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Final Country-wide Mortality from the Novel Coronavirus (COVID-19) Pandemic and Notes Regarding Mask Usage by the Public.

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Abstract. Background. Many authorities have assumed that the novel coronavirus (COVID-19) pandemic will inevitably infect large fractions of the population in most countries. In addition, public health authorities and governments have varied in their policies regarding the use of face masks by the public.

Methods. Mortality data from COVID-19 and policies regarding mask usage in various countries were compiled from publicly available sources.

Results. The per-capita mortality approaches an upper bound which varies substantially between regions, from close to 1 in 3,200 dead in Italy and Spain, to less than 1 in 1,000,000 dead in other regions (e.g. Japan, Hong Kong, Taiwan, Slovakia). Numerous countries which have maintained their mortality asymptote orders of magnitude below that of the hardest-hit regions have widespread adoption of masks by the public. The mortality curve of the Czech Republic following a mandate for public mask usage on March 19, 2020 is consistent with a levelling off of mortality, with avoidance of the high upper bound of mortality seen in much of the West.

Conclusions. There is up to 3 orders of magnitude of variation between regions in the total fraction of the population killed by the coronavirus well after the disease becomes established. Therefore, widespread infection with the coronavirus in a country is not inevitable—some countries have substantially controlled the spread of the disease. Public mask usage is one of several plausible explanations for the mortality reduction in some regions. The benefit of broad public use of masks might be better established by the end of April 2020, when the mortality trajectories in Western regions recently mandating mask usage are known. In the meantime, broad adoption of public mask usage is a reasonable strategy for infection control which should be adopted on the precautionary principle.

Introduction.

The novel coronavirus (COVID-19) pandemic which began in 2019 has resulted in substantial morbidity and mortality, has caused economic chaos, and has disrupted the livelihoods and the daily lives of many millions worldwide. Like all infectious diseases, COVID-19 has the capacity to expand in an exponential fashion, meaning that it can rapidly spread to affect a very high percentage of the population. The mortality observed to date could be a small fraction of what will be observed within a few doubling times of the disease. On the other hand, with adequate suppression of transmission, the exponential spread could be converted to an exponential decay, resulting in a very low prevalence of the disease.

Face masks may decrease the spread of COVID-19. However, contradictory recommendations have been issued regarding broad adoption of face masks by the public. Some East Asian countries have used face masks to control this novel coronavirus outbreak.¹ In contrast, the World Health Organization recommended that asymptomatic people should only wear a mask if caring for someone with suspected SARS-CoV-2 infection.² Likewise, the United States Centers for Disease Control did not initially recommend that people who feel well should wear a mask³, until very recently (see below).

The purpose of this report is to discuss: 1) the fraction of the population which a country might anticipate will ultimately die from COVID-19, and 2) the possible effect of widespread adoption of face-covering with a mask (or bandana, scarf, etc.) on the course of the pandemic.

Methods.

We compiled the country-wide mortality related to the novel coronavirus (COVID-19) from a sample of countries thought to be important prototypes of various public health policies, or whose experience with the pandemic has been notable. Italy⁴ and Spain⁵ were studied, because they have been hit especially hard by the virus.

We looked at several countries which varied in their testing response. The United States had difficulty with fielding diagnostic tests, while Germany was one of the leaders in testing. Also of note, the German government guidelines discouraged mask-wearing by the public by quoting the WHO: “wearing a mask in situations where it is not recommended to do so can create a false sense of security.”⁶

¹ Feng 2020.

² Feng 2020.

³ Feng 2020.

⁴ Worldometers, Italy, 2020.

⁵ Worldometers, Spain, 2020.

⁶ Feng 2020.

Several Asian countries have recommended masks to be worn by the public during this outbreak. Hong Kong recommended surgical or disposable masks for people in crowded places.⁷ Mainland China also recommended masks for most of the public.⁸ The Japanese government declared that “If you wear a face mask in confined, badly ventilated spaces, it might help avoid catching droplets emitted from others...”⁹ In Thailand, it was reported on March 12, 2020 that health authorities encouraged the public to use home-made cloth masks. Panpimon Wipulakorn, Director-General for the Department of Health in Thailand stated: “The droplet from coughing and sneezing is around five microns and we have tested already that cloth masks can protect against droplets bigger than one micron.”¹⁰

Sweden was studied because they have not shut down or limited dine-in restaurants and schools to the same extent as many other western countries.¹¹

Mandates of several Western nations for their public to use masks recently went into effect: the Czech Republic on March 19, 2020,¹² Slovakia on March 24, 2020, Austria on March 31, 2020 (in grocery stores), and Israel on April 1, 2020.

Therefore, we obtained mortality data from the novel coronavirus from the Hopkins Coronavirus Resource Center,¹³ confirming the numbers from other sources when possible, for Austria,¹⁴ mainland China,¹⁵ the Czech Republic,¹⁶ Germany,¹⁷ Israel, Hong Kong,¹⁸ Italy, Japan,¹⁹ Singapore,²⁰ Slovakia,²¹ Spain, Sweden, Taiwan, Thailand, and Vietnam. Country population statistics were also obtained from public sources.²²

Results.

Fraction of the Population Expected to Die.

For countries in which the infection has been established for some period of time, the mortality grows at first in an exponential fashion (which appears linear on a logarithmic scale), with eventual approach towards an asymptote (upper bound) (Figure

⁷ Feng 2020.

⁸ Feng 2020.

⁹ Feng 2020.

¹⁰ Kuhakan 2020.

¹¹ Habib 2020.

¹² Chen 2020.

¹³ Johns Hopkins, 2020.

¹⁴ Worldmeters, Austria, 2020.

¹⁵ Worldometers, China, 2020.

¹⁶ Ministerstvo Zdravotnictvi Ceske Republiky, 2020.

¹⁷ Worldmeters, Germany, 2020.

¹⁸ Worldometers, Hong Kong 2020.

¹⁹ World Health Organization, Situation Reports.

²⁰ Ministry of Health, Singapore, Apr 3, 2020; 2020 coronavirus pandemic in Singapore, Wikipedia.

²¹ 2020 coronavirus pandemic in Slovakia, Wikipedia.org; Schiffmann 2020.

²² Worldometers.com.

1). The worst-hit countries, Italy and Spain, seem to be approaching a mortality asymptote of $10^{-3.5}$, or about 1 in 3,200 of the population dying. Other countries which adopt public health policies similar to those in Italy and Spain might presumably have a total mortality which stays below this upper bound as well.

There are enormous differences in this mortality asymptote between countries. Both mainland China and South Korea had vigorous outbreaks early on. In fact, the mortality curve in South Korea was running in parallel with that of Italy early in the outbreak (Figure 1). However, both China and South Korea have ultimately kept their mortality below the 1 in 100,000 mark (according to the data reported by their governments, Figure 1). Moreover, a number of Asian countries (Japan, Singapore, Hong Kong, Taiwan, Thailand, and Vietnam) have kept their mortality below 1 in 1,000,000 dead (Figure 1). In fact, Vietnam's mortality data was not illustrated because that country reports no deaths from coronavirus, as of April 4, 2020.

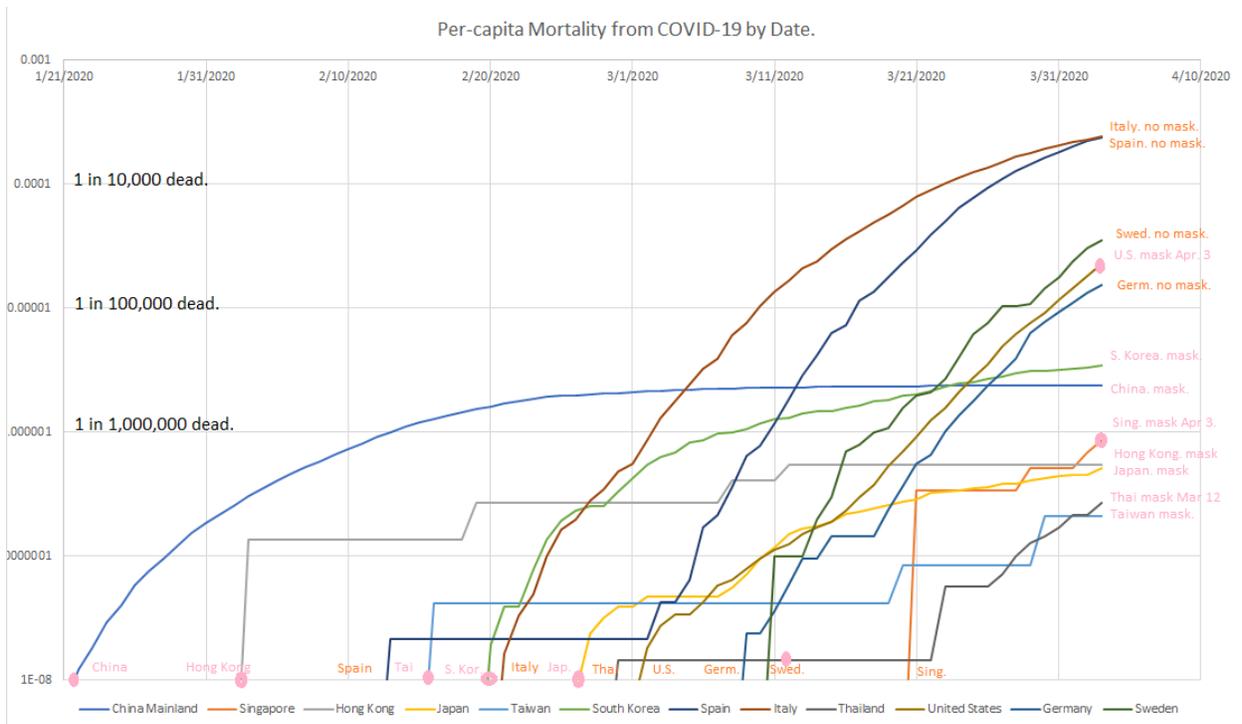


Figure 1. Per-capita mortality from coronavirus, demonstrating that mortality tends to approach an asymptote, which varies between countries.

Mask Usage.

Among the countries which have succeeded in keeping the coronavirus mortality below 1 in 1,000,000 over a prolonged period, many wear masks (Hong Kong, Japan, Thailand, Taiwan, Vietnam, and Slovakia) (Figure 2). Singapore has also maintained a low mortality rate, though it has crept up just a bit recently, and the government mandated mask use by the public on April 3, 2020 (Figure 2).

In an ever-increasing number of western countries, broad mask usage by the public has recently been mandated or recommended: the Czech Republic (Mar. 19), Slovakia (March 24), Austria (in grocery stores, March 31), Israel (April 1), and the United States (April 3) (Figure 2). As the earliest among this group, all eyes will be on the mortality experience of the Czech Republic. As it takes on average 23 days from infection with coronavirus until death (see below), we may not see the full effect of the mask mandate in the Czech Republic until April 11, 2020. Nonetheless, as of April 4, 2020, we can see that the coronavirus mortality curve in the Czech Republic looks a bit less steep than in other western countries at this stage of their outbreak (Figure 2).

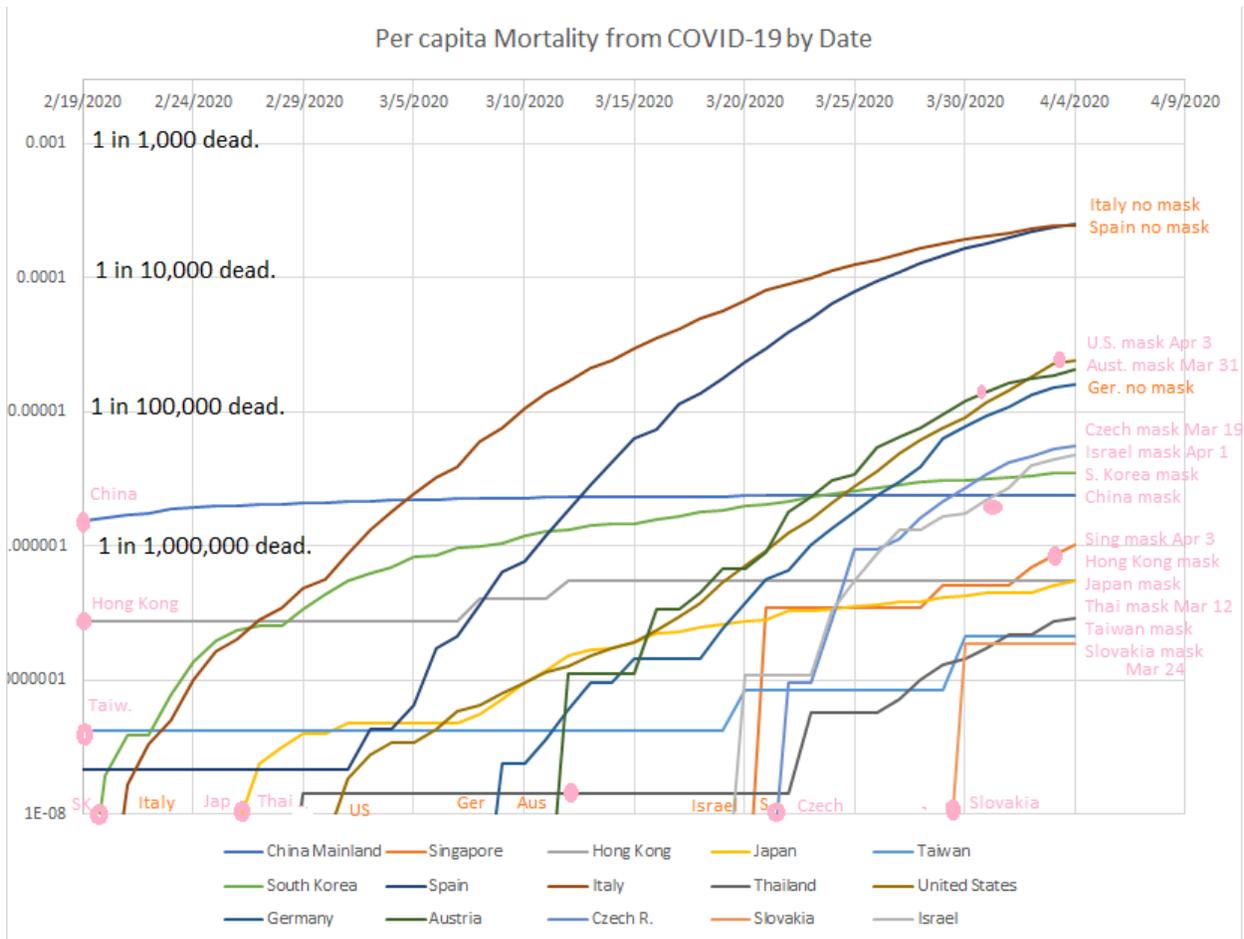


Figure 2. Per-capita mortality from coronavirus, with illustration of recommendations to use masks by the public.

Discussion.

We have demonstrated two key findings. The first is that the fraction of a country’s population dying during the epidemic varies by several orders of magnitude, between about 1 in 3,200 and 1 in 1,000,000. In other words, numerous countries have

succeeded not merely in delaying infections, but in actually preventing most of their population from becoming infected.

Many have assumed that very high rates of infection were inevitable in the population. Numerous scientists and politicians have floated the idea that infection would keep going until 40% to 70% of the population was infected.

In their view, the only thing that would stop the infection was when so many people had been infected that the virus was less successful at finding a susceptible host (herd immunity). Under this scenario, the observed mortality could have been quite high. For instance, if 50% of the population is infected and the mortality among those infected is 2%, then 1 person out of every 100 in the population could die from infection.

According to this view, the purpose of the public health response was merely to slow down the spread of the disease over a longer period of time (the so-called "flattening the curve"), to avoid having the health system overwhelmed by the volume.

That view could have been true, but the data suggest otherwise. Even the hardest-hit countries seem to approach a maximum level of mortality which is lower than under the "herd immunity" scenario. For instance, Italy and Spain appear to be approaching an upper bound of about 1 in 3,200 of the population dying.

Interestingly, the asymptote defining the total mortality varies substantially between countries. Many regions approach a much lower mortality asymptote. South Korea, for instance, had a mortality curve which closely paralleled that of Italy early in the course. However, ultimately, South Korea controlled the situation, and approached an asymptote of about 1 in 250,000 dead. In fact, some countries which took aggressive measures at the outset seem to be approaching an asymptote of less than 1 in 1,000,000 dead (e.g. Hong Kong, Japan, Thailand, Taiwan, and Singapore). Slovakia also has a mortality rate well below 1 in 1,000,000, but more time must elapse to know if this record can be maintained.

Of course, the statement that the total mortality for a country approaches an upper bound relates to the duration studied (months, rather than years) and other relevant conditions. For instance, if countries open schools or businesses, relax social distancing, stopped testing for the disease or wearing masks, etc., a new upper bound for infections could be approached. Moreover, the virus will still circulate, and could become endemic, producing occasional outbreaks at a lower level.

Because no antibody test has been widely deployed yet, we do not actually know the fraction of the population infected. But we can estimate some upper and lower bounds. For instance, we might presume that the countries with an asymptote of 1 in 1,000,000 dead have a fraction of the population infected which is about 300 times less than those with an asymptote of 1 in 3,200. Therefore, in the highly unlikely scenario that the spread of the infection in the high-mortality countries is limited only because absolutely everyone is infected (100%), then the infection rate would be about 0.3% in

the low-mortality countries. As a lower bound, if we choose the other extreme, and assumed that the virus had a very high mortality rate (say 5%), then the infection rate in the low-mortality countries would be 1 in 50,000. Either way, it is clear that the countries with very low mortality appear to be preventing infection in well over 99% of their citizens (assuming their mortality reports are accurate).

The U.S. administration has stated that the virus, with social distancing measures in place, could cause between 100,000 and 240,000 deaths in the coming months. The administration has been criticized on the grounds that the workings of the model have not been published, and therefore there is no way for outside scientists to evaluate their assumptions. Our graphical analysis provides some support for the lower end of this figure. Put simply, if the United States follows the pattern of Italy and Spain in approaching an asymptote of 1 in 3,200 dead, this would be close to 100,000 dead in the United States. Thus, our analysis provides some support for the lower end of this figure. However, the trajectory followed will depend on the policies adopted. If we relax social distancing or open businesses and schools, the number could be higher. On the other hand, the CDC policy to recommend voluntary usage of masks by the public announced on April 3, 2020 might lower the death toll (see below), especially if it is strengthened further.

The wide variation in observed mortality between countries might be explained by myriad factors, including the widespread use of masks, amount of testing for COVID-19, social distancing and “lockdown” policies, and customary methods of greeting (e.g. shaking hands). It is incumbent on the high-mortality countries to study and understand all of the factors at play in the more successful countries.

Could the differences relate to testing? Of course, a capable testing program for both active and prior infection is key to understanding and controlling an epidemic. With respect to coronavirus, Germany was a leader in testing, while the U.S. testing capabilities lagged considerably. Germany does have a mortality curve a bit lower than the U.S., but not by an order of magnitude. Thus, in this case, Germany’s early testing capability has not resulted in a dramatically different per-capita mortality trajectory from that in the United States.

Could the differences between high and low-mortality countries be accounted for by closing businesses and schools? It certainly is a logical practice, because infections are less likely to spread when people are separated. Sweden stayed largely open for business, compared with the U.S. Indeed, Sweden has a per-capita mortality curve slightly higher than that of the U.S. But again, the differences are not on the level of an order of magnitude. Both countries seem to be on track to follow the path of Italy and Spain towards the 1 in 3,200 mortality asymptote. Of course, it must be emphasized that countries should be able to change their mortality trajectory through vigorous public health measures.

Could the differences between high and low-mortality countries be related to wearing of masks by the public? Here, the differences appear to be striking. Almost every country proven to have kept the asymptotic mortality to less than 1 in 1,000,000 for the entire outbreak has adopted widespread mask usage by the public.

The effect of mask usage by the public on mortality from coronavirus will likely be substantially more clear by the end of April 2020, because we will be able to see the ultimate mortality path followed by the Czech Republic, Slovakia, Israel, Austria, and the United States all of which have mandated or recommended public mask usage too recently to fully determine what the impact will be. The median incubation period between coronavirus infection and the onset of symptoms is 5.1 days.²³ On average, there are 17.8 days between developing symptoms of coronavirus infection and death.²⁴ Thus, it could easily be expected to take 23 days between implementation of a new public health policy and full realization of the effect.

Singapore's public was not initially advised by the government to wear masks. However, the public in Singapore public likely had attitudes towards masks intermediate between those in the West and some nearby regions. In 2004 (just after the 2003 SARS outbreak), 28% of the Singapore population had worn a face mask in public in the previous two years, compared with 5% in the United States, 93% in Hong Kong, and 88% in Taiwan.²⁵ That year, 64% of the Singapore public favored mandatory wearing of a face mask in public in the event of contagion, compared with 53% in the United States, 86% in Hong Kong, and 96% in Taiwan.²⁶ On April 3, 2020, Singapore did advise its citizens to wear masks in public, and announced a program for mask distribution.²⁷

Is it biologically plausible that masks might prevent transmission of infection by blocking respiratory droplets containing the virus? Anthony S. Fauci, MD, the director of United States National Institute of Allergy and Infectious Diseases has stated:

"The primary purpose of a face mask is to protect a healthcare worker when he or she is taking care of somebody that's sick. The secondary use is to get somebody who is sick to put it on themselves to prevent them from infecting somebody else. Other people who want to protect against getting infected in society, they can use face masks. The reason we didn't recommend it early on is we didn't want the supply of face masks to be used for people who didn't really need it, when the physicians and the nurses and the other healthcare providers who needed weren't getting it. In a perfect world, if you have enough face masks, there's nothing wrong with wearing a face mask. Is it 100% protective? No way. What is it? Estimate? Maybe 50% or so, and that's merely an

²³ Lauer 2020.

²⁴ Verity 2020.

²⁵ Blendon 2006.

²⁶ Blendon 2006.

²⁷ Wei 2020.

estimate. There's some degree of protection, but it isn't completely protective against transmission."²⁸

The number of people infected on average by a virus is not a fixed number, but depends on the circumstances. For instance, policies to social distance and close schools and businesses can lower this value. Mask usage might provide additional lowering of this value. A 50% reduction in transmission could be a potentially enormous effect in an exponential process. If each infected person tends to infect 1.8 other people (in a given environment), and masks reduce the transmission by 50%, as estimated by Dr. Fauci, then each person infects only 0.9 other people, and exponential growth becomes exponential decay.

Even though the final outcomes in the Western countries which recently mandated masks are not yet known, it seems prudent to advise wearing of masks by the public when they are anywhere near other members of the public, or close to surfaces touched by others, such as keyboards, tables, or doorknobs. Indeed, the U.S. CDC on April 3, 2020 issued a new guideline stating:

"CDC recommends wearing cloth face coverings in public settings where other social distancing measures are difficult to maintain (e.g., grocery stores and pharmacies) especially in areas of significant community-based transmission."²⁹

This is potentially a major step forward towards control of the disease. Still, the new guidelines should go farther. First, the current social-distancing guidelines ask people to maintain a distance of 6 feet. If one is acting on the assumption that masks might help reduce transmission, there is every reason to continue to wear a mask even if one is 6 feet from one's neighbor. Both distancing and masks can be used to lower risk simultaneously. We have not seen evidence that the virus can travel 5 feet but not 6 feet. If our current policies (including the 6 foot spacing) were sufficient, then we would probably not find ourselves in the middle of a pandemic. Second, the guideline does not mention wearing a mask when near a surface touched by others, such as a table, desk, keyboard, or groceries. Handwashing has been universally advocated because virus particles can settle on the surfaces we touch with our hands. If a mask is worn in public, it will block many of the respiratory droplets, and prevent them from landing on these surfaces to begin with. Combining masks with handwashing provides the highest level of protection. Another problem with the guideline is that really all community-based transmission is significant. The guideline implies that in the middle of a pandemic there could be a low-level (not "significant") of community transmission at which it is acceptable to fail to take minimal precautions. In fact, it is the failure to take such basic steps which has permitted the virus to take hold in communities and expand exponentially. Finally, the guideline is voluntary, and it may be difficult to attract public support if important leaders fail to wear a mask themselves. Currently, a patient at the slit lamp or a rider on a bus might falsely believe that they do not have a duty to wear a

²⁸ Singh, Fauci 2020.

²⁹ United States Centers for Disease Control, April 3, 2020.

mask to protect those around them. The new guideline is somewhat akin to an automobile regulation which stated:

“We no longer want to discourage people from using headlights on their cars when driving at night. In fact, we recommend that people voluntarily turn on the headlights at night if their car does not have functioning turn signals, especially if they are in an area which has had a ‘significant’ number of traffic fatalities. The guideline is voluntary, and many of our leaders doubt that they will ever turn on their headlights.”

Thus, the guideline is a major step forwards, but it should be strengthened and implemented more vigorously.

The guideline also does not address other personal protective equipment, such as gloves and goggles. It may seem extreme to use a mask, gloves, and goggles, but use of this type of equipment is certainly less extreme than closing all schools and businesses. In fact, the manufacture, sale, and distribution of personal protective equipment can provide jobs for many people, and can help other people return to their jobs.

During the HIV epidemic, the principle of universal precautions was emphasized. Rather than assess an individual’s risk of having a particular disease, gloves were required whenever drawing blood from any patient. The principle of universal precautions with respect to the novel coronavirus requires that distancing be respected, and masks be worn, for all encounters.

As ophthalmologists who, collectively, have backgrounds in public health and government service, we felt compelled to study the epidemiology of COVID-19 disease. Physicians from all specialties, especially those practicing close to the airway, have died from COVID-19. One of the first to call attention to the novel coronavirus disease was Li Wenliang, a Chinese ophthalmologist, who believed he acquired the disease from an asymptomatic patient with glaucoma.³⁰ Subsequently, two more ophthalmologists in Li’s department in Wuhan died from COVID-19. Our belief more broadly that all people should cover their mouth and nose in public has specific application to ophthalmology. When in the same room, but especially when at the slit lamp, droplet precautions specify that the physician should wear a mask (and gloves) and the patient should also wear a face covering. Slit lamps must have a breath shield.

More broadly, as citizens whose communities have been upended by this tragic pandemic, we seek a vigorous public health response, which can save lives, and help our communities to return to a more normal way of life.

³⁰ Lee 2020.

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