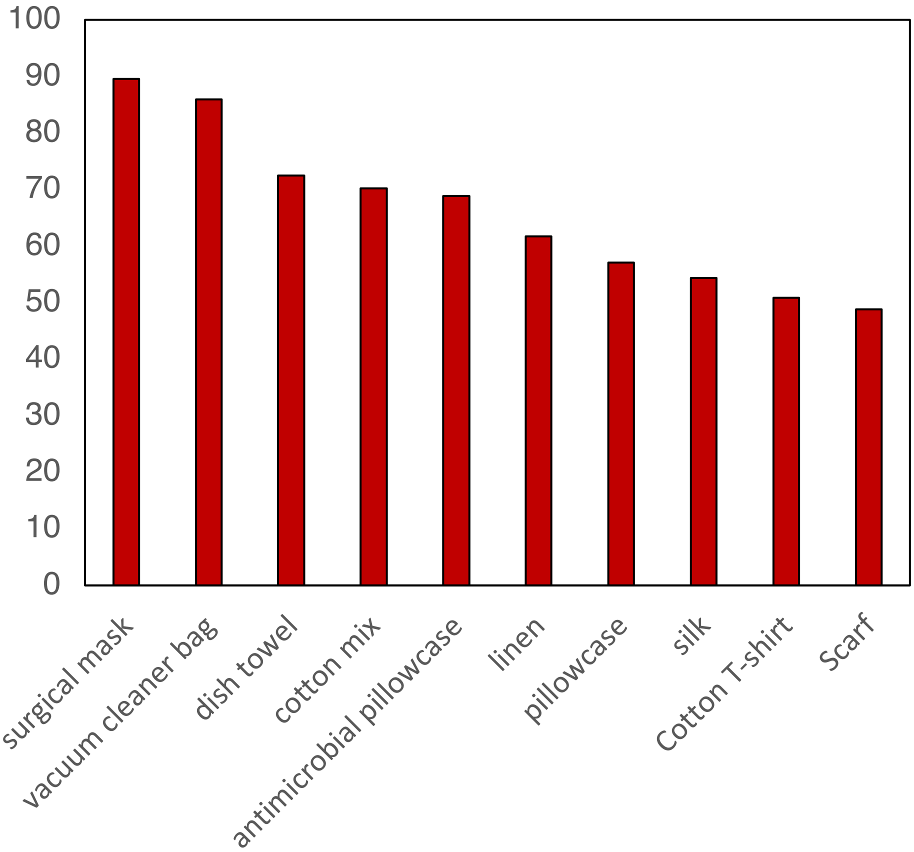

Fig. 4. Performance of various materials used in masks (percentage of viral particles stopped) comparing surgical masks and various materials used in improvised masks.

Improvised masks made from cotton fabric might perform similar to a T-shirt or linen, letting through about 3-5 times as many viral aerosol particles as a surgical mask.

Another study again found that improvised materials such as towels and T-shirts showed inferior performance against surgical masks [52]. Penetration of small saline droplets (2-1000 µm) was much higher than measured for viral particles in the previous study [50]. The relevance of this finding will presumably depend on the extent to which SARS-CoV disperses as larger droplets versus smaller aerosols.

Importantly, a tradeoff generally exists between breathability (which is inversely proportional to pressure drop across the mask) and filtration efficiency, an effect that has been known for more than a century [8]. More effective filters are denser, which can be achieved by using a layer of fabric with a higher thread count (increased number of threads in the warp and weft), a thicker filter achieved with a thicker fabric (e.g., a towel), or multiple layers of fabric (e.g., several layers of gauze or T-shirt cotton) [8 51 50]. However, these denser filters that more effectively restrict the passage of particles also restrict the passage of air, making them less breathable.

This tradeoff is noted even in the earliest use of gauze facemasks during the 1918-19 influenza pandemic, where high thread counts of 220 per inch or more (accomplished by layering coarse gauze) produced masks that were highly effective filters, but with very poor breathability [8], which limited their use in practice. Similarly, the filter material used in vacuum cleaner bags is a highly efficient filter but has poor breathability, potentially limiting its use as a mask material in the real world. The nonwoven polyethylene material used in surgical masks and N95 respirators is unusual in combining very high filtration efficiency with relatively high breathability (Fig. 5). Among improvised materials studied, the fine fabrics used in materials such as bedding and linens seem to be better than materials such as T shirt cotton or scarves, by providing superior filtration efficiency with comparable breathability. However, they still fall short of the performance of materials used in medical masks. A better understanding of the properties of various materials used to make improvised masks is clearly needed.

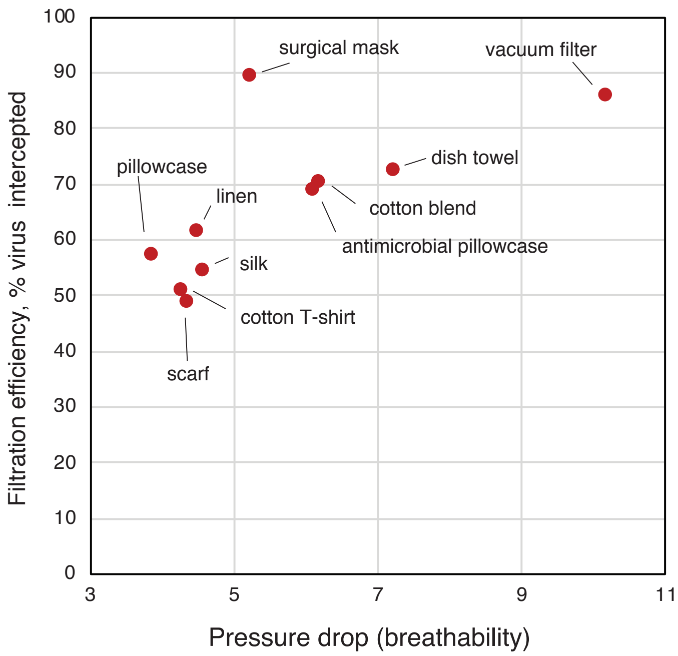

Figure 5. Filter efficiency (percent of virus stopped) versus pressure drop (which is inversely proportional to breathability) for different mask materials [50].

The only real-world study of cloth masks found they were less effective than medical masks in preventing influenza, consistent with laboratory studies [53]. Unfortunately, this study lacked a proper control - a no-mask group - and so can't be used to argue that cloth masks don't work, because the alternative - no masks - wasn't evaluated. Again, there are also issues with extrapolating from studies of transmission in influenza to coronaviruses, given that the two may disperse in different ways.

Clearly, improvised or non-medical masks should only be used when access medical masks is impossible. However, the speed and spread of the current pandemic have created a widespread shortage of medical masks. This creates a need to find innovative solutions to such shortages, and specifically value engineering [54] of the sort that dealt with materials shortages in World War II to identify ways to produce filtration comparable to medical masks with cheaper, more easily sourced materials and production techniques. Ongoing research into this problem has been reported by the media, but we still await published research.

Arguments against the use of masks

Little has been published about potential risks or drawbacks to the use of masks in controlling infection, in part because of limited study of the problem. As a result, such arguments tend to be hypothetical or anecdotal, but they require serious consideration.

One argument put forwards holds both that the public do not need masks to protect themselves, but that doctors and nurses do. This argument has been criticized as logically inconsistent [55]. It is difficult to see how both can be true. Masks cannot work for doctors and nurses and be vital to protect them inside a hospital, but fail to work to protect people elsewhere. A more reasonable argument would be that doctors and nurses need masks more than the public. This may be true, and it is of upmost importance to protect frontline health care workers. However, this argument is so far not backed up by published scientific studies or real-world experience. It also assumes that wearing masks is a purely defensive act. In fact, wearing a mask not only protects the wearer against infection, but reduces potential for onward spread from infected people. If they are an effective barrier to the spread of SARS-Cov-2, a single mask worn by an average person could stop a chain of infection or a super-spreading event. Clearly, ensuring access to masks by health care workers must remain a top priority, but it may be useful to issue them to others as well if this would reduce spread. Models could be developed to provide an evidence-based rationale for a distribution of masks that would minimize worldwide loss of life, human suffering, and economic damage, in that order.

Another argument holds that masks are only effective in preventing spreading, not infection; therefore only infected people need wear them. There are two potential problems with this argument. First, as discussed above, studies suggest masks may be effective to prevent people from catching, not just from spreading, coronaviruses. Second, even assuming the primary function of a mask is to prevent spreading of virus, it is difficult to know who is infected. Around half the people spreading COVID-19 show no symptoms, and so do not know they are infected [56]. This is the point of lockdowns; if it was known who was infected, these individuals could be isolated and society could function normally. Because we do not we act as if everyone is. The same logic applies, assuming their effectiveness in limiting spread, to masks. In a rapidly spreading pandemic, with limited access to testing, it is logical to act as if everyone is infected: everyone wears a mask.

Another argument sometimes made against masks is that might increase the risk of infection. While there is little evidence one way or another on this issue, it is conceivable that improper mask use would increase the risk of infection. For example, improper fitting masks, failure to sterilize a mask properly, or touching the infected outer surface- could promote transmission. However, in practice, public education campaigns could potentially educate people on the proper use of masks to minimize improper use and maximize effectiveness.

Masks have also been suggested to provide a false sense of confidence to their wearers. There is a real chance that those wearing masks might be less vigilant in using other means of prevention, such as hand washing and social distancing. If so, people using masks might receive little or no protection against COVID-19. Where masks are used in place of other methods such as handwashing, social distancing, and self-isolation, users might see limited reductions in risk, or concievably see their risks increased. Again, education of the public will be critical. An honest and open statement of the potential benefits and uncertainties around masks- that they may provide some protection, but not a guarantee of perfect safety- seems the appropriate way to communicate to the public that would ensure mask use without encouraging poor compliance with other pandemic control measures.

Last, our incomplete understanding of the effectiveness of masks has often been used to argue against their use. It has sometimes been argued that we can't really do anything because we know too little. This isn't logical. If one wakes up in the middle of the night to find the house burning down, one quickly faces unknowns. How did it start? What's on fire? How fast is it spreading? Where is the family? Despite these uncertainties, one immediately takes action. The same applies in a pandemic. Public health workers must act with incomplete data with gaps and inaccuracies in their intelligence, but never the less make difficult, life-or-death decisions, because failure to make a decision is often fatal. In a crisis situation, we can't wait for studies. In this respect masks may be an asymmetrical gamble. There is a potential upside, with questionable downsides. Widespread mask use might not help, help a little, or help a lot, and the cost might not be trivial, but they come with little risk. The real risks lie largely or entirely in not acting. At least masks send a powerful social signal that the threat is real, and we need to rapidly, collectively change our behaviors.

Conclusions

There are both scientific evidence and rational arguments supporting the public use of facemasks. The principle behind facemasks- they should reduce the amount of virus exhaled by infected people, and inhaled by uninfected- suggest they could be a useful tool in combating a respiratory infection. Scientific research, including experimental studies, studies of the SARS epidemic, hospital studies of COVID-19, and modeling studies, all suggests masks may be helpful in controlling the pandemic. Most importantly, the experience of countries using masks against SARS-Cov-1 and the current SARS-Cov-2 pandemic imply that they could form part of an effective public response to pandemic spread. However, both modeling studies and the real-world experience of countries such as China and South Korea suggests that neither masks, nor anything else, provides a magic bullet against a pandemic. Strategies should not rely on any single intervention, but rather a wide range of interventions, potentially including masks.

There is a critical need for more information, but this may be the wrong time to provide answers or false certainty. Rather, it may be best to focus on questions, what remains to be known.

How effective are masks in preventing the spread of the SARS-Cov-2 virus? How effective are they in preventing infection by healthy individuals? Assuming they are effective in preventing transmission, what factors are likely to either increase or limit their effectiveness? How do masks work, in terms of filtering viral particles and altering flow around the users, and between users? What materials and methods of manufacture are most appropriate for masks?

And assuming masks are an effective pandemic control strategy, this raises the question of how should this intervention be targeted. Important issues include who should be prioritized in wearing masks, and in what order: health care workers, infected individuals, individuals at high risk of hospitalization, or individuals at high risk of catching and passing on the virus? Likewise, in what context should masks be used- e.g. crowded spaces such as public transit, grocery stores, churches- and in what contexts, e.g. a walk in the country, might a more relaxed policy be appropriate? Distribution is also a serious issue. How could governments, industry, and the general public work together to ensure an optimal distribution of masks- one that is simultaneously ethical, fair, and effective?

Further scientific research, discussion, and open debate are required on these issues to develop a rational, evidence-based and effective policy of mask use.

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