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Comprehensive review of mask utility and challenges during the COVID-19 pandemic

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SUMMARY

Masks are widely discussed during the course of the ongoing COVID-19 pandemic. Most hospitals have implemented universal masking for their healthcare workers, and the Center for Disease Control currently advises even the general public to wear cloth masks when outdoors. The pertinent need for masks arises from plausible dissemination of the SARS-CoV-2 through close contacts, as well as the possibility of virus transmission from asymptomatic, pre-symptomatic, and mildly symptomatic individuals. Given current global shortages in personal protective equipment, the efficacy of various types of masks: N95 respirators, surgical masks, and cloth masks are researched. To accommodate limited supplies, techniques for extended use, reuse, and sterilization of masks are strategized. However, masks alone may not greatly slow down the COVID-19 pandemic unless they are coupled with adequate social distancing, diligent hand hygiene, and other proven preventive measures.

Keywords: mask efficacy, universal masking, coronavirus, COVID-19, N95 respirators.

INTRODUCTION

On April 3, 2020, the Center for Disease Control (CDC) issued an advisory that the general public have to wear cloth face-masks when outside, particularly those residing in areas with significant Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) community transmission [1]. Recent research reveals several factors related to the nature of the virus as well as the epidemiological spread of the illness that may have led to this decision. However, controversy prevails whether this recommendation will alleviate or aggravate disease progression. Since hospitals across America lacking sufficient Personal Protective Equipment (PPE) and scrambling for supplies, universal masking may create more chaos- especially with certain states imposing monetary fines on individuals spotted outdoors without a mask. As new information being discovered each day about the Coronavirus Disease 2019 (COVID-19), it is more imperative than ever to update existing strategies and formulate more effective methods to flatten the contagion curve.

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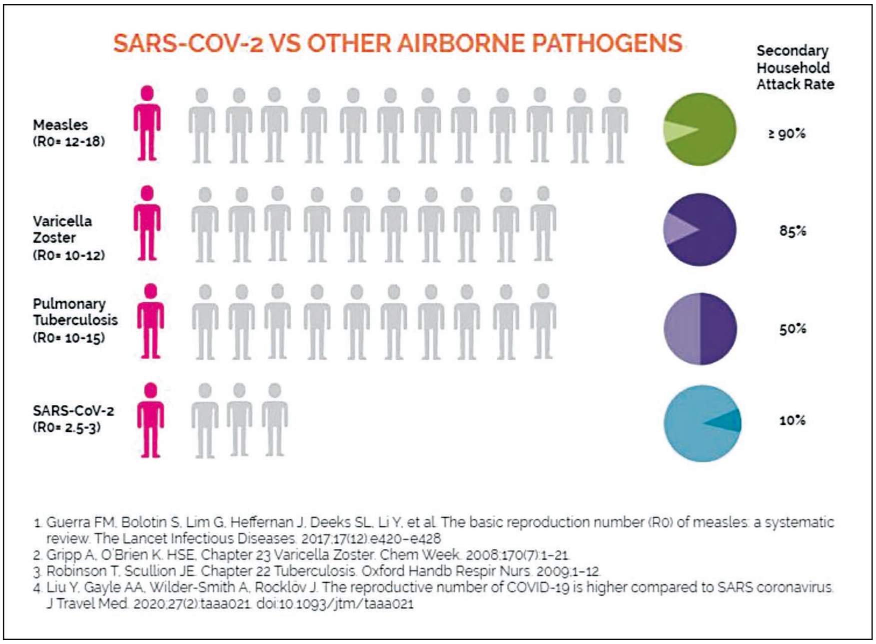
AIRBORNE VS. DROPLET TRANSMISSION OF THE DISEASE

In a scientific brief released by the World Health Organization (WHO), there have been studies with mixed evidence and opinions regarding the presence of SARS-CoV-2 ribonucleic acid (RNA) in air samples. Santarpia *et al.* from the University of Nebraska Medical Center detected viral RNA in samples taken from beneath the patient's bed and from the window ledge, both areas where neither the patient nor health care personnel had any direct contact. They also found that 66.7% of air samples taken from the hospital hallway carried virus-containing particles [2, 3]. It is worth noting that certain Aerosol-Generating Procedures (AGP) may increase the likelihood of airborne dissemination. Whether airborne transmission is a major mode of SARS-CoV-2 spread in the community and in routine clinical settings (with no aerosol-generating procedures) is still a debatable question with no definitive answer.

We should consider the epidemiology of COVID-19 thus far in the pandemic, to determine if transmission patterns are more consistent with that of other common respiratory viral pathogens, or more consistent with that of the agents we classically consider to be transmitted by the airborne route (measles, varicella zoster virus, and *Mycobacterium tuberculosis*). The attack rates in various settings (household, healthcare, and the public) as well as the expected number of secondary cases from a single infected individual in a susceptible population (basic reproduction number or R_0) are more consistent with those of a droplet spread pathogen. For measles, the R_0 is 12-18, and the secondary household attack rates are ≥90%. In the case of the varicella zoster virus, the R_0 is ~10, and the secondary household attack rate is 85% [4, 5]. The R_0 for pulmonary tuberculosis is up to 10 (per year) and the secondary household attack rate has been reported to be >50%. With SARS-CoV-2, the R_0 is around 2.5 -3 and secondary household attack rates are 10-30% from the data available so far (Figure 1) [6, 7]. A systematic review of reported reproductive numbers from previous seasonal influenza outbreaks and pandemics by Biggerstaff et al. shows a median R_0 of 1.28 [8]. This data suggests that droplet transmission may be more likely. The dichotomy of airborne versus droplet mode of spread may be better described as a continuum rather, as pointed out in a recent article in the Journal of the American Medical Association (*JAMA*). Infectious droplets form turbulent gas clouds allowing the virus particles to travel further and remain in the air longer [9]. The neces-

Figure 1 - Infographic comparing basic reproduction number (R_0) and secondary household attack rate of SARS-CoV-2 vs that of known airborne pathogens (measles, varicella zoster, pulmonary tuberculosis) based on historical data.



sary precautions for an airborne illness should be chosen over droplet precautions, especially when there is concern for an AGP.

UNIVERSAL MASKING: RISKS AND BENEFITS

The idea of universal masking has been debated extensively since the initial stages of the COVID-19 pandemic. According to public health authorities, significant exposure is defined as "face-to-face contact within 6 feet with a patient with symptomatic COVID-19" in the range of a few minutes up to 30 minutes [10]. The chance of catching COVID-19 from a passing interaction in a public space is therefore minimal, and it may seem unnecessary to wear a mask at all times in public. Randomized clinical studies performed on other viruses in the past have shown no added protection conferred by wearing a mask, though small sample sizes and noncompliance are limiting factors to their validity [11]. On the contrary, it has been enforced in many parts of Asia including Hong Kong and Singapore with promising results [10]. Leung et al. state that the lack of proof that masks are effective should not rule them as ineffective. Also, universal masking would reduce the stigma around symptomatic individuals covering their faces. It has become a cultural phenomenon in many southeast Asian countries and has been cited as one of the reasons for successful containment in Singapore, South Korea, and Taiwan. The most important benefit of universal masking is protection attained by preventing spread from asymptomatic, mildly symptomatic and pre-symptomatic carriers [12].

In a study carried out by Park *et al.* to estimate viral loads during various stages of the disease, it was found that asymptomatic patients had similar viral loads to symptomatic patients, thereby suggesting high potential for transmission [13]. Furthermore, numerous cases are being reported concerning the spread of illness from asymptomatic carriers [14-17]. In an outbreak at a skilled nursing facility in Washington described by Kimball et al., 13 of 23 residents with positive test results were asymptomatic at the time of testing out of whom 3 never developed any symptoms [17]. Many hospitals are now embracing the policy of universal masking. A mask is a critical component of the Personal Protective Equipment (PPE) clinicians need when caring for symptomatic patients with respiratory viral infections, in conjunction with a gown, gloves, and eye protection. Masking in this context is already part of routine operations in most hospitals. There are two scenarios in which there may be possible benefits. One scenario is the lower likelihood of transmission from asymptomatic and minimally symptomatic healthcare workers with COVID-19 to other providers and patients. The other less plausible benefit of universal masking among healthcare workers is that it may provide some protection in the possibility of caring for an unrecognized COVID-19 patient. Rhee et al. mention that the prevalence of asymptomatic infection in the general population is only 1-2% in most areas but among confirmed cases, is around 20-50%. Given the 70% sensitivity rate for nasopharyngeal swab polymerase chain reaction testing and high number of affected individuals who test negative initially, undue caution is undeniably warranted [18].

Universal masking should be coupled with other favorable practices like temperature checks and symptom screening on a daily basis to avail the maximal benefit from masking. Despite varied opinions on the outcomes of universal masking, this measure helps improve health care workers' safety, psychological well-being, trust in their hospital, and decreases anxiety of acquiring the illness. On the other hand, universal masking may give a false impression of protection and may result in increased face touching.

EFFICACY OF VARIOUS TYPES OF MASKS

The World Health Organization (WHO) recommended in February that surgical masks should suffice when treating COVID-19 patients, and N95 respirators or PAPRs should be used only in case of aerosol generating procedures. The CDC, however, insisted that N95 respirators be used by all medical professionals coming in contact with COVID-19 patients. Once hospitals suffered shortages, surgical masks were also permitted. Rhee et al. pose the question: are the CDC's recommendations "driven by supply shortages rather than science" [18]? How different are the levels of protection conferred by N95 respirators as compared to surgical masks? With the possibility of airborne transmission of the virus, are cloth masks truly helpful in preventing infection in the public? A study by Ma et al. demonstrates 99.98%, 97.14%, and 95.15% efficacy for N95, surgical, and homemade masks respectively in blocking the avian influenza virus (comparable to coronavirus in size and physical characteristics). The homemade mask was created using 1 layer of polyester cloth and a 4-layered kitchen filter paper [19]. N95 masks (equivalent to FFP/P2 in European countries) are made of electrostatically charged polypropylene microfibers designed to filter particles measuring 100-300nm in diameter with 95% efficacy. A single COVID measures 125 nm approximately. N99 (FFP3) and N100 (P3) masks are also available, though not as widely used, with 99% and 99.7% efficacy respectively for the same size range. Though cloth masks are the clear-cut last resort for medical professionals, a few studies state no clinically proven difference in protection between surgical masks and N95 respirators [20. 21]. Even aerosolized droplets (<5 µm) were found to be blocked by surgical masks in a study by Leung et al. in which 4/10 subjects tested positive for coronavirus in exhaled breath samples without masks and 0/10 subjects with masks [22]. On the contrary, Bae et al. found in their study of four COVID-19 positive subjects that "neither surgical masks nor cloth masks effectively filtered SARS-CoV-2 during coughs of infected patients." In fact, more contamination was found on the outer surface of the masks when compared to the inner surface, probably owing to the masks' aerodynamic properties [23]. Due to limitations present in the above-mentioned studies, further research is necessary to conclusively determine which types of masks are efficacious in preventing infection by the virus. In a scarcity of surgical masks and respirators for healthcare personnel, sub-optimal masks can be of some use provided there is adherent use, minimal donning and doffing, and it is to be accompanied by adequate hand washing practices [21]. Furthermore, even the most effective mask is useless if not worn correctly or fitted properly. Though healthcare workers may feel falsely safe or protected while wearing a mask (particularly loose fitting industrial masks), minimal air leakage, regular fit-testing and seal checks with N95 respirators are of paramount importance.

In case of severe infections with high viral loads or patients undergoing aerosol-generating procedures, Powered Air-Purifying Respirators (PAPRs) are also advisable as they confer greater

Table 1 - Summary table comparing features, benefits, and drawbacks of various types of masks currently being use.

	Features	*Benefits*	*Drawbacks*
N95 Respirators	- Tight fitting (filtration rate >95%) - To be used by healthcare workers	- Greater protection against aerosols and droplets	- Requires regular fit-testing and seal check - Diminishing supplies - Higher cost than surgical masks
Surgical Masks	- Loose fitting, provides physical barrier - To be used by healthcare workers	- Cheaper, more easily available - Can be layered over N95 masks	- Air leakage (cannot be used during aerosol-generating procedures) - Disposable, meant for one-time use
Cloth Masks	- Loose fitting, usually made of polyester or cotton - Can be layered with filter paper - For use by general public	- Can be homemade, washed and reused - Use can prevent hoarding of medical masks	- Insufficient protection from aerosols
Powered Air-Purifying Respirators (PAPRs)	- Loose head-top with battery powered blower to filter air - For use during aerosol-generating procedures	- Greater protection compared to N95 - Does not require fit-testing, can be worn with facial hair - More comfortable	- Expensive, limited availability - High cost and difficulty of maintenance

Source: Respiratory Protection During Outbreaks: Respirators versus Surgical Masks
https://blogs.cdc.gov/niosh-science-blog/2020/04/09/masks-v-respirators/

protection than N95 respirators. Despite being more comfortable for long-term use and accommodative of facial hair, their use is limited due to high cost and difficult maintenance [24] (Table 1). 3-D printing is also being utilized to combat the current shortage of masks worldwide. However, virological testing for leakage between the two reusable components and contamination of the components themselves after one or multiple disinfection cycles is essential before application in real-life situations [25].

ONGOING ISSUES

WHO estimates a monthly requirement of nearly 90 million masks exclusively for healthcare workers to protect themselves against COVID-19 [26]. In spite of increasing the production rate by 40%, if the general public hoards masks and respirators, the results could be disastrous. Personal protective equipment is currently at 100 times the usual demand and 20 times the usual cost, with stocks backlogged by 4-6 months. The appropriate order of priority in distribution to healthcare professionals first, followed by those caring for infected patients is critical. In the US alone, a survey conducted by the Association for Professionals in Infection Control and Epidemiology revealed that 48% of the healthcare facilities that responded were either out or nearly out of respirators as of March 25, 2020. The gravest risk behind the universal masking policy is the likely depletion of medical resources [27, 28]. A possible solution to this issue could be to modify the policy to stagger the requirement based on the severity of community transmission in that area of residence. In the article appropriately titled "Rational use of face masks in the COVID-19 pandemic" published in the Lancet, Feng et al. describe how the Chinese population was classified into moderate, low, and very low risk of infection categories and advised to wear a surgical or disposable mask, disposable mask, and no mask respectively [29]. This curbs widespread panic and eagerness by the general public to stock up on essential medical equipment when it may not even be necessary.

In the hospital setting, there is need for a clear consensus on when N95 respirators are indicated versus surgical masks. Amidst CDC's shift in recommendations to battle diminishing supplies, certain hospitals and professional societies have accelerated their infection control protocols to be extra cautious. This includes expanding the definition of AGPs "based on theoretical concerns rather than documented transmissions" [18].

REUSE, EXTENDED USE, AND DECONTAMINATION

Several studies have been conducted to identify the viability of the COVID-19 on various surfaces [30, 31]. CDC and National Institute for Occupational Safety and Health (NIOSH) guidelines state that an N95 respirator can be used up to 8 hours with intermittent or continuous use- though this number is not fixed and heavily depends upon the extent of exposure, risk of contamination, and frequency of donning and doffing. Though traditionally meant for single-time usage, after 8 hours, the mask can be decontaminated and reused. CDC defines extended use as the "practice of wearing the same N95 respirator for repeated close contact encounters with several patients, without removing the respirator between patient encounters." Reuse is defined as "using the same N95 respirator for multiple encounters with patients but removing it ('doffing') after each encounter. The respirator is stored in between encounters to be put on again ('donned') prior to the next encounter with a patient." It has been established that extended use is more advisable than reuse given the lower risk of self inoculation. Furthermore, health care professionals are urged to wear a cleanable face shield or disposable mask over the respirator to minimize contamination and practice diligent hand hygiene before and after handling the respirator. N95 respirators are to be discarded following aerosol-generating procedures or if they come in contact with blood, respiratory secretions, or bodily fluids. They should also be discarded in case of close contact with an infected patient or if they cause breathing difficulties to the wearer [32]. This may not always be possible given the unprecedented shortage of PPE, hence decontamination techniques and repurposing are the need of the hour.

Dr. Nathan of Northeastern University Feinberg School of Medicine recommends recycling four masks in series using one per day, keeping the mask in a dry clean environment and then repeating the first mask on the 5th day, second on the 6th day, and so forth. This ensures clearance of the virus particles by the next use. Alternatively, respirators can be sterilized between uses by heating to 70ºC (158ºF) for 30 minutes. Liquid disinfectants such as alcohol and bleach as well as ultraviolet rays in sunlight tend to damage the mask [33]. Steam sterilization is the most commonly utilized technique used in hospitals. Other methods include gamma irradiation at 20kGy (2MRad) for large-scale sterilization (though the facilities may not be widely available), vaporized hydrogen peroxide, ozone decontamination, ultraviolet germicidal irradiation, and ethylene oxide [34]. Though a discussion on various considerations of decontamination techniques is out of the scope of this paper, detailed guidelines have been published by the CDC and the COVID-19 Healthcare Coalition [35, 36].

CONCLUSIONS

A recent startling discovery by Sanche *et al.* shows that the basic reproductive number (R_0) is actually much higher than previously thought. Using expanded data, updated epidemiological parameters, and the current outbreak dynamics in Wuhan, the team came to the conclusion that the R_0 for the novel coronavirus is actually 5.7 (95% CI 3.8-8.9) compared to initial estimate of 2.2-2.7 [37]. Concern for transmissibility demands heightened prevention strategies until more data evolves. The latest recommendation by the CDC regarding cloth masking in the public may help slow the progression of the pandemic. However, it is of paramount importance to keep in mind that masks alone are not enough to control the disease and must be coupled with other non-pharmacological interventions such as social distancing, quarantining/isolation, and diligent hand hygiene.

Conflict of interest
The authors declare no conflict of interest.

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