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**COVID-19 and Keeping Clean:
A Narrative Review to Ascertain the Efficacy of Personal Protective Equipment to
Safeguard Healthcare Workers Against SARS-CoV-2**

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Abstract

Identifying the optimal amount of personal protective equipment (PPE) is a formidable challenge when faced with a new contagion such as SARS-CoV-2. Unequivocally, there are dangers to healthcare workers—and by extension, their patients, colleagues, and community—if not enough equipment is donned to safeguard them. And yet, there are also dangers to patients, colleagues, and the community if resources are over-consumed and/or result in hoarding, shortages, and inequitable distribution, all of which are occurring as the worldwide COVID-19 pandemic continues.

Research to ascertain the precise PPE required to defend specifically against SARS-CoV-2 encompasses an area of active investigation that will likely remain unresolved for some time. While awaiting more definitive conclusions, we must look to past evidence to provide a reasonable basis upon which protocols and policies might be refined. What follows is a narrative review of PPE efficacy and how existing evidence might apply to protecting healthcare workers against COVID-19. Findings are extrapolated from investigations in four general domains: early investigations into SARS-CoV-2, retrospective studies about SARS-CoV-1, prospective studies of influenza and other common respiratory viruses, and laboratory PPE studies.

Available evidence suggests that contact and droplet precautions, in addition to eye protection and standard hygiene measures, should be adequate in the vast majority of clinical settings when

caring for patients with SARS-CoV-2. Adherence to guidelines promoting appropriate levels of PPE should safeguard practitioners while mitigating against resource overuse.

Introduction

Among the many uncertainties arising from the ongoing global COVID-19 pandemic are queries into the optimal form of personal protective equipment (PPE) for hospital-based practitioners including pediatricians. What is the appropriate level of gear to don? How might we effectively protect ourselves—and by extension, our patients, our colleagues, and our community—while caring for patients infected with SARS-CoV-2?

While such questions encompass an area of active investigation that will likely remain unresolved for some time, past evidence provides a reasonable basis upon which we can refine protocols and policies. Many PPE-related topics were queried in the aftermaths of Severe Acute Respiratory Syndrome (SARS), caused by SARS-CoV-1, and various influenza outbreaks. For example, in 2006 the Institute of Medicine was asked to specifically (and presciently) comment on measures “that can be taken that would permit the reuse of disposable N95 respirators in healthcare settings.”¹

Determining the right amount of protective gear is not just about safeguarding individuals; it is a matter of equity. Reports of PPE shortages are ubiquitous in domestic and international contexts.^{2,3} There is hoarding; supply chains are disrupted; and low and middle-income countries are suffering the brunt of discriminatory resource distribution.^{4,5} The extent to which rich

hospitals and rich countries consume resources has global implications on mortality and morality.

What follows is a narrative review about PPE efficacy and how available evidence might apply to the COVID-19 pandemic. It is organized into the classic modes of infection control—contact, droplet, and airborne precautions—and also covers issues related to the extended use of N95 respirators. The review is not intended to replace any local, national, or international guideline, but rather to provide the (often corroborating) scientific rationale underlying them. Findings are extrapolated from investigations in four general settings: early investigations into SARS-CoV-2, retrospective studies of SARS-CoV-1, prospective studies of influenza and other common respiratory viruses, and laboratory PPE studies. Although each evidence domain has inherent limitations (primarily recall bias, potential confounding, and imperfect generalizability), together they form a composite picture from which we might surmise a reasonable approach forward.

Contact Precautions

For contact-based transmission of COVID-19 to occur, an infected person must transfer SARS-CoV-2 directly onto another person—or indirectly via an intermediary surface (fomite)—after which the recipient would need to inoculate susceptible mucosal surfaces (e.g., eyes, nose, or mouth). Additionally, contact-based transmission would only transpire if defenses against this form were not employed or not effective. These issues are explored below.

The potential for contact-based transmission of respiratory viruses has been known for four decades. In 1981, researchers instructed healthy volunteers to touch items (e.g., countertops, toys, etc.) contaminated with secretions from infants with Respiratory Syncytial Virus (RSV) and then directed these volunteers to “gently rub the mucous membranes of their nose or eye.”⁶ Study participants—who never directly interacted with the infected infants—contracted RSV on average six days after exposure. When institutions acted on these findings and implemented control measures such as cohorted nursing, gowning, and gloving (without masking), nosocomial RSV rates dropped precipitously.⁷ Although perhaps not generalizable, studies of RSV provide a foundation for the plausibility of contact-based transmission of respiratory viruses.

Virus survival on fomite surfaces has been directly studied. Transmissible gastroenteritis virus (TGEV)—a type of coronavirus which causes disease in pigs⁸—remained viable for hours on scrub fabric, gloves, and masks in laboratory conditions.⁹ However, the virus inactivates with time. Two percent of the TGEV load survived on scrub fabric after two hours in room air; 0.2% lingered after 4 hours. Preliminary data on SARS-CoV-1 and SARS-CoV-2 corroborate viability for hours-to-days on surfaces including plastic, cardboard, and stainless steel.¹⁰

Viral particles can be transported by touching contaminated surfaces. Transfer efficiency—the amount of virus transferred from a given surface to a fingertip after 10 seconds of contact—is humidity- and material-dependent and in general, non-porous materials enable greater transfer. For example, MS2 bacteriophage—a single-stranded RNA virus with many research applications¹¹—had low average transfer rates from cotton (0.03%) and rates as high as 67%

from glass.¹² Clinically pathogenic viruses such as rhinovirus and parainfluenza have also successfully transferred from stainless steel to fingertips after 5 seconds of contact.¹³

High humidity settings facilitate transfer from fomites. Transfer efficiency from stainless steel-to-fingertip was 6.9% in low humidity compared to 37.4% in high humidity.¹² In humid conditions, respiratory viral droplets more readily settle on surfaces and remain more stable when suspended in a liquid medium.¹⁴ This is one of the reasons contact-based transmission is suspected to be the predominant form of influenza transmission in tropical climates.¹⁵

Defense against contact-based transmission encompasses standard measures (e.g., avoiding hand-to-face contact, hand hygiene) and specific protective equipment (e.g., disposable gowns and gloves). Avoiding hand-to-face contact is common-sense and yet notoriously challenging. Over the course of a two-hour lecture, medical students touched their face on average 23 times hourly, with nearly half of the touches going to their eyes, nose, or mouth.¹⁶ The use of gloves and/or facemasks is widely theorized to decrease facial touching through psychological and physical deterrence,¹⁷ although no formal research has specifically interrogated this hypothesis.

The efficacy of rigorous hand hygiene to halt contact-based spread of pathogens was demonstrated more than 150 years ago,¹⁸ and recent evidence continues to support this fundamental tenet of infection control. Hygiene interventions have reduced transmission of respiratory infections in many community¹⁹ and healthcare settings.¹⁸ World Health Organization (WHO)-recommended formulations of alcohol-based solutions have been specifically tested against SARS-CoV-1 and found to be effective.²⁰

Measures against contact transmission mitigated infection of healthcare workers (HCWs) during the 2002 SARS-CoV-1 outbreak. A pooled analysis across multiple retrospective case-control studies demonstrated decreased odds of contracting SARS for HCWs who frequently washed their hands (OR 0.45, 95% CI 0.36 to 0.57), wore gloves (OR 0.43, 95% CI 0.29 to 0.65), and wore gowns (OR 0.23, 95% CI 0.14 to 0.37).²¹ Adherence to standardized protocols for donning/doffing PPE and participation in active training sessions decreased self-contamination in simulation studies.²²

Taken in summation, it remains biologically and epidemiologically plausible for SARS-CoV-2 to transfer from infected individuals to others via direct physical contact or fomites. Transmission is dependent on multiple factors, and likely highest when occurring shortly after contact with infected individuals or with non-porous contaminated fomites, particularly in humid conditions. Measures against contact transmission, including avoiding hand-to-face contact, partaking in hand hygiene, and wearing gloves and isolation gowns should protect against SARS-CoV-2 when employed effectively.

Droplet Precautions

Droplet-based transmission occurs when respiratory secretions containing active virus travel from an infected person across a short distance in the air directly onto the mucosal surface of another person. Physical contact with infected individuals is not necessary. The plausibility of this transmission mode has been validated through many experiments. Examples include the transfer of influenza from infected guinea pigs to susceptible counterparts in adjacent, non-

touching cages;¹⁵ the transfer of coxsackie virus from infected persons to those on the other side of a shared barrack separated in half by a wire barrier preventing physical contact between the study's participant groups;²³ and the transmission of rhinovirus from infected individuals playing poker to others at the same table wearing restraints preventing hand-to-face touching (i.e., contact-based transmission).²⁴

The distance traveled by a respiratory droplet depends on multiple elements. Factors favoring shorter distances include larger droplet size ($>5\mu\text{m}$), slower expulsion, increased humidity, and minimal air flow away from the patient.^{15,25} The CDC's historical radius for droplet transmission was loosely defined as 3 feet but after the SARS-CoV-1 outbreak, this distance was extended to 6 feet based on data suggesting that medical students in Hong Kong were infected at greater rates when adjacent to (approximately 6 feet away from) an index SARS patient with whom they had no direct physical contact.^{25,26}

In retrospective real-world observations, such as those undertaken during emerging pandemics such as SARS and COVID-19, it is often not possible to dissect whether infection occurred via contact- or droplet-based transmission. Both can occur from close proximity interactions. However, biologic plausibility, laboratory studies, and epidemiological data (described in greater detail in the next section) all imply droplet-based transmission to be a major form of SARS-CoV-2 propagation.

The primary measures against droplet-based transmission include remaining a safe distance away from infected individuals (commonly considered to be 6 feet, but would depend on specific

clinical contexts) and/or donning facial protection (surgical mask—not N95 respirator—and eye protection) to block physical entry of particles onto susceptible mucosa.²⁵ The efficacy of such measures is presented in the next section to allow for a direct comparison between droplet and airborne PPE.

Airborne Precautions

In contrast to droplet-based transmission, airborne transmission occurs when patient secretions containing infective viral particles travel long distances (>6 ft) and enter the respiratory tract of susceptible individuals. Airborne (or aerosolized) particles are generally small (<5 μm) and dry (desiccated) and thus able to remain suspended in air and travel on currents great distances before settling on persons, the ground, or atop objects.²⁵

Measures to protect against airborne transmission include environmental controls (e.g., specialized air handling) and provider gear (e.g., N95 respirator).²⁵ When fit-tested to ensure a proper seal on the user's face, an N95 respirator blocks 95% of non-oily particles as small as 0.3 μm .²⁷ Although droplet and airborne precautions are generally operationalized in a dichotomous manner, emerging data suggest a continuum between these two modes of transmission based on both host and environmental factors.¹⁴ For example, despite containing large particles that theoretically should not travel far, the gas cloud formed by sneezing has been demonstrated to transit beyond 20 feet.²⁸

A number of recent studies provoked concern that SARS-CoV-2 may infect via airborne mechanisms. In laboratory conditions—which entailed a rotating drum maintained under strict

temperature control (22 degrees Celsius) and humidity parameters (65%)— the virus survived in the air for hours.¹⁰ Additionally, researchers in Wuhan, China and Nebraska, United States discovered that SARS-CoV-2 RNA was present in air samples of wards and intensive care units housing patients with COVID-19.^{29,30} The presence of viral RNA as detected by polymerase chain reaction assays, however, does not necessarily mean those particles can successfully infect others. Virus viability (or infectivity)— measured by inoculating a tissue culture and examining subsequent cell death—was not assessed in the Wuhan study and not detected in any samples from the Nebraska study.^{29,30}

The question thus remains, are airborne precautions necessary to care for patients with COVID-19, or will droplet precautions suffice? While ongoing investigations continue to uncover how SARS-CoV-2 behaves in real-world clinical settings, a review of past evidence provides four relevant points.

First, substantial evidence indicate that the predominant modes of transmission for respiratory viruses are through droplet and contact mechanisms, not airborne means. In a separate study arm of the aforementioned research into RSV communicability, none of the volunteers who sat in the exam room *without* a mask six feet away from an infected infant contracted the disease.⁶ Studies of influenza demonstrate far greater transmission from person-to-person in close contact settings.^{55,56} Contact tracing in a Canadian hospital noted SARS-CoV-1 infections in HCWs among only those who touched the index patient, with the exception of one HCW for whom no clear etiology was identified.³¹

Emerging data from SARS-CoV-2 similarly corroborate a propensity for close contact (i.e., contact/droplet) transmission.³² In a review of 1,286 contacts of 391 individuals with COVID-19 in Shenzhen, China, increased odds of transmission were observed in settings where contacts spent considerable time with infected individuals, including living together (OR 6.27, 95% CI 1.49 to 26.33), eating together (OR 7.13, 95% CI 0.73 to 69.32) or traveling together (OR 7.06, 95% CI 1.43 to 34.91).³³ Others have also reported SARS-CoV-2 case clusters within families.³⁴

Second, both retrospective and prospective data suggest contact and droplet PPE are adequate protection in most clinical contexts. In another SARS-CoV-1 contact tracing study involving 254 HCWs (13 of whom contracted SARS) exposed to 11 index cases in Hong Kong, 0 of 51 staff workers who wore a surgical mask were infected, as well as 0 of 92 who wore an N95 respirator.³⁵ Both were protective, although the study did not include any index cases receiving nebulized therapies.

Prospective data corroborates this general finding. A trial of Canadian nurses randomized to wear fit-tested N95s or surgical masks (even during nebulized treatments) during influenza season demonstrated nearly identical rates of lab-confirmed influenza between the two arms and concluded that surgical masks were non-inferior.³⁶ A similarly designed prospective study in outpatient settings across the United States over multiple years demonstrated the same: there was no significant difference in the incidence of lab-confirmed influenza and other respiratory illnesses (include common coronavirus strains) in HCWs wearing N95 respirators compared to those wearing surgical masks.³⁷

Third, although airborne transmission may not be a primary mechanism of transmission, viral spread through small-particle aerosolization is plausible in certain clinical contexts. Air samples obtained from rooms of patients with laboratory-confirmed H1N1 revealed that certain aerosol generating procedures such as bronchoscopy increased the quantity (although not statistically significant) of small particles containing virus.³⁸ A systematic review of SARS-CoV-1 studies calculated the odds ratio of contracting SARS for HCWs performing or being exposed to tracheal intubation was 6.6 (95% CI 4.1 to 10.6) relative to those not exposed to the procedure.³⁹ Data on nebulized therapies was mixed, as was the case for a number of other clinical interventions including high-flow oxygen.³⁹ This general lack of evidence has left public health authorities unable to enumerate a validated list of “aerosol generating procedures” for COVID-19.⁴⁰

Fourth, the amount of airborne virus can be mitigated through physical and environmental controls. For example, the amount of small-particle aerosolized virus in patients with influenza and common coronavirus strains substantially decreased when infected patients wore a facemask.^{41,42} Source control through masking may not be possible in young children. A systematic review of facemask use at mass gatherings identified 11 years as the youngest age studied;⁴³ the CDC does not recommend face coverings for anyone under 2 years.⁴⁴ Provider-based physical barriers, including face-shields,¹ may also decrease the potential for aerosolized particles to be transferred to a HCW.

In summary, current evidence suggests the use of contact and droplet precautions are adequate protection against SARS-CoV-2 in most clinical contexts, and physical controls can decrease the load of airborne virus. There are situations (such as intubation) during which additional

precautions are warranted, but routine use of N95 respirators outside of high-risk settings is not supported by the current evidence base.

Extended Use of N95 Respirators

Current PPE shortages and the resultant need for institutions to extend the use of heretofore disposable N95 respirators have put many at unease. Concerns have been raised as to whether these respirators might be teeming with viral particles and increase the propagation of disease.

In 2014, Fisher and Shaffer from National Institute for Occupational Safety and Health (NIOSH) identified four reassuring properties related to extended respirator use.⁴³ First, most viral particles are trapped in the middle, not external, surface of the mask. Dissecting influenza-laden masks infected in laboratory settings demonstrated that nearly 70% of viral particles were present in the middle layer which typically has electrostatic properties that trap virus there.⁴⁶ Second, as previously mentioned, the virus inactivates with time. Laboratory studies of TGEV demonstrated that 15% of a viral load on the surface of an N95 respirator survived after two hours in room air, while approximately 0.1% lingered after 24 hours.⁹ Third, only a small fraction of viral particles is transferred onto fingertips when any particular surface is touched. No study has looked at viral transfer specifically from N95-to-finger, but transfer efficiency was quite low (0.3%) from polyester-to-fingertip,¹² the material used for the shell of most N95s.⁴⁷ And finally, even during a forceful cough, only a small fraction of viral particles is transferred back into the air. During laboratory cough simulations, at most 0.2% of mask's viral load was re-aerosolized.⁴⁸

Another concern is that extended respirator use may impact the mask's inherent ability to protect the user, in terms of filtration or fit. Again, there are some reassuring features to note as described by NIOSH.⁴⁵ First, when masks were continuously loaded (with flow rates of 85 L/m) for 5 straight hours, filtration efficiency remained >97%.⁴⁹ Second, the fit test is a good test. Simulation of three 10-min patient encounters (obtaining vital signs, wound dressing change, IV care) demonstrated that initial mask-fit was predictive of mask-fit during care tasks.⁵⁰ However, fit can decrease with each re-use. When lab participants were asked to don-doff respirators 20 times consecutively (keeping the N95 on for two minutes each time), there was decreasing fit with each re-use, with only 60% passing fit test on the twentieth use.⁵¹ This is one of the reasons “extended” use (keeping the respirator on) is generally recommended over “re-use” (on/off/on). Another reason is the donning/doffing process requires a seal check each time, meaning that hands touch the mask more with each re-use.

Other studies have demonstrated general physiologic tolerance of extended respirator use, although such investigations have been conducted in healthy young adults without co-morbid conditions.^{52,53} In sum, N95 respirators have a number of technical features which, alongside the implementation of administrative and environmental controls, mitigate the potential for viral disease propagation during extended use.

Conclusion

Identifying the optimal amount of PPE is a daunting challenge when faced with the outbreak of a new contagion such as SARS-CoV-2. Unequivocally, there are dangers to HCWs—and by extension, their patients, colleagues, and community—if not enough equipment is donned to

safeguard them. And yet, there are also dangers to patients, colleagues, and community if scarce resources are over-consumed and/or result in hoarding, shortages, and inequitable distribution, as is currently occurring while the COVID-19 pandemic continues.

A review of currently available evidence suggests that contact and droplet precautions, in addition to eye protection and standard hygiene measures, are adequate in the vast majority of clinical settings when caring for patients with SARS-CoV-2. Adherence to guidelines⁵⁴ promoting appropriate levels of PPE should safeguard practitioners while minimizing resource overuse.

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