JAMA Network | Open

Special Communication | Infectious Diseases

Masks During Pandemics Caused by Respiratory Pathogens—Evidence and Implications for Action

Shama Cash-Goldwasser, MD, MPH; Arthur L. Reingold, MD; Stephen P. Luby, MD; Lisa A. Jackson, MD, MPH; Thomas R. Frieden, MD, MPH

Abstract

IMPORTANCE As demonstrated by the influenza virus and SARS-CoV-2, viruses spread by the respiratory route can cause deadly pandemics, and face masks can reduce the spread of these pathogens. The effectiveness of responses to future epidemics and pandemics will depend at least in part on whether evidence on masks, including from the COVID-19 pandemic, is utilized.

OBSERVATIONS Well-designed observational studies have demonstrated the association of mask use with reduced transmission of SARS-CoV-2 in community settings, and rigorous evaluations of mask mandates have found substantial protection. Disagreement about whether face masks reduce the spread of SARS-CoV-2 has been exacerbated by a focus on randomized trials, which are limited in number, scope, and statistical power. Many effective public health policies have never been assessed in randomized clinical trials; such trials are not the gold standard of evidence for the efficacy of all interventions. Masking in the community to reduce the spread of SARS-CoV-2 is supported by robust evidence from diverse settings and populations. Data on the epidemiologic, environmental, and mask design parameters that influence the effectiveness of masking provide insights on when and how masks should be used to prevent transmission.

CONCLUSIONS AND RELEVANCE During the next epidemic or pandemic caused by a respiratory pathogen, decision-makers will need to rely on existing evidence as they implement interventions. High-quality studies have shown that use of face masks in the community is associated with reduced transmission of SARS-CoV-2 and is likely to be an important component of an effective response to a future respiratory threat.

JAMA Network Open. 2023;6(10):e2339443. doi:10.1001/jamanetworkopen.2023.39443

Key Points

Question During the COVID-19 pandemic, what has been learned about whether face mask use is associated with lower transmission of SARS-CoV-2 in community settings, and how has it been learned?

Findings Literature review revealed many high-quality observational studies demonstrating the association of face mask use in the community and of mask mandates with reduced spread of SARS-CoV-2. Randomized clinical trials conducted during the pandemic provide limited information.

Meaning Robust available data support the use of face masks in community settings to reduce transmission of SARS-CoV-2 and should inform future responses to epidemics and pandemics caused by respiratory viruses.

+ Multimedia

Author affiliations and article information are listed at the end of this article.

Introduction

More than 3 years after the COVID-19 pandemic began, the use of face masks in the community remains controversial. Vaccination, treatment, population immunity, and other developments have enabled a return to a semblance of prepandemic life, but disagreement about what the evidence shows about masks—and the implications for their use—persists. SARS-CoV-2 is still a disruptive and deadly presence, and future epidemics or pandemics caused by pathogens spread by the respiratory route are a near certainty.[1] Failure to understand the evidence on the role of masks in preventing the spread of SARS-CoV-2 could undermine our ability to respond to epidemics and pandemics caused by respiratory pathogens.

Evidence on Community Masking at the Advent of the COVID-19 Pandemic

In early 2020, when SARS-CoV-2 was spreading globally and the World Health Organization declared a Public Health Emergency of International Concern, there were neither vaccines against nor treatments for COVID-19. Furthermore, we lacked understanding of the virus's routes of transmission, extent of presymptomatic and asymptomatic spread, and degree of transmissibility. As a result, prevention and control strategies were based on what was known about transmission of other respiratory pathogens, especially influenza viruses and previously characterized human betacoronaviruses, such as those that cause severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS), and the common cold.[2-4] Public health officials needed to consider that available evidence came from studies on specific types of masks (particularly N95 respirators vs surgical masks), that there was variation in the aims of masking interventions (ie, wearer protection vs source control), and that epidemiologic and behavioral differences between study settings (especially in health care settings vs the community) might influence apparent mask effectiveness.

These considerations are essential to the interpretation of evidence on mask efficacy and effectiveness. When the COVID-19 pandemic began, there were limited data on masks to prevent community transmission of respiratory pathogens.[2] In addition, there were legitimate concerns that studies on prevention of influenza might not be relevant to COVID-19, as the influenza and SARS-CoV-2 viruses differ in their degree of transmissibility, proportion of transmission attributable to asymptomatic shedding, and other factors. Studies on community masking and transmission of SARS-CoV-2 were eagerly awaited and, once available, widely cited. As the pandemic progressed, high-quality data demonstrated the benefits of masking as well as increased protection associated with certain mask types and patterns of use. However, the robustness and nuance of those data have at times been overshadowed by attention to one particular type of study: the randomized clinical trial (RCT).

RCTs on Community Masking During the COVID-19 Pandemic

Two RCTs[5,6] on mask use in the community conducted during the COVID-19 pandemic have been published.[7] The first, which randomized 3030 people in Denmark to receive surgical masks and a recommendation to mask outside the home vs no intervention, produced inconclusive results.[5] The incidence of SARS-CoV-2 infection was 20% lower in the intervention group, but the sample size was insufficient for the difference in infection rates to achieve statistical significance. During the study period, it is possible that other interventions diluted measurable effects of masking or that detected infections were largely transmitted within households. Only 46% of participants in the intervention group reported masking as recommended. Rates of community masking were also low; any effects of the intervention would have been derived primarily from wearer protection alone.[8]

The second, much larger study[6] showed that widespread community masking in Bangladesh was associated with a modest, statistically significant reduction in symptomatic SARS-CoV-2 infections. This was a cluster RCT in which 600 villages with more than 340 000 residents were randomized to receive either cloth or surgical masks and promotion of masking in public spaces vs no intervention. Mask use was observed to be 3 times more common (42% vs 13%) in intervention than control villages, with the largest increases in mask use observed in mosques. In villages assigned to the intervention, the incidence of symptomatic SARS-CoV-2 infection was reduced 9.5% overall and 35% among people aged 60 years or older compared with controls. Surgical masks appeared to be more effective than cloth masks.

Why do we not have more RCTs on masks to prevent the spread of SARS-CoV-2? In a pandemic caused by a lethal respiratory virus, it is difficult to find a setting in which it is ethical and feasible to randomize people to masking vs no masking. The time needed for RCTs to be funded, designed, and implemented further limits their feasibility during public health emergencies.[9] Other challenges to conducting RCTs of masking during a pandemic include adequately powering a study amid fluctuating community transmission levels and crossover between study groups (ie, inadequate adherence by participants in the intervention group or adoption of the intervention by those in the control group). Perfect adherence with the intervention (ie, wearing a mask correctly at all times of potential exposure) can be impractical, biasing results toward the null. Although imperfect adherence might mimic reality, it can complicate the interpretation of study results. It is not possible to conduct a blinded RCT on mask use vs no mask use, and crossover can be a particular problem if the intervention carries social meaning or if fear of the disease influences adherence with randomization assignment.

In the clinical world, choices between therapeutic regimens to treat various conditions are, whenever possible, guided by the results of carefully planned and executed RCTs. Although the RCT is often referred to as the gold standard, methodological considerations correct the misconception that RCTs are necessarily superior.[10] RCTs are not the only—or even the most important—way to assess the efficacy of health interventions. Although a well-designed RCT can provide valuable and internally valid information on the efficacy of a health intervention, in many areas of public health and medical practice, RCTs are impractical to conduct.[11] Furthermore, extrapolation to populations and settings outside the study may be invalid. Many highly effective policies and recommendations that reduce illness and injury have never been assessed in either an individual-level or cluster RCT. Examples include speed limits on highways; seatbelt and motorcycle helmet laws; interventions such as taxation and smoke-free indoor areas to reduce tobacco use; and putting babies to sleep on their backs to reduce the risk of sudden infant death syndrome.[11-13] In public health practice, evidence that does not come from RCTs is, appropriately, almost invariably assessed and used in support of policy making.

When RCT data are sparse, creating a summary measure of effect using meta-analysis can seem appealing.[14] Meta-analysis was originally developed as a tool for combining results of multiple RCTs that assessed the efficacy of the same therapeutic agent against the same disease outcome, especially when available studies were of limited size and therefore limited statistical power. A meta-analysis does not create new data. Rather, it assesses previously conducted studies, assigning weights based on study size and quality, to improve understanding of an intervention. If the studies available for inclusion in a meta-analysis differed in their methods, populations, contexts, or measurements, combining them for the purposes of conducting a meta-analysis may yield invalid results and conclusions. Meta-analysis can work well for simple interventions expected to have consistent effects across populations (eg, the effect of a particular drug on a specific patient outcome). However, if masking is the intervention under investigation, the effectiveness of the intervention might vary greatly depending on the type of mask, masking behavior in the nonintervention group, force of infection in the community, whether the intervention is designed for individual protection or for source control, uptake of the intervention, and characteristics of the circulating pathogen. If any of these components vary among studies, different interventions are being tested. Lumping studies together because they include a mask can yield invalid conclusions and conceal important findings of individual studies. The results of a Cochrane review of RCTs and cluster RCTs on interventions to reduce the spread of respiratory viruses[14] exemplified this pitfall; studies on masking to prevent influenza virus transmission and studies on masking to prevent SARS-CoV-2 virus transmission were analyzed together. When interpreting study findings, decision-makers should strive to understand the conditions under which specific interventions are likely to be useful.

Observational Studies on Community Masking During the COVID-19 Pandemic

Before the emergence of SARS-CoV-2, observational studies of measures to prevent transmission of the related betacoronaviruses that cause SARS and MERS indicated that use of respirators or masks was associated with a large reduction in the risk of infection in health care settings and in the community.[2] Since the pandemic began, high-quality case-control, cohort, and ecologic studies support the effectiveness of masks in the community to prevent transmission of SARS-CoV-2 (**Table 1**).[6,7,15-21] Proof of concept that masking can reduce transmission of SARS-CoV-2 comes from laboratory evaluations that have used simulated human respiration and other techniques to show that cloth masks, surgical masks, and N95 respirators reduce the spread of potentially infectious respiratory droplets and aerosols.[15,22,23] Masks can offer effective source control and some wearer protection; reduction of droplet and aerosol spread is greatest when both the source and the exposed individual are masked.[15,22,24] Studies show that mask type and fit influence efficacy.[15,17,22,25,26] The higher filtration efficiency of N95 respirators compared with surgical masks provides further evidence of efficacy—essentially, a dose-response association of the intervention with the outcome.

Observational studies have demonstrated the effectiveness of mask use to prevent transmission of SARS-CoV-2 on airplanes,[27] in schools,[28,29] and among household[30] and community[17,18,31] contacts of individuals with COVID-19. A COVID-19 outbreak on the USS Theodore Roosevelt aircraft carrier was particularly instructive. Ships are high-risk environments for respiratory disease outbreaks because they bring people together for prolonged periods in often poorly ventilated close quarters. The outbreak on the USS Theodore Roosevelt occurred early in the COVID-19 pandemic, before crew members would have had immunity to SARS-CoV-2. More than

Table 1. Types of Studies Supporting Efficacy and Effectiveness of Mask Use in the Community to Reduce Transmission of SARS-CoV-2, Selected Strengths and Weaknesses, and Exemplar Study Descriptions

Type of study	Strengths for studying mask use during the pandemic	Weaknesses for studying mask use during the pandemic	Exemplar study, intervention assessed, and notable findings
Laboratory model	• Can be well controlled • Can be conducted rapidly and at relatively low cost • Can quantify mechanistic efficacy of the intervention	• Results may not reflect clinical effectiveness	• Study: Ueki et al,[15] 2020 • Intervention: source control and personal protection with cotton and surgical masks, and N95 respirators • Findings: masks reduced spread of infectious respiratory particles; reduction was greater when masks were worn by the virus spreader alone than by the receiver alone, and there was a synergistic effect when both spreader and receiver were masked; N95 respirators offered better protection than surgical or cotton masks
Randomized clinical trial	• Can identify causal relationships • High internal validity with minimal bias • Can determine efficacy of specific interventions	• Limited external validity • Resource intensiveness and fluctuating exposure and outcome incidence can contribute to underpowering • Potential crossover between study groups • Long study duration • Potential ethical concerns	• Study: Abaluck et al,[6] 2022 • Intervention: distribution of cloth and surgical masks for personal protection and source control; strategies to promote mask wearing • Findings: in villages receiving the intervention, symptomatic SARS-CoV-2 infection was reduced by 9.5% overall and 35% among those ≥60 y, relative to controls
Meta-analysis	• Can be conducted rapidly and at low cost • Pooled results can increase power of estimates • Collection of new data not required	• Eligible studies may be limited in number and quality • Potential for invalid conclusions if studies using different interventions and study methods are combined	• Study: Talic et al,[16] 2021 • Intervention: personal protection and source control, range of mask types • Findings: pooled analysis of 6 studies showed that masks were associated with a 53% reduction in incidence of SARS-CoV-2 infection, although heterogeneity between studies was substantial and risk of bias across the 6 studies was moderate or high. It was not possible to evaluate type of mask or patterns of mask use.
Cohort	• Can evaluate multiple outcomes • Potentially highly generalizable • Retrospective: can be conducted rapidly and at low cost • Prospective: can establish temporal relationships	• Biases and confounding can reduce validity • Lack of standardization of intervention • Retrospective: potential for selection and recall bias • Prospective: long study duration; differential loss to follow up	• Study: Andrejko et al,[17] 2022 • Intervention: personal protection of cloth and surgical masks and N95/KN95 respirators • Findings: compared with those who reported never wearing a mask, those who reported always wearing a cloth mask, surgical mask, or N95/KN95 respirator in indoor public settings had 56%, 66%, and 83% lower odds, respectively, of a positive SARS-CoV-2 test result. There was some, albeit less, protection among those who reported sometimes wearing a mask or respirator.
Case-control	• Can be conducted rapidly and at low cost • Avoids need for follow-up	• Quality of exposure assessment can vary • Potential for selection and recall bias • Lack of control for unknown or unmeasured confounders	• Study: Duong-Ngern et al,[18] 2020 • Intervention: personal protection of cloth and surgical masks • Findings: self-reported consistent mask use during high-risk contact with COVID-19 cases was associated with a 77% reduced risk of SARS-CoV-2 infection
Cross-sectional	• Can be conducted rapidly and at low cost • Can provide prevalence estimates of multiple exposures and outcomes	• Cannot draw conclusions about causality • Difficult to control for confounding • Cannot assess trends unless serial assessments are conducted	• Study: Rader et al,[19] 2021 • Intervention: personal protection and source control, mask type not specified • Findings: compared with no masking, a 10% increase in masking was associated with 3.5 times greater odds of community control of SARS-CoV-2 transmission
Ecologic	• Can be conducted rapidly and at low cost • Provides population-level data • Potentially highly generalizable	• Cannot draw conclusions about causality • Difficult to control for confounding • Difficult to control for temporal changes that may influence exposure or outcome	• Study: Huang et al,[20] 2022 • Intervention: personal protection and source control, mask type not specified • Findings: mandating mask use decreased transmission of SARS-CoV-2, and the effect size increased over time after mandate implementation

80% of those who reported not masking were infected; the odds of infection were 30% lower among those on the ship who reported masking.[32]

In many COVID-19 outbreak settings, including the USS Theodore Roosevelt, masking was not the sole implemented public health measure (eg, hand hygiene, isolation of cases, physical distancing). Confounding can be a particular problem in observational studies. Studies demonstrating the effectiveness of masks to prevent COVID-19 have attempted to address this by controlling for factors, such as other interventions[7,30,33-35] or demographic characteristics that might influence risk of infection.[17,31] Others have used stratified analysis and shown that the impact of masking varies across patterns of use, populations, and settings. For example, masking in the household was protective if performed in the days prior to symptom onset in the index case,[30] demonstrating the risk of presymptomatic transmission and the effectiveness of masking to prevent asymptomatic transmission. Masks were associated with a greater reduction in risk of infection among unvaccinated than vaccinated individuals and with reduced risk of infection among those exposed outside their households but not among those exposed within their households[31] (possibly because low rates of masking within households precluded sufficient assessment). Several studies have shown increased protection with greater consistency of masking.[7,17,18]

Other Considerations: Mask Mandates, Risk-Benefit Calculations, and Areas of Uncertainty

Whether masks work is a different question from whether mask mandates work. The effectiveness of mandating an even partially effective intervention depends on many factors, and the impact of the intervention can be challenging to demonstrate. If adherence to a public health mandate is low, a mandate is unlikely to have an impact (seat belts reduce the risk of death, if they are worn). Higher rates of indoor masking in parts of Asia (eg, Hong Kong, Japan, Korea, and Singapore) may account for lower rates of infection and death, especially early in the pandemic.[36,37] For a population in which use of the intervention is already common, a statistically significant reduction in infection rates will be more difficult to establish. Furthermore, assessment of the effectiveness of mask mandates requires either cluster randomized studies or ecologic studies in which the unit of observation is the group, not the individual. Such studies have been done: rigorous evaluations of mask mandates in several settings suggested substantial protective benefits. In Germany, an opportunity to generate high-quality data arose when different regions mandated masking at different times during the COVID-19 pandemic. Mask mandates were associated with a 45% reduction in SARS-CoV-2 infections.[38] Variation in timing of mask mandates across the United States provided a similar study opportunity, and a matched cohort analysis of more than 400 US counties showed that enactment of a mask mandate was associated with a 25% reduction in COVID-19 incidence 4 weeks later.[20] Although it is possible that cases might soon peak without intervention if masking is implemented when incidence is increasing, US communities with mask mandates had less transmission than those without mandates after controlling for potential confounders, including premandate incidence.[19,20]

The risk-benefit calculations that shape public health recommendations may differ by setting and may change over time (**Table 2**).[15,17-20,22,24-26,28-33,35,39-46] When the COVID-19 pandemic began, scarcity of medical masks and respirators precluded their use outside of health care settings. There was concern that community members wearing masks might self-contaminate with SARS-CoV-2 or might fail to practice other public health measures due to a false sense of security. However, although respiratory viruses can contaminate the outside of masks when masks are worn for hours in high-exposure clinical settings,[46] the relevance of this finding to community settings is unclear. There is no compelling evidence that masking is associated with neglect of other public health measures; in fact, studies have suggested the opposite.[18]

Other concerns raised about masks included possible impacts on respiratory function; although masking can be uncomfortable, especially in warm conditions, there is no compelling evidence of consequential deleterious effects on physiology, including during exercise.[47] It can be difficult for young children to wear well-fitting masks, and the possibility that masking may impede cognitive and social development[40,41] suggests that this risk should be considered, balancing with possible benefits of masking. There is abundant evidence that school closures are deleterious to children's health and that masking in schools decreases transmission of SARS-CoV-2 within schools.[28,29,39] Using measures including masking to protect high-risk people in the school community and to keep schools open is likely to result in better health and educational outcomes than school closures. Consideration of trade-offs should inform future decisions about masking in schools to prevent the spread of

Table 2. Evidence-Based Perspectives and Contextual Considerations on Mask Mandates and on the Characteristics of Masks for Use in the Community Against COVID-19

Question	Evidence-based perspectives	Contextual considerations	Comments
When and where should masking be mandated?	• Essential services are strained: mandates can decrease SARS-CoV-2 transmission as well as COVID-19 case and death rates, thus easing the burden on overwhelmed health care systems or on other essential services strained by absenteeism.[19,20,35] • To protect those within congregate settings: masking can decrease transmission in crowded living conditions[32] (eg, ships, homeless shelters, correctional institutions). Universal masking can reduce the spread of disease within schools even when community transmission rates are high.[29,39] • Other interventions are unavailable or unlikely to be effective: masking can decrease transmission when effective vaccines are not available (for example against a new immune-escape and virulent variant of SARS-CoV-2 or a new virus) or when other interventions (eg, physical distancing, increased ventilation) are not implemented.[30-33]	• Will people comply with the mandate: the effectiveness of a mandate depends on the prevalence of community masking, as transmission is reduced most when both source and receiver are masked.[15,22,24] • Is there extensive transmission in settings other than where masks are mandated: if household secondary attack rates are high and masking within households is not commonly practiced, the effectiveness of a mandate might be limited.[31] • Will mandates be observed in higher-risk environments: masking in higher-risk settings (eg, public indoor settings) is more likely to significantly decrease transmission than masking in lower risk settings (eg, outdoor settings).[31] • Are masks available: if there is a scarcity of masks, use should be prioritized in high-risk settings, such as health care settings, or among high-risk populations, such as those at risk of severe COVID-19. • What is the risk-benefit in different populations: among young children, masking may be less protective against SARS-CoV-2 infection than among older children and adults, and masking may impede cognitive and social development.[40,41]	• Mandates can make masking the social norm but might also increase opposition. Some public health interventions have not been effective without an enforcement mechanism. • Tracking the prevalence of appropriate masking, whether mandated or not, can elucidate ways to increase masking.[19,42-44] These data are also critical to understanding the effectiveness of a mandate. • Layered mitigation measures are important. Studies have demonstrated synergistic effects of masking and other interventions, such as isolation and quarantine, physical distancing, and selective closures. • Masking can be increased in settings where it is indicated by clear and consistent messaging, effective risk communication, provision of masks, and engagement of community leaders.

In which scenarios is mask type important?	• If masking is for wearer protection: there is an advantage of N95/KN95 respirators over surgical and cloth masks when used for wearer protection.[17,25] Mask type might matter less when used for source control, as the degree of respiratory particle reduction may be similar across types.[25]
	• In settings where risk of transmission is high: N95/KN95 respirators can reduce transmission more than surgical masks, which can reduce transmission more than many cloth masks (especially those that are not tightly woven). This may be especially important to consider in the following high-risk settings:
	  • Crowded and poorly ventilated public indoor settings[17];
	  • congregate settings[28,32,39];
	  • if known or suspected cases are present[30,31];
	  • if other protective measures (eg, physical distancing, adequate ventilation) are not in place.
		• Mask fit: poor mask fit can decrease wearer protection. This is the case for all mask types, and a poorly fitting surgical mask may provide less protection than a well-fitting, tightly woven cloth mask.[26,45]
		• Influence of mask type on consistency of use: a high-filtration mask worn inconsistently may be less protective than a lower-filtration mask that is worn more of the time. A high proportion of SARS-CoV-2 transmission is from asymptomatic or presymptomatic people. Masks are more effective if worn during all contacts when transmission is possible.[17,18,30]
		• Availability: if there is a scarcity of respirators or surgical masks, use should be prioritized in high-risk settings, such as health care settings, or among high-risk populations, such as those at risk of severe COVID-19.
			• Some types of masks are more likely to be reused than others. The external surfaces of masks used in health care settings can be contaminated with influenza virus[46]; ideally, masks should rest for several days before reuse so that any contaminating virus is no longer infectious. Mask effectiveness can decrease if the mask is misshapen, torn, wet, or worn, or if the straps are stretched.
			• Elastomeric respirators which facilitate speech better than many existing respirator models may be developed; this type of respirator can safely be cleaned and reused. They should be fit tested and are currently primarily used in health care settings.
			• For certain populations, use of an N95 or KN95 respirator should be considered: those at risk of severe disease due to comorbidities or immunosuppressive medications; those who are unvaccinated; those who might expose a high-risk person; and those concerned about sequelae of infection (eg, post-COVID-19 conditions).

How important is good mask fit and how can it be achieved?	• Mask fit is important when there may be more exposure to respiratory particles: simple modifications that improve mask fit include double masking, knotting ear loops, using masks with head straps or attaching extenders to ear loops, and tucking in mask sides to decrease gaps between mask and face.[22,26]	• Filtration efficiency: simple modifications that improve mask fit can make some cloth masks more protective against respiratory particles than some surgical masks. Mask material with high filtration efficiency might not provide high levels of protection if the mask does not fit well.[22,26,45] • Will a well-fitting mask be used less frequently: test users of masks have reported difficulty assembling, discomfort, and lack of tolerability with certain modifications.[26] Gains in effectiveness associated with improved fit could be offset if the mask is not worn correctly and consistently (ie, during all contacts when transmission is possible).	• Health care workers undergo fit testing of respirators to ensure optimal mask effectiveness. In the community, several techniques (using well-fitting head straps, molding the nose piece, breathing tests to assess for gaps) can be used to improve fit, but it may be difficult to achieve ideal fit; a well-fitted respirator can efficiently reduce wearer exposure to respiratory particles even in the absence of fit testing.[25] • Mask fit is especially important to protect those at risk of severe disease due to comorbidities or immunosuppressive medications; those who are unvaccinated; those who might expose a high-risk person if infected; and those concerned about sequelae of infection (eg, post-COVID-19 conditions).

respiratory viruses, and frequent reassessments of the epidemiologic context and available evidence can help maximize benefits and reduce disruption and potential harms.

Although available evidence strongly suggests that masking in the community can reduce the spread of SARS-CoV-2, knowledge gaps persist. It is challenging to disentangle the impacts of masks from those of other interventions on transmission of SARS-CoV-2. The effectiveness of masks may differ between variants of SARS-CoV-2. Until recently, respirators such as N95s were not widely available outside health care settings. We lack precise estimates of the extent to which the community spread of SARS-CoV-2 is reduced at different levels of uptake of different mask types in different contexts. However, there is alignment between findings from laboratory models and limited available effectiveness data: a study on the use of masks or respirators in indoor public settings[17] showed that respirators were more protective against SARS-CoV-2 infection than surgical masks, which were more protective than cloth masks.

Conclusions

Effectiveness depends on many factors. No public health intervention, even a highly efficacious vaccine, is 100% effective. Even the best masks will not provide complete protection, and benefits of masking are limited if masks are not worn everywhere transmission occurs (eg, health care workers who consistently wear masks while working with patients but not in break rooms with other health care workers or in the community can be infected in the latter settings). In any pandemic or epidemic, masking will be just one of a series of interventions. The most effective strategies to limit illness and death from SARS-CoV-2 and other respiratory pathogens involve a layered response, including vaccination when available, isolation of infectious people, and protection through risk reduction—including use of high-quality masks in areas and at times and by vulnerable populations when the pathogen may be spreading. The COVID-19 pandemic and the global mpox outbreak are sobering reminders that we will confront new infectious disease threats in the future. Despite new approaches to developing and manufacturing vaccines (particularly mRNA technology) that can reduce the time between pathogen discovery and vaccine availability, that time frame will still be months at best and, for some pathogens, years or decades. Thus, decision-makers will again need to rely on existing and rapidly generated evidence as they implement interventions to mitigate disease spread. In these circumstances, RCTs and meta-analyses have important limitations and should not form the sole, or even primary, basis of public health decisions. Available evidence strongly suggests that masking in the community can reduce the spread of SARS-CoV-2 and that masking with the highest-quality masks that can be made widely available should play an important role in controlling whatever pandemic caused by a respiratory pathogen awaits us.

ARTICLE INFORMATION

Accepted for Publication: September 6, 2023.

Published: October 31, 2023. doi:10.1001/jamanetworkopen.2023.39443

Corresponding Author: Shama Cash-Goldwasser, MD, MPH, Resolve to Save Lives, 85 Broad St, Ste 1626, New York City, NY 10004 (shamacg@gmail.com).

Author Affiliations: Resolve to Save Lives, New York City, New York (Cash-Goldwasser, Frieden); School of Public Health, University of California at Berkeley (Reingold); Division of Infectious Diseases and Geographic Medicine, Stanford University, Stanford, California (Luby); Kaiser Permanente Washington Health Research Institute, Seattle (Jackson).

Author Contributions: Dr Cash-Goldwasser had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Concept and design: Cash-Goldwasser, Reingold, Jackson, Frieden.

Acquisition, analysis, or interpretation of data: Cash-Goldwasser, Reingold, Luby, Frieden.

Drafting of the manuscript: Cash-Goldwasser, Reingold, Jackson, Frieden.

Critical review of the manuscript for important intellectual content: Cash-Goldwasser, Reingold, Luby, Frieden.

Administrative, technical, or material support: Cash-Goldwasser, Reingold, Frieden.

Supervision: Reingold, Frieden.

Conflict of Interest Disclosures: Dr Frieden reported that Resolve to Save Lives received funding from Bloomberg Philanthropies, #startsmall, Gates Philanthropy Partners, which is funded with support from the Chan Zuckerberg Foundation, and the Bill & Melinda Gates Foundation. No other disclosures were reported.

Funding/Support: This analysis was conducted with funding from Resolve to Save Lives. Resolve to Save Lives is funded by grants from Bloomberg Philanthropies; the Bill and Melinda Gates Foundation; and the Chan Zuckerberg Initiative DAF, an advised fund of Silicon Valley Community Foundation.

Role of the Funder/Sponsor: The funder had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

REFERENCES

1. Marani M, Katul GG, Pan WK, Parolari AJ. Intensity and frequency of extreme novel epidemics. *Proc Natl Acad Sci U S A*. 2021;118(35):e2105482118. doi:10.1073/pnas.2105482118

2. Chu DK, Akl EA, Duda S, Solo K, Yaacoub S, Schünemann HJ; COVID-19 Systematic Urgent Review Group Effort (SURGE) study authors. Physical distancing, face masks, and eye protection to prevent person-to-person transmission of SARS-CoV-2 and COVID-19: a systematic review and meta-analysis. *Lancet*. 2020;395(10242): 1973-1987. doi:10.1016/S0140-6736(20)31142-9

3. Liang M, Gao L, Cheng C, et al. Efficacy of face mask in preventing respiratory virus transmission: a systematic review and meta-analysis. *Travel Med Infect Dis*. 2020;36:101751. doi:10.1016/j.tmaid.2020.101751

4. MacIntyre CR, Chughtai AA. A rapid systematic review of the efficacy of face masks and respirators against coronaviruses and other respiratory transmissible viruses for the community, healthcare workers and sick patients. *Int J Nurs Stud*. 2020;108:103629. doi:10.1016/j.ijnurstu.2020.103629

5. Bundgaard H, Bundgaard JS, Raaschou-Pedersen DET, et al. Effectiveness of adding a mask recommendation to other public health measures to prevent SARS-CoV-2 infection in Danish mask wearers: a randomized controlled trial. *Ann Intern Med*. 2021;174(3):335-343. doi:10.7326/M20-6817

6. Abaluck J, Kwong LH, Styczynski A, et al. Impact of community masking on COVID-19: a cluster-randomized trial in Bangladesh. *Science*. 2022;375(6577):eabi9069. doi:10.1126/science.abi9069

7. Chou R, Dana T. Major update: masks for prevention of SARS-CoV-2 in health care and community settings—final update of a living, rapid review. *Ann Intern Med*. 2023;176(6):827-835. doi:10.7326/M23-0570

8. Frieden TR, Cash-Goldwasser S. Of masks and methods. *Ann Intern Med*. 2021;174(3):421-422. doi:10.7326/M20-7499

9. Lurie N, Manolio T, Patterson AP, Collins F, Frieden T. Research as a part of public health emergency response. *N Engl J Med*. 2013;368(13):1251-1255. doi:10.1056/NEJMsb1209510

10. Deaton A, Cartwright N. Understanding and misunderstanding randomized controlled trials. *Soc Sci Med*. 2018;210:2-21. doi:10.1016/j.socscimed.2017.12.005

11. Frieden TR. Evidence for health decision making—beyond randomized, controlled trials. *N Engl J Med*. 2017;377(5):465-475. doi:10.1056/NEJMra1614394

12. Mitchell EA, Scragg R, Stewart AW, et al. Results from the first year of the New Zealand cot death study. *N Z Med J*. 1991;104(906):71-76.

13. Wisotzky M, Albuquerque M, Pechacek TF, Park BZ. The National Tobacco Control Program: focusing on policy to broaden impact. *Public Health Rep*. 2004;119(3):303-310. doi:10.1016/j.phr.2004.04.009

14. Jefferson T, Dooley L, Ferroni E, et al. Physical interventions to interrupt or reduce the spread of respiratory viruses. *Cochrane Database Syst Rev*. 2023;1(1):CD006207.

15. Ueki H, Furusawa Y, Iwatsuki-Horimoto K, et al. Effectiveness of face masks in preventing airborne transmission of SARS-CoV-2. *mSphere*. 2020;5(5):e00637-20. doi:10.1128/mSphere.00637-20

16. Talic S, Shah S, Wild H, et al. Effectiveness of public health measures in reducing the incidence of COVID-19, SARS-CoV-2 transmission, and COVID-19 mortality: systematic review and meta-analysis. *BMJ*. 2021;375: e068302. doi:10.1136/bmj-2021-068302

17. Andrejko KL, Pry JM, Myers JF, et al; California COVID-19 Case-Control Study Team. Effectiveness of face mask or respirator use in indoor public settings for prevention of SARS-CoV-2 Infection—California, February-December 2021. *MMWR Morb Mortal Wkly Rep*. 2022;71(6):212-216. doi:10.15585/mmwr.mm7106e1

18. Doung-Ngern P, Suphanchaimat R, Panjangampatthana A, et al. Case-control study of use of personal protective measures and risk for SARS-CoV 2 infection, Thailand. *Emerg Infect Dis*. 2020;26(11):2607-2616. doi:10.3201/eid2611.203003

19. Rader B, White LF, Burns MR, et al. Mask-wearing and control of SARS-CoV-2 transmission in the USA: a cross-sectional study. *Lancet Digit Health*. 2021;3(3):e148-e157. doi:10.1016/S2589-7500(20)30293-4

20. Huang J, Fisher BT, Tam V, et al. The effectiveness of government masking mandates on COVID-19 county-level case incidence across the United States, 2020. *Health Aff (Millwood)*. 2022;41(3):445-453. doi:10.1377/hlthaff.2021.01072

21. Centers for Disease Control. Science brief: community use of masks to control the spread of SARS-CoV-2. Accessed March 5, 2023. https://www.cdc.gov/coronavirus/2019-ncov/science/science-briefs/masking-science-sars-cov2.html

22. Brooks JT, Beezhold DH, Noti JD, et al. Maximizing fit for cloth and medical procedure masks to improve performance and reduce SARS-CoV-2 transmission and exposure, 2021. *MMWR Morb Mortal Wkly Rep*. 2021;70(7):254-257. doi:10.15585/mmwr.mm7007e1

23. Leung NHL, Chu DKW, Shiu EYC, et al. Respiratory virus shedding in exhaled breath and efficacy of face masks. *Nat Med*. 2020;26(5):676-680. doi:10.1038/s41591-020-0843-2

24. Riley J, Huntley JM, Miller JA, Slaichert ALB, Brown GD. Mask effectiveness for preventing secondary cases of COVID-19, Johnson County, Iowa, USA. *Emerg Infect Dis*. 2022;28(1):69-75. doi:10.3201/eid2801.211591

25. van der Sande M, Teunis P, Sabel R. Professional and home-made face masks reduce exposure to respiratory infections among the general population. *PLoS One*. 2008;3(7):e2618. doi:10.1371/journal.pone.0002618

26. Clapp PW, Sickbert-Bennett EE, Samet JM, et al; US Centers for Disease Control and Prevention Epicenters Program. Evaluation of cloth masks and modified procedure masks as personal protective equipment for the public during the COVID-19 pandemic. *JAMA Intern Med*. 2021;181(4):463-469. doi:10.1001/jamainternmed.2020.8168

27. Freedman DO, Wilder-Smith A. In-flight transmission of SARS-CoV-2: a review of the attack rates and available data on the efficacy of face masks. *J Travel Med*. 2020;27(8):taaa178. doi:10.1093/jtm/taaa178

28. Budzyn SE, Panaggio MJ, Parks SE, et al. Pediatric COVID-19 cases in counties with and without school mask requirements—United States, July 1-September 4, 2021. *MMWR Morb Mortal Wkly Rep*. 2021;70(39):1377-1378. doi:10.15585/mmwr.mm7039e3

29. Jehn M, McCullough JM, Dale AP, et al. Association between K-12 school mask policies and school-associated COVID-19 outbreaks—Maricopa and Pima Counties, Arizona, July-August 2021. *MMWR Morb Mortal Wkly Rep*. 2021;70(39):1372-1373. doi:10.15585/mmwr.mm7039e1

30. Wang Y, Tian H, Zhang L, et al. Reduction of secondary transmission of SARS-CoV-2 in households by face mask use, disinfection and social distancing: a cohort study in Beijing, China. *BMJ Glob Health*. 2020;5(5):e002794. doi:10.1136/bmjgh-2020-002794

31. Andrejko KL, Pry J, Myers JF, et al; California COVID-19 Case-Control Study Team. Predictors of severe acute respiratory syndrome coronavirus 2 infection following high-risk exposure. *Clin Infect Dis*. 2022;75(1):e276-e288. doi:10.1093/cid/ciab1040

32. Payne DC, Smith-Jeffcoat SE, Nowak G, et al; CDC COVID-19 Surge Laboratory Group. SARS-CoV-2 infections and serologic responses from a sample of U.S. Navy service members—USS Theodore Roosevelt, April 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69(23):714-721. doi:10.15585/mmwr.mm6923e4

33. Guy GP Jr, Lee FC, Sunshine G, et al; CDC COVID-19 Response Team, Mitigation Policy Analysis Unit; CDC Public Health Law Program. Association of state-issued mask mandates and allowing on-premises restaurant dining with county-level COVID-19 case and death growth rates—United States, March 1-December 31, 2020. *MMWR Morb Mortal Wkly Rep*. 2021;70(10):350-354. doi:10.15585/mmwr.mm7010e3

34. Gonçalves MR, Dos Reis RCP, Tólio RP, et al. Social distancing, mask use, and transmission of severe acute respiratory syndrome coronavirus 2, Brazil, April-June 2020. *Emerg Infect Dis*. 2021;27(8):2135-2143. doi:10.3201/eid2708.204757

35. Joo H, Miller GF, Sunshine G, et al. Decline in COVID-19 hospitalization growth rates associated with statewide mask mandates—10 states, March-October 2020. *MMWR Morb Mortal Wkly Rep*. 2021;70(6):212-216. doi:10.15585/mmwr.mm7006e2

36. Cheng VC, Wong SC, Chuang VW, et al. The role of community-wide wearing of face mask for control of coronavirus disease 2019 (COVID-19) epidemic due to SARS-CoV-2. *J Infect*. 2020;81(1):107-114. doi:10.1016/j.jinf.2020.04.024

37. Leffler CT, Ing E, Lykins JD, Hogan MC, McKeown CA, Grzybowski A. Association of country-wide coronavirus mortality with demographics, testing, lockdowns, and public wearing of masks. *Am J Trop Med Hyg*. 2020;103(6):2400-2411. doi:10.4269/ajtmh.20-1015

38. Mitze T, Kosfeld R, Rode J, Wälde K. Face masks considerably reduce COVID-19 cases in Germany. *Proc Natl Acad Sci U S A*. 2020;117(51):32293-32301. doi:10.1073/pnas.2015954117

39. Boutzoukas AE, Zimmerman KO, Inkelas M, et al. School masking policies and secondary SARS-CoV-2 transmission. *Pediatrics*. 2022;149(6):e2022056687. doi:10.1542/peds.2022-056687

40. Ruba AL, Pollak SD. Children's emotion inferences from masked faces: Implications for social interactions during COVID-19. *PLoS One*. 2020;15(12):e0243708. doi:10.1371/journal.pone.0243708

41. Gori M, Schiatti L, Amadeo MB. Masking emotions: face masks impair how we read emotions. *Front Psychol*. 2021;12:669432. doi:10.3389/fpsyg.2021.669432

42. Czeisler ME, Tynan MA, Howard ME, et al. Public attitudes, behaviors, and beliefs related to COVID-19, stay-at-home orders, nonessential business closures, and public health guidance—United States, New York City, and Los Angeles, May 5-12, 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69(24):751-758. doi:10.15585/mmwr.mm6924e1

43. Vest J, Cash-Goldwasser S, Bandali E, et al. Direct observation, estimates, and correlates of public mask-wearing during the COVID-19 pandemic. *Harvard Public Health Rev*. 2021:29. doi:10.54111/0001/cc18

44. Woodcock A, Schultz PW. The role of conformity in mask-wearing during COVID-19. *PLoS One*. 2021;16(12):e0261321. doi:10.1371/journal.pone.0261321

45. Hill WC, Hull MS, MacCuspie RI. Testing of commercial masks and respirators and cotton mask insert materials using SARS-CoV-2 virion-sized particulates: comparison of ideal aerosol filtration efficiency versus fitted filtration efficiency. *Nano Lett*. 2020;20(10):7642-7647. doi:10.1021/acs.nanolett.0c03182

46. Chughtai AA, Stelzer-Braid S, Rawlinson W, et al. Contamination by respiratory viruses on outer surface of medical masks used by hospital healthcare workers. *BMC Infect Dis*. 2019;19(1):491. doi:10.1186/s12879-019-4109-x

47. Shaw KA, Zello GA, Butcher SJ, Ko JB, Bertrand L, Chilibeck PD. The impact of face masks on performance and physiological outcomes during exercise: a systematic review and meta-analysis. *Appl Physiol Nutr Metab*. 2021;46(7):693-703. doi:10.1139/apnm-2021-0143