Face Masks Against COVID-19: An Evidence Review

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The science around the use of masks by the general public to impede COVID-19 transmission is advancing rapidly. Policymakers need guidance on how masks should be used by the general population to combat the COVID-19 pandemic. Here, we synthesize the relevant literature to inform multiple areas: 1) transmission characteristics of COVID-19, 2) filtering characteristics and efficacy of masks, 3) estimated population impacts of widespread community mask use, and 4) sociological considerations for policies concerning mask-wearing. A primary route of transmission of COVID-19 is likely via respiratory droplets, and is known to be transmissible from presymptomatic and asymptomatic individuals. Reducing disease spread requires two things: first, limit contacts of infected individuals via physical distancing and other measures, and second, reduce the transmission probability per contact. The preponderance of evidence indicates that mask wearing reduces the transmissibility per contact by reducing transmission of infected droplets in both laboratory and clinical contexts. Public mask wearing is most effective at reducing spread of the virus when compliance is high. The decreased transmissibility could substantially reduce the death toll and economic impact while the cost of the intervention is low. Given the shortages of medical masks for now we recommend the adoption of public cloth mask wearing, as an effective form of source control, in conjunction with existing hygiene, distancing, and contact tracing strategies. We recommend that public officials and governments strongly encourage the use of widespread face masks in public, including the use of appropriate regulation.

COVID-19 | SARS-CoV-2 | Masks | Pandemic

Policymakers need urgent guidance on the use of masks by the general population as a tool in combating SARS-CoV-2, the respiratory virus that causes COVID-19. Masks have been recommended as a potential tool to tackle the COVID-19 pandemic since the initial outbreak in China (1), although usage during the outbreak varied by time and province (2). Globally, countries are grappling with translating the evidence of public mask wearing to their contexts. These policies are being developed in a complex decision-making environment, with a novel pandemic, rapid generation of new research, and exponential growth in cases and deaths in many areas. There is currently a global shortage of N95/FFP2 respirators and surgical masks for use in hospitals. Simple cloth masks present a pragmatic solution for use by the public. This has been supported by the United States and European Centres for Disease Control. We present an interdisciplinary narrative review of the literature on the role of simple cloth masks and policies in reducing COVID-19 transmission.

1. Components to Evaluate for Public Mask Wearing

In order to identify whether public mask wearing is an appropriate policy, we need to consider these questions:

a Do asymptomatic or pre-symptomatic patients pose a risk of infecting others?

b Would a face mask likely decrease the number of people infected by an infectious mask wearer?

c Are there face covers that will not disrupt the medical supply chain, e.g. homemade cloth masks?

d Will wearing a mask impact the probability of the wearer becoming infected themselves?

e Does mask use reduce compliance with other recommended strategies, such as physical distancing and quarantine?

Significance Statement

Governments are evaluating the use of non-medical masks in the community amidst conflicting guidelines from health organizations. This review synthesizes available evidence to provide clarity, and advances the use of the 'precautionary principle' as a key consideration in developing policy around use of non-medical masks in public.

Jeremy Howard prepared the initial literature list; Reshama Shaikh prepared the initial literature summaries; Frederik Questier conducted additional literature searches and summaries; Zhiyuan Li, Violet Tang, Lei-Han Tang, and Danny Hernandez did impact modeling; Zeynep Tufekci provided sociological research and analysis; Helene-Mari van der Westhuizen and Arne von Delft provided analysis of additional impacts; Christina Bax provided review and feedback; All authors contributed to the writing.

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f Are there any other sociological considerations that will lead to unintended benefits or harm?

g What could the overall population-level impact of public mask wearing be?

We will evaluate each consideration in turn.

2. Transmission Characteristics of COVID-19

A primary route of transmission of SARS-CoV-2 is likely via respiratory droplets that are ejected when speaking, coughing or sneezing. The most common droplet size threshold has a minimum at 5 µm to 10 µm (3, 4). There is much debate about whether these droplets should sometimes be considered an aerosol (5). An added complexity is that aerosols are not consistently defined in the literature. Although earlier studies assumed that droplets were spread mainly through coughing, a more recent analysis has found that transmission through talking may be a key vector, with louder speech creating increasing quantities and sizes of droplets (6).

SARS-CoV-2 is highly transmissible, with a basic reproduction number estimated to be approximately 2.4 (7) although estimates vary (8) and will likely change as improved measurements of asymptomatic spread become available. Many COVID-19 patients are asymptomatic, and nearly all have a pre-symptomatic incubation period ranging from 2 to 15 days, with a median length of 5.1 days (9). Patients are most infectious during the initial days of infection (10–15), when symptoms are mildest or not present. This characteristic differentiates SARS-CoV-2 (COVID-19) from SARS-CoV, as replication is activated early in the upper respiratory tract (14, 16). High viral titers of SARS-CoV-2 are reported in the saliva of COVID-19 patients. These titers have been highest at time of patient presentation and viral levels are just as high in asymptomatic or presymptomatic patients (11, 16).

A consequence of these disease characteristics is that any successful intervention policy must properly address transmission due to infectious patients that display few or no symptoms and may not realize that they are infected.

3. Ingress: Filtering Capability of Masks

Masks can be made of different materials and designs (17) which influence their filtering capability. There are rigorous standards evaluating masks used in healthcare settings but these focus on personal protective equipment (PPE) efficacy, that is, the ability of the mask to protect the wearer from infectious particles. Masks can also be used for source control, which refers to blocking droplets ejected by the wearer. Although we consider both of these as important, our focus in this paper is on source control. If everyone is wearing masks to decrease the chance that they themselves are unknowingly infecting someone, everyone ends up being more protected.

Multiple studies show the filtration effects of cloth masks relative to surgical masks. Particle sizes for speech are on the order of 1 µm (18) while typical definitions of droplet size are 5 µm-10 µm (5). Generally available household materials had between a 49% and 86% filtration rate for 0.02 µm exhaled particles whereas surgical masks filtered 89% of those particles (19). In a laboratory setting, household materials had 3% to 60% filtration rate for particles in the relevant size range, finding them comparable to some surgical masks (20). In another laboratory setup, a tea cloth mask was found to filter 60% of particles between 0.02 µm to 1 µm, where surgical masks filtered 75% (21). Dato et al (22), note that "quality commercial masks are not always accessible." They designed and tested a mask made from heavyweight T-shirts, finding that it "offered substantial protection from the challenge aerosol and showed good fit with minimal leakage." Many recommended cloth mask designs also include a layer of paper towel or coffee filter, which could increase filter effectiveness for PPE, but it does not appear to be necessary for blocking droplet emission (6, 23, 24).

One of the most frequently mentioned papers evaluating the benefits and harms of cloth masks has been by MacIntyre et al (25). Findings have been misinterpreted, and therefore justify detailed discussion here. The authors "caution against the use of cloth masks" for healthcare professionals compared to the use of surgical masks and regular procedures, based on an analysis of transmission in hospitals in Hanoi. We emphasize the setting of the study - health workers using masks to protect themselves against infection. The study compared a "surgical mask" group which received 2 new masks per day, to a "cloth mask" group that received 5 masks for the entire 4 week period and were required to wear the masks all day, to a "control group" which used masks in compliance with existing hospital protocols, which the authors describe as a "very high level of mask use". It is important to note that the authors did not have a "no mask" control group because it was deemed "unethical to ask participants to not wear a mask." The study does not inform policy pertaining to public mask wearing as compared to the absence of masks in a community setting, since there was not a "no mask" group. The results of the study show that the group with a regular supply of new surgical masks each day had significantly lower infection of rhinovirus than the group that wore a limited supply of cloth masks. This study lends support to the use of clean, surgical masks by medical staff in hospital settings to avoid rhinovirus infection by the wearer, and is consistent with other studies that show surgical masks provide poor filtration for rhinovirus, compared to seasonal coronaviruses (NL63, OC43, 229E and HKU1) (26). It does not inform the effect of using cloth masks versus not using masks in a community setting for source control of SARS-CoV-2.

Guideline development for health worker PPE have focused on whether surgical masks or N95 respirators should be recommended. Most of the research in this area focuses on influenza. At this point, it is not known to what extent findings from influenza studies apply to COVID-19 filtration. Wilkes et al (27) found that "filtration performance of pleated hydrophobic membrane filters was demonstrated to be markedly greater than that of electrostatic filters." However, even substantial differences in materials and construction do not seem to impact the transmission of droplet-borne viruses in practice, such as a meta-analysis of N95 respirators compared to surgical masks (28) that found "the use of N95 respirators compared with surgical masks is not associated with a lower risk of laboratory-confirmed influenza." Radonovich et al (29) found in an outpatient setting that "use of N95 respirators, compared with medical masks in the outpatient setting resulted in no significant difference in the rates of laboratory-confirmed influenza."

4. Egress: Masks for Source Control

When considering the relevance of studies of ingress (masks as protection for the wearer), it is important to note that they are likely to substantially underestimate effectiveness of masks for source control. When someone is breathing, speaking, or coughing, only a small amount of what is coming out of their mouths is already in aerosol form. Nearly all of what is being emitted is droplets. Many of these droplets will then evaporate and turn into aerosolized particles that are 3 to 5-fold smaller. (30) Wearing a mask as source control is largely to stop this process from occurring, since big droplets dehydrate to smaller aerosol particles that can float for longer in air (26).

In a study by Johnson et al (31) on 9 influenza patients, surgical and N95 masks appeared to be equally effective in blocking egress droplets, given that no influenza could be detected by RT-PCR on sample plates at 20 cm distance of the coughing patients, while it was detectable without mask for 7 of the 9 patients. Milton et al (32) checked whether exhaled droplets might be large enough prior to evaporation to be effectively captured by masks used as source control. They found surgical masks produced a 3.4 (95% CI 1.8 to 6.3) fold reduction in viral copies in exhaled breath by 37 influenza patients. Vanden Driessche et al (33) used an improved sampling method based on a controlled human aerosol model, allowing longer time for droplets to evaporate and become airborne. By sampling a homogeneous mix of all the air around the patient, the authors could also detect any aerosol that might leak around the edges of the mask. Among their 6 cystic fibrosis patients producing infected aerosol particles while coughing, the airborne Pseudomonas aeruginosa load was reduced by 88% when wearing a surgical mask compared with no mask (95% confidence interval [CI], 81-96%; P=0.03). Wood et al (34) found for their 14 cystic fibrosis patients with high viable aerosol production during coughing, a reduction in aerosol Pseudomonas aeruginosa concentration at 2 meters from the source by using a N95 mask (94% reduction, $P<0.001$), surgical mask (94%, $P<0.001$), or cough etiquette (53%, $P<0.001$). Stockwell et al (35) confirmed in a similar Pseudomonas aeruginosa aerosol cough study that surgical masks are effective as source control and tolerable after extended wear. Dharmadhikari et al (36) found surgical masks to decrease transmission of tuberculosis (an airborne bacterial infection) by 56% (95% CI, 33-70.5%) when used as source control and measuring differences in guinea pig tuberculosis infections.

Anfinrud et al (6) used laser light-scattering to sensitively detect droplet emission while speaking. Their analysis showed that virtually no droplets were "expelled" with a homemade mask consisting of a washcloth attached with two rubber bands around the head, while significant levels were expelled when speaking without a mask. The authors stated that "wearing any kind of cloth mouth cover in public by every person, as well as strict adherence to distancing and handwashing, could significantly decrease the transmission rate and thereby contain the pandemic until a vaccine becomes available."

One of the most relevant papers (26), with important implications for public mask wearing during the COVID-19 outbreak, is one that compares the efficacy of surgical masks for source control for seasonal coronaviruses (NL63, OC43, 229E and HKU1), influenza, and rhinovirus. With ten participants, the masks were effective at blocking coronavirus droplets of all sizes for every subject. However, masks were far less effective at blocking rhinovirus droplets of any size, or of blocking small influenza droplets. The results suggest that masks may have a significant role in source control for the current coronavirus outbreak. The study did not use COVID-19 patients, and it is not yet known whether SARS-CoV-2 behaves the same as these seasonal coronaviruses; however, they are closely related viruses, so similar behavior is likely.

In another potentially relevant, but very under-powered study (37), four patients with COVID-19 were asked to cough repeatedly, alternating between no mask, surgical mask, cloth mask and then again without a mask onto a sample plate placed approximately 20 cm from the coughing person's mouth. The authors state "The median viral loads after coughs without a mask, with a surgical mask, and with a cotton mask were 2.56 log copies/mL, 2.42 log copies/mL, and 1.85 log copies/mL, respectively." In this statement, they exclude Patient 2 who had detectable virus in all experiments except when she was wearing a cotton mask. If we assume, conservatively, the limit of detection is 1.4 log copies/mL and use this value for the ND value for Patient 2, and allow each patient to serve as their own control (using the fact that the study design allows for paired comparisons) the median within patient difference of no mask control versus wearing a cotton mask results in an approximately 1 log (10 fold) decrease in virus. Note that we, like Bae et al, exclude Patient 4 in these calculations as they did not have detectable virus in the first 3 trial conditions. While the study is under-powered, the results are suggestive that cloth masks are able to reduce the level of SARS-CoV-2 escaping from an infected person coughing. However, more studies are needed.

A comparison of homemade and surgical masks for bacterial and viral aerosols (19) observed that "the median-fit factor of the homemade masks was one-half that of the surgical masks. Both masks significantly reduced the number of microorganisms expelled by volunteers, although the surgical mask was 3 times more effective in blocking transmission than the homemade mask." Research focused on aerosol exposure has found all types of masks are at least somewhat effective at protecting the wearer. Van der Sande et al (38) found that "all types of masks reduced aerosol exposure, relatively stable over time, unaffected by duration of wear or type of activity," and concluded that "any type of general mask use is likely to decrease viral exposure and infection risk on a population level, despite imperfect fit and imperfect adherence." However, overall analysis of particle filtration is likely to underestimate the effectiveness of masks, since the fraction of particles that are emitted as aerosol (vs. droplet) is quite small (30). Analysis of seasonal coronavirus compared to rhinovirus (26) suggests that filtration of COVID-19 may be much more effective, especially for source control.

In summary, there is laboratory-based evidence that household masks have some filtration capacity in the relevant droplet size range, as well as efficacy in blocking droplets and particles from the wearer (26). That is, these masks help people keep their droplets to themselves.

5. Evaluating masks as intervention

When evaluating the available evidence for the impact of masks on community transmission, it is critical to clarify the setting of the research study (health care facility or community), whether masks are evaluated as source control or protection for the wearer, the respiratory illness being evaluated and what control group was used. Although no randomized controlled trials (RCT) on the use of masks as source control for SARS-CoV-2 have been conducted, a number of studies have investigated masks during other disease outbreaks. A Cochrane review (39) on physical interventions to interrupt or reduce the spread of respiratory viruses included 67 studies that were randomized controlled trials and observational studies. It found that "overall masks were the best performing intervention across populations, settings and threats." The review recommended that “the following effective interventions should be implemented, preferably in a combined fashion, to reduce transmission of viral respiratory disease: 1. frequent handwashing with or without adjunct antiseptics; 2. barrier measures such as gloves, gowns, and masks with filtration apparatus; and 3. suspicion diagnosis with the isolation of likely cases.” However, it cautioned that routine long-term implementation of some measures assessed might be difficult without the threat of an epidemic. There is an updated review available in preprint format by the same lead author (40). In the update, only studies where mask wearing was tested as a stand-alone intervention were included, without combining it with hand hygiene and physical distancing. Observational studies from previous epidemics were also excluded. The updated review concluded that “there was insufficient evidence to provide a recommendation on the use of facial barriers without other measures” but this has not been broadened to evaluate combinations of interventions as to update the Cochrane review.

Several other systematic reviews have recently been conducted. MacIntyre (41) published a review evaluating masks as protective intervention for the community, protection for health workers, and as source control. The authors conclude that “community mask use by well people could be beneficial, particularly for COVID-19, where transmission may be pre-symptomatic. The studies of masks as source control also suggest a benefit, and may be important during the COVID-19 pandemic in universal community face mask use as well as in health care settings.” Two other preprint systematic reviews by Brainard (42) and (43) concluded against and for the use of face masks by the public respectively. This conflicting interpretation of the literature points to fundamental disagreements in what is considered to be best available evidence. Greenhalgh (44) argues that an “interpretive and discursive synthesis” is needed when analysing the evidence base for cloth masks instead of “narrowly-defined biomedical questions”.

Randomised control trial evidence that investigated the impact of masks on household transmission during influenza and SARS epidemics indicate potential benefit. Suess et al conducted an RCT (45) that suggests household transmission of influenza can be reduced by the use of non-pharmaceutical interventions, namely the use of face masks and intensified hand hygiene, when implemented early and used diligently. Concerns about acceptability and tolerability of the interventions should not be a reason against their recommendation (45). Cowling et al (46) investigated hand hygiene and face masks in an RCT that seemed to prevent household transmission of influenza virus when implemented within 36 hours of index patient symptom onset. These findings suggest that non-pharmaceutical interventions are important for mitigation of pandemic and inter-pandemic influenza.

RCT findings by Aiello et al (47) “suggest that face masks and hand hygiene may reduce respiratory illnesses in shared living settings and mitigate the impact of the influenza A (H1N1) pandemic”. A randomized intervention trial (48) found that “face masks and hand hygiene combined may reduce the rate of ILI [influenza-like illness] and confirmed influenza in community settings. These non-pharmaceutical measures should be recommended in crowded settings at the start of an influenza pandemic.” The authors noted that their study “demonstrated a significant association between the combined use of face masks and hand hygiene and a substantially reduced incidence of ILI during a seasonal influenza outbreak. If masks and hand hygiene have similar impacts on primary incidence of infection with other seasonal and pandemic strains, particularly in crowded, community settings, then transmission of viruses between persons may be significantly decreased by these interventions.”

An observational study in Hong Kong on SARS (49) found that “frequent mask use in public venues, frequent hand washing, and disinfecting the living quarters were significant protective factors (OR 0.36 to 0.58)”. An important observation was that “members of the case group [infected with SARS] were less likely than members of the control group [not infected] to have frequently worn a face mask in public venues (27.9% vs. 58.7%).”

Although case reports from aeroplanes could have multiple confounders, they provide some contribution to understanding SARS-CoV-2 transmission outside of controlled experimental settings. One case report (50) describes a man who flew from China to Toronto and then tested positive for COVID-19. He was wearing a mask during the flight. The 25 people closest to him on the plane and the flight attendants all tested negative. Nobody from that flight has been reported as acquiring COVID-19. Another case study involving a masked influenza patient on an airplane (51) found that “wearing a face mask was associated with a decreased risk for influenza acquisition during this long-duration flight.”

6. Sociological Considerations

Some of the concerns about public mask wearing have not been around primary evidence for the efficacy of source control, but concerns about how they will be used.

A. Risk compensation behavior. It is difficult to predict the behavior change that would accompany regulations encouraging public mask use. One concern around public health messaging promoting the use of face-covering has been that members of the public may use risk compensation behavior. This involves neglecting other important preventative measures like physical distancing and hand hygiene based on overvaluing the protection a surgical mask may offer due to an exaggerated or false sense of security (52). Similar arguments have previously been made for HIV prevention strategies (53) (54) motorcycle helmet laws (55), seat-belts (56) and alpine skiing helmets (57). However, contrary to predictions, risk compensation behaviors have not been significant on population level, being out-weighed by increased safety in each case (56, 58–60). Risk compensation is unlikely to undo the positive benefits at the population level. (61) These findings strongly suggest that, instead of withholding a preventative tool, accompanying it with accurate messaging that combines different preventative measures would display trust in the general public's ability to act responsibly and empower citizens.

B. Managing the stigma associated with wearing a mask. Stigma is a powerful force in human societies, and many illnesses come with stigma for the sick as well as fear of them. Managing the stigma is an important part of the process of controlling epidemics, as stigma also leads to people avoiding treatment as well as preventative measures that would "out" their illness (62). Tuberculosis is an example of an illness where masks are used as source control, but become a public label associated with the disease. Many sick people are reluctant to wear a mask if it identifies them as sick, and thus end up not wearing them at all in an effort to avoid the stigma of illness (63, 64). Some health authorities have recommended wearing masks for COVID-19 only if people are sick; however, reports of people wearing masks being attacked, shunned and stigmatized have also been observed (65). Having masks worn only by the people with disease also has led to employers in high-risk environments like grocery stores, hospitals and prisons, banning employees from wearing masks to prevent them from scaring the customer, patients or inmates. (66, 67). In many countries, minorities suffer additional stigma and assumptions of criminality (68). Black people in the United States have reportedly been reluctant to wear masks in public during this pandemic for fear of being mistaken as criminals (69, 70). Even if it were possible to encourage only infected people to wear masks, given the lack of access to testing in many countries, it is not possible for many people to know for sure if they are infected or not (71). Thus, while this paper has shown the importance of masks for source-control – preventing asymptomatic and pre-symptomatic people from infecting others – it may not even be possible to have sick people wear masks due to stigma, employer restrictions, or simple lack of knowledge of one's status without mask-wearing becoming universal policy.

C. Creating new symbolism around wearing a mask. Ritual and solidarity are important in human societies and can combine with visible signals to shape new societal behaviors (72, 73). Universal mask wearing could serve as a visible signal and reminder of the pandemic. Signaling participation in health behaviors by wearing a mask as well as visible enforcement (for example, shops asking customers to wear masks) can increase compliance with public mask wearing, but also other important preventative behaviors (74). Historically epidemics are a time of fear, confusion and helplessness (75, 76). Mask-wearing, and even mask-making or distribution, can provide feelings of empowerment and self-efficacy (77). Health, especially during an epidemic, is a form of public good in that everyone else's health behaviors improve the health odds of everyone else, and that it is non-rivalrous in that one person's health does not diminish the health of anyone else (78, 79). This can make masks symbols of altruism and solidarity (80). In Hong Kong, for example, a community-driven focus on epidemic prevention started in the early days of COVID-19, and included community activists acquiring and distributing masks especially to those without resources and the elderly, even before it was officially declared a pandemic or before the government had taken strong steps (81, 82). Currently, Hong Kong has not only a relatively contained epidemic compared with many other countries, but a significant reduction in influenza cases as well which their health authorities attribute, among other factors, to the near-universal mask wearing and strong norms around it (83–85).

7. Implementation considerations

Globally, health authorities have followed different trajectories in recommendations around the use of face masks by the public. In China, Taiwan, Japan and South Korea, face masks were utilized from the start of the pandemic (2). Other countries, like Czechia and Thailand, were early adopters in a global shift towards recommending cloth masks. We present considerations for the translation of evidence about public mask wearing to diverse countries across the globe, outside of the parameters of a controlled research setting.

A. Supply chain management of N95 respirators and surgical masks. There has been a global shortage of protective equipment for health workers, with health workers falling ill and dying of occupationally acquired COVID-19 disease (86). N95 respirators (the equivalent in Europe is FFP2 respirators) are recommended for health workers conducting aerosol-generating procedures during clinical care of COVID-19 patients, while surgical masks are recommended for non-aerosol generating procedures (87). The importance of masks for health worker protection was emphasised in the early phases of the global pandemic in hospitals in China (88). Strategies to manage this critical shortage of PPE has been to appeal to the public to reduce their use of medical masks, and explore options like sterilization and re-use of respirators (89). There have been major concerns that public messaging encouraging mask use will deplete critical supplies. Some regions, like South Korea and Taiwan, have combined recommendations for the public to use surgical masks with rapidly increasing production of surgical masks. In other regions where surgical mask supplies are limited or unreliable due to supply chain interruptions, cloth masks are promoted as alternative to surgical masks as source control. This has been accompanied by public messaging to avoid using medical masks. Cloth masks offer additional sustainability benefits through re-use, thus limiting costs and reducing environmental waste.

B. Mandatory mask wearing. Ensuring compliance with non-pharmaceutical interventions can be challenging, but would likely rapidly increase during a major pandemic (90). Perceptions of risk play an important role in mask use (91). Telephone surveys during the SARS-CoV-2 outbreak in Hong Kong reported enhanced adherence to public mask wearing as the pandemic progressed over three weeks, with 74.5% self reported mask wearing when going out increasing to 97.5%, without mandatory requirements (92). Similar surveys reported face mask use in Hong Kong during the SARS outbreak in 2003 as 79% (93), and approximately 10% during the influenza A(H1N1) pandemic in 2009 (94). This suggests that the public have enhanced awareness of their risk, and display higher adherence levels to prevention strategies than during other epidemics. At the height of the 2009 influenza epidemic in Mexico City it was found (95) that mandatory mask requirements increased compliance compared to voluntary recommendations. Voluntary compliance was strongly influenced by public perception regarding the effectiveness of the recommended measures. Countries like Czechia and Hong Kong offer interesting perspectives on the role of citizen advocacy and on the acceptability of face-covering in public.

Modelling suggests (96) that population level compliance with public mask wearing of 70% combined with contact tracing would be critical to halt epidemic growth. Population level uptake of an intervention to benefit the whole population is similar to vaccinations. A common policy response to this conundrum is to ensure compliance by using laws and regulations, such as widespread state laws in the US which require vaccinations to attend school. Research shows that the strength of the mandate to vaccinate greatly influences compliance rates for vaccines and that policies that set a higher bar for vaccine exemptions result in higher vaccination rates (97). The same approach is now being used in many jurisdictions to increase mask wearing compliance, by mandating mask use in a variety of settings (such as public transportation or grocery stores or even at all times outside the home). Early results suggest that these laws are effective at increasing compliance and slowing the spread of COVID-19 (98).

C. Additional benefits for concurrent epidemics. While the focus of this article is on preventing the spread of COVID-19 disease through public mask wearing, many countries face concurrent epidemics of contagious respiratory diseases like tuberculosis and influenza. Tuberculosis kills 1.5 million people globally per year, and in 2018, 10 million people fell ill (99). Face covering has been shown to also reduce the transmission of tuberculosis (36). Similarly, influenza transmission in the community declined by 44% in Hong Kong after the implementation of changes in population behaviors, including social distancing and increased mask wearing, enforced in most stores, during the COVID-19 outbreak (92).

8. Estimating COVID-19 Impacts

At the national and global scale, effective local interventions are aggregated into epidemiological parameters of disease spread. The standard epidemiological measure of spread is known as the basic reproduction number R_0 which parameterizes the number of cases infected by one case, in a completely susceptible population. The goal of any related healthcare policy is to have an aggregate effect of reducing the effective reproduction number R_e to below 1.

Efficacy of face masks within local interventions would have an aggregate effect on the reproduction number of the epidemic. What is the possible magnitude of such an effect? The HKBU COVID-19 Modelling Group developed a transmission model that incorporated mask wearing and mask efficacy as a factor in the model (96). They estimate reductions in the effective reproduction number R_e under common intervention measures. For wearing masks, they find that wearing masks reduces R_e by a factor $(1 - ep_m)^2$, where e is the efficacy of trapping viral particles inside the mask, and p_m is the percentage of the population that wears masks. When combined with contact tracing, the two effects multiply.

A conservative assessment applied to the COVID-19 estimated R_0 of 2.4 (7) might posit 50% mask usage and a 50% mask efficacy level, reducing R_e to 1.35, an order of magnitude impact rendering spread comparable to the reproduction number of seasonal influenza. To put this in perspective, 100 cases

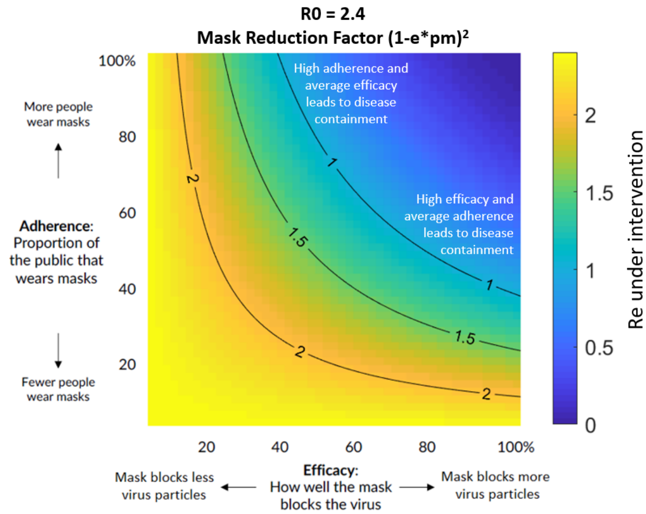

Fig. 1. Impact of public mask wearing under the full range of mask adherence and efficacy scenarios. The color indicates the resulting reproduction number R_e from an initial R_0 of 2.4 (7). Blue area is what is needed to slow the spread of COVID-19. Each black line represents a specific disease transmission level with the effective reproduction number Re indicated. An R_e below 1, if sustained, will lead to the outbreak ending.

at the start of a month become 31,280 cases by the month's end ($R_0 = 2.4$) vs. only 584 cases ($R_e = 1.35$). Such a slowdown in case-load protects healthcare capacity and renders a local epidemic amenable to contact tracing interventions that could eliminate the spread entirely.

A full range of efficacy e and adherence p_m is shown with the resulting R_e in Figure 1, illustrating regimes in which growth is dramatically reduced ($R_e < 1$) as well as pessimistic regimes (e.g. due to poor implementation or population compliance) that nonetheless result in a beneficial effect in suppressing the exponential growth of the pandemic.

Yan et al (100) provide an additional example of an incremental impact assessment of respiratory protective devices using an augmented variant of a traditional SIR model in the context of influenza with N95 respirators. They showed that a sufficiently high adherence rate (~ 80% of the population) resulted in the elimination of the outbreak with most respiratory protective devices.

Qualitative comparisons of outcomes between countries (98, 101) are suggestive of policy differences leading to differences in disease spread of up to three orders of magnitude. Although between-country comparisons do not allow for causal attribution, they suggest mask wearing to be a low-risk measure with a potentially large positive impact on number of cases. In these countries, masks seem to be a part of a broadly successful suite of interventions and appears not to have meaningfully reduced compliance with other measures.

Abaluck et al (102) extend the between-country analyses from a cost perspective, estimating the marginal benefit per cloth mask worn to range from \$3,000-\$6,000. They also found that "the average daily growth rate of confirmed positives is 18% in countries with no pre-existing mask norms and 10% in countries with such norms" and "that the growth rate of deaths is 21% in countries with no mask norms and 11% in countries with such norms."

9. Discussion and Recommendations

Our review of the literature offers evidence in favor of widespread mask use as source control to reduce community transmission: non-medical masks use materials that obstruct droplets of the necessary size; people are most infectious in the initial period post-infection, where it is common to have few or no symptoms (10–16); non-medical masks have been effective in reducing transmission of influenza; and places and time periods where mask usage is required or widespread have shown substantially lower community transmission.

The available evidence suggests that near-universal adoption of non-medical masks when out in public, in combination with complementary public health measures could successfully reduce R_e (effective-R) to below 1, thereby reducing community spread if such measures are sustained. Economic analysis suggests that the impact of mask wearing could be thousands of US dollars saved per person per mask (102).

Interventions to reduce COVID-19 spread should be prioritized in order of their expected multiple on effective R divided by their cost. By this criterion, experimentation with and deployment of universal masks look particularly promising. When used in conjunction with widespread testing, contact tracing, quarantining of anyone that may be infected, hand washing, and physical distancing, face masks are a valuable tool to reduce community transmission. All of these measures, through their effect on R_e, have the potential to reduce the number of infections. As governments talk about relaxing lockdowns, keeping transmissions low enough to preserve health care capacity will be critical until a vaccine can be developed. Mask wearing may be instrumental in preventing a second wave of infections from overwhelming the health care system – further research is urgently needed here.

UNESCO states that "when human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm" (103). This is known as the "precautionary principle." The World Charter for Nature, which was adopted by the UN General Assembly in 1982, was the first international endorsement of the precautionary principle. It was implemented in an international treaty in the 1987 Montreal Protocol. The loss of life and economic destruction that has been seen already from COVID-19 is a "morally unacceptable harm." The positive impact of public mask wearing on this is "scientifically plausible but uncertain". This notion is reflected in Figure 1 - while researchers may reasonably disagree on the magnitude of transmissibility reduction and compliance, seemingly modest benefits can be massively beneficial in the aggregate due to the exponential character of the transmission process. Therefore, the action of ensuring widespread use of masks in the community should be taken, based on this principle (104).

Models suggest that public mask wearing is most effective at reducing spread of the virus when compliance is high (96). We recommend that mask use requirements are implemented by governments, or when governments do not, by organizations that provide public-facing services, such as transit service providers or stores, as "no mask, no service" rules. Such mandates must be accompanied by measures to ensure access to masks, possibly including distribution and rationing mechanisms so that they do not become discriminatory, but remain focused on the public health benefit. Given the value of the source control principle, especially for presymptomatic people, it is not good enough for only employees to wear masks, customers must wear masks as well.

It is also important for health authorities to provide clear guidelines for the production, use and sanitization or re-use of face masks, and consider their distribution as shortages allow. A number of countries have distributed surgical masks (South Korea, Taiwan) from early on, while Japan, Singapore and Belgium are now distributing cloth masks to their entire populations. Clear and implementable guidelines can help increase compliance, and bring communities closer to the goal of reducing and ultimately stopping the spread of COVID-19.

Materials and Methods

A community-driven approach was used for identifying key studies for this literature review. A multidisciplinary team of researchers reviewed and identified additional papers to create a narrative review of the effectiveness of public mask wearing as source control.

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