

## Disrupting the Transmission of Influenza A: Face Masks and Ultraviolet Light as Control Measures

[Martin Meyer Weiss](#), MD, [Peter D. Weiss](#), MD, [Danielle E. Weiss](#), MD, and [Joseph B. Weiss](#), MD

Martin Weiss is with the Veterans Administration, Sepulveda, Calif, and the School of Medicine, University of California, Los Angeles. Peter D. Weiss is with the School of Medicine, University of California, Los Angeles. Danielle E. Weiss is with Scripps Mercy Medical Center, San Diego, Calif. Joseph B. Weiss is with the School of Medicine, University of California, San Diego.

*Requests for reprints should be sent to Martin Weiss, Veterans Administration, 16111 Plummer St, Sepulveda, CA 90143 (e-mail: [martin.weiss@med.va.gov](mailto:martin.weiss@med.va.gov)).*

Accepted December 6, 2006.

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### Abstract

In the event of an influenza pandemic, where effective vaccine and antiviral drugs may be lacking, disrupting environmental transmission of the influenza virus will be the only viable strategy to protect the public. We discuss 2 such modalities, respirators (face masks) and ultraviolet (UV) light. Largely overlooked, the potential utility of each is underappreciated. The effectiveness of disposable face masks may be increased by sealing the edges of the mask to the face. Reusable masks should be stockpiled, because the supply of disposable masks will likely prove inadequate. UV light, directed overhead, may be beneficial in hospitals and nursing homes.

**PUBLIC HEALTH POLICY FOR** influenza has focused on vaccination and antiviral agents for prophylaxis and therapy. Both modalities concede viral penetration of the host. Interruption of transmission, before the virus has invaded the body, has received scant attention. We examine 2 potential modalities for the latter. Face masks (respirators) largely have received perfunctory notice from policymakers and are generally held, at best, to be of only modest value.<sup>1</sup> Ultraviolet (UV) light has been largely ignored. The potential utility of each is underappreciated. In the event of a pandemic where effective vaccine and antiviral drugs may be lacking, disrupting environmental transmission of the virus will be the only viable strategy to protect the public.

### FACE MASKS

Respirators (N–95 and N–100; both commercially available) are masks designed to shield the wearer from inhalational hazards, as opposed to surgical masks, which are designed to protect others from contaminants generated by the wearer. In the discussion that follows, use of the word *mask* refers only to the former.

Respirators were first described by Pliny in the first century CE. Dried animal bladders were used as protective masks by workers in dye manufacturing to prevent the inhalation of vermilion powder, a pigment containing mercuric sulfide.<sup>2</sup> Current respirator filters are typically made of polypropylene wool felt, or fiberglass paper. Particles collide with and become enmeshed within these non-woven fibers.<sup>1</sup> Another mechanism for the filtering media may be the electrostatic charge that these fibers have, which attract and hold oppositely charged particles.<sup>1</sup> The influenza virus has charges at its hemagglutinin spikes.<sup>3</sup>

In theory, N-100 respirators are 99.999% effective in filtering particles of more than 120 nm in size.<sup>4</sup> Respirators are also effective against particles much smaller in size (e.g., 40–50 nm).<sup>5</sup> The influenza virus is 80 to 120 nm in size.

N-95 respirators, which are less effective than N-100 respirators, have been reported to be protective in preventing transmission of the severe acute respiratory syndrome (SARS) virus (size 100 nm),<sup>6,7</sup> but use of these masks failed to prevent a cluster of cases in 1 hospital.<sup>8</sup>

If one assumes that influenza is transmitted by respiratory droplets (> 10 µm in size, which immediately fall to the ground) rather than by aerosols (< 10 µm in size, which remain suspended in air for long periods of time), the supposition may be that keeping a safe distance may obviate the need for a mask. It is stated that the range of such droplets is generally no more than 3 ft.<sup>1,9</sup> We are unable to locate the basic science behind that assertion. It appears to arise from a quote by Chapin in 1910.<sup>10</sup> There is a body of German scientific literature from the 1890s that other than as a historical (and mistranslated) curiosity<sup>11</sup> has been overlooked. Laschtschenko found that talking sprayed viable bacteria 6 m (approximately 20 ft).<sup>12</sup> Koeniger repeated the study and found that even whispering sprayed bacteria (*Bacillus prodigiosus*) 7.4 m (approximately 24 ft) and a mixture of coughing, speaking, and sneezing carried bacteria 12.4 m (40 ft).<sup>12</sup> The measurements were the maximum lengths permitted by the 2 rooms where the experiments were conducted.<sup>12</sup> These demonstrations may be germane. From these very old reports, the distinction between respiratory droplets and aerosols may be more apparent than real. As a respiratory droplet falls to the ground, the aqueous portion quickly evaporates, but the bacterial or viral portion remains. Theoretically, a viral particle, if it remains viable, could be carried by wind or reaerosolized by ground disturbances.

Whether contagious as a respiratory droplet, aerosol, or both, there have been no controlled studies to investigate the efficacy of respirators in preventing the transmission of influenza A.<sup>13</sup> Moreover, whereas respirators could be critical in mitigating a pandemic, several factors may adversely impact the feasibility of their use.

## Penetration

The filtering mechanism of the respirator is the face piece. N-95 masks are so named because they are rated to block 95% of particulate aerosols from penetrating the mask. The particulate aerosols that N-95 (and N-100) masks have been tested against are uncharged sodium chloride particles, 0.3 µm in size. The rationale for testing against particles of this specific size is that particles at this diameter traditionally have been deemed the most penetrating through the filter.<sup>2</sup> That assumption, however, appears to be mistaken. A recent report asserts that it is particles in the 40- to 50-nm range that are the most penetrating through N-95 respirators, resulting in 94% protection at an inhalation rate of 85 L/min of air.<sup>5</sup>

Although the extremely high filtration rates used in grading the respirators exaggerate the stress that, in normal use, would be placed on the filter, there is a theoretical problem in the logic underlying N-95 respirators. Assume an N-95 mask functions better than its rating and at a sedentary inhalation rate blocks 98% of the bioaerosols that it is confronted with. We are still left with the 2% that penetrate

through the filter, to be inhaled by the wearer. Whether discussing tuberculosis, influenza, measles, or smallpox, we do not know the concentration of pathogenic bioaerosols in the environment, nor do we know the minimum infectious dose for these pathogens.

As such, the N-100 respirator, which is 99.999% effective, is probably a more prudent protective device. The retail cost, however, is roughly 10 times that of an N-95 respirator.

## Leakage

The aforementioned efficacy for respirators is idealized. The measurements on which these gradings were based were made on mannequins, with an impermeable seal applied between the mask and the mannequins face. Reality is quite different. Leakage, even when the mask has been fit tested to the wearer's face, occurs around the edges of the mask.<sup>1</sup>

In an attempt to accomplish a tight seal, fit testing is required in the health care setting. This testing uses trained technicians to administer solutions such as saccharin, isoamyl acetate ("banana oil"), or denatonium benzoate (Bitrex). The presence of sensation (taste, irritation, or smell) demonstrates the lack of an effective seal.

Total penetration (direct penetration through the N-95 filter and around the margin of the face) was measured in 25 human participants for 21 different models of N-95 respirators. In the absence of successful fit testing, exposure to airborne particles was reduced, on average, to only 33% of the ambient level.<sup>14</sup> With successful fit testing, the average exposure was 4% of the ambient level.<sup>14</sup>

Per National Institute for Occupational Safety and Health standards, the net expected level of protection afforded by a successfully fit tested N-95 respirator is one where the concentration of airborne contaminants inside the respirator (i.e., between the mask and face) is less than or equal to 10% of ambient levels.<sup>14</sup> Implicit in that standard is the supposition that this level of leakage is inconsequential; we can find no data to support that assumption.

Fit testing is time consuming, and in the health care setting, requires a technician. The test typically involves molding the mask until a seal is accomplished. Coffey et al<sup>15</sup> found that most persons cannot be adequately fit tested to commercially available N-95 respirators.

Furthermore, it is uncertain if the utility of fit testing extends to beyond a single use. We could find no measurement of filtering efficacy with removal and immediate reapplication of the respirator, nor were we able to find any data to support the supposition that fit testing in 1 model of mask carries over into other masks of the same make and model. We also were unable to find assessments of efficacy after sustained use. The face is not a static surface; for example, motion of the jaw from swallowing, facial grimacing, or talking likely alters the seal. Even if all of these variables are negligible, there is still the effect of gravity pulling down on the mask.

There are 2 possible options that may correct for leakage through an incomplete seal. A disposable N-100 moldable respirator has been developed with an adhesive seal.<sup>16</sup> It claims (unpublished) a filtration efficacy of more than 99.9% and a penetration of less than 0.05% at 30 L/min for particles at 0.3  $\mu\text{m}$ .<sup>16</sup> The cost has not been disclosed.

An obvious solution to the leakage problem would be to coat the mask margin and facial skin interface of an N-95 or N-100 respirator with a gel, paste, or substance such as petroleum jelly or cosmetic cold cream. The efficacy of this measure has not been tested nor has the duration of the seal and effect of sweat and so forth been explored.

## Disposability

Assuming a competent seal, N-95 and N-100 respirators can intercept viruses during inhalation. However, they are disposable and are rated to be used only once. An adequate supply in the presence of a pandemic, therefore, is problematic. In Taiwan, during the SARS scare, N-95 masks, which should retail for no more 85 cents a piece, were going for US \$20.<sup>17</sup>

To extend the supply, several questions must be answered. How long can these masks be worn and still remain effective?<sup>1</sup> With time, moisture buildup causes significant breathing resistance. Can these masks be resterilized? For instance, would placing the mask in a microwave kill viruses on the mask without denaturing the mask? Would bleach work? The risk of contact transmission from handling a contaminated, virus-laden mask would appear to be the same for removing the mask for disposal alone or for resterilization. There is little financial incentive, however, for respirator manufacturers to establish reusability for these products, and there is a legal disincentive, in terms of potential liability.<sup>1</sup> Indications from manufacturers are that face masks are likely to degrade with attempted sterilization.<sup>1</sup> Unfortunately, face masks are seen as a mundane topic and have attracted little academic interest.

A solution to the problem of inadequate supply and inadequate seals could be reusable respirators. These elastomeric devices have face pieces that can be cleaned and reused, and the National Academy of Sciences has posited they might be preferable for stockpiling over N-95 respirators.<sup>1</sup> The retail cost is US \$7.50. Their filter media, a replaceable cartridge, blocks 98% of particulate aerosols from penetrating.<sup>18</sup> The cartridge, when no longer suitable for use, is not rated to be cleaned or decontaminated,<sup>1</sup> but this has not been studied. The wearer can easily perform a fit check before each use, by inhaling and exhaling, while blocking, with his or her palms, the inhalation and exhalation ports, respectively.<sup>2</sup> A practical goal would be to produce a filtering capability in the cartridge for an elastomeric frame that matches that of the N-100 respirator and devise a mechanism to resterilize that cartridge.

There are problems that limit the utility of face masks. The masks are uncomfortable, particularly in warm weather, and may be impossible to wear for people with chronic lung disease. Eating and drinking require removal of the mask. Most importantly, masks are not produced for children, and if they were, children would likely not keep them on.

Nonetheless, competent masks could prove vital in the control of a pandemic that overwhelms our health care system and paralyzes our cities. Availability of masks might allow some measure of confidence for essential services to continue. Masks have an indefinite shelf life and could be pivotal in responding to a potential bioengineered microbial event, such as smallpox and tularemia. Ensuring an adequate, readily available supply of masks is critical.

## EYE PROTECTION

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A generally overlooked possible portal of entry is the conjunctiva. Such a portal is reported for some strains of influenza,<sup>19</sup> and the H7N7 virus, in particular, caused many cases of conjunctivitis in humans.<sup>20</sup> It is postulated that this mode of entry may also be operative in some cases of smallpox.<sup>21</sup> It is unclear whether the conjunctivitis is a consequence of aerosolized viral particles landing on the ocular surface or a consequence of transfer via the hands or fomites. If the conjunctiva is a significant portal of entry for influenza A, suction-type swimming goggles might be a prudent measure to prevent transmission of disease.

## FOMITES

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It is unknown whether influenza A is also transmitted by fomites, but there is supporting evidence for this premise.<sup>13</sup> Influenza A was found on a wide range of fomites in homes and day care centers.<sup>22</sup> The virus survives for up to 48 hours on hard nonporous surfaces (stainless steel and plastic) and for

less than 8 to 12 hours on cloth and tissues.<sup>23</sup> Whether disinfection of surfaces (such as doorknobs) would prove beneficial or futile has not been studied.

## UV LIGHT

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Wells, working with *Escherichia coli*, discovered that UV light can sterilize infectious aerosols.<sup>24</sup> UV light is electromagnetic radiation with a wavelength shorter than that of visible light. UV light is categorized as consisting of 3 wavelength bands, each of which has different properties. Ninety-nine percent of the UV light that reaches the earth's surface is UV-A (400–320 nm). UV-B (320–290 nm) is responsible for skin tanning and sunburn and with long exposure may cause skin malignancies and cataracts.<sup>24</sup> UV-C (290–100 nm) has the highest energy of the UV light bands.<sup>24</sup> The primary germicidal range for UV light is 260 to 254 nm, which is within the UV-C band. The theory behind use of UV light to disinfect air is that respiratory infections may be spread by suspended aerosols.

Unlike the outdoor atmosphere, where aerosols are rapidly diluted, aerosols may remain suspended and, in relative high concentration, trapped within the air of enclosed buildings for long periods of time. To apply UV irradiation in rooms, UV fixtures have been suspended from walls or ceilings and directed horizontally to irradiate only the air above head level, that is, above 6.5 ft. Such fixtures do not expose occupants to UV light. The upper and lower air mixes because of convection currents related to temperature gradients. Even without fans, there is a complete air exchange between the upper and lower air within rooms at a rate of 95 times per hour.<sup>25</sup> The germicidal effect of UV light, however, diminishes at humidities greater than 70% and is low at humidities greater than 80%.<sup>27</sup> Technical aspects have been described elsewhere.<sup>27:28</sup>

Several studies were undertaken in the 1940s to test the use of UV light in preventing airborne respiratory infections, with 1 positive study and 3 negative studies. The positive study involved a measles outbreak at a rural school system.<sup>29</sup> The negative studies involved schools and communities where there was much intermingling outside the UV irradiated area and where the majority of the day was spent without exposure to a UV-C-treated environment.<sup>30–32</sup>

Supporters of UV irradiation argue that UV can be expected to work only at the site where it is applied, and thus, is practical only for those who will be largely confined to a single site, such as hospital and nursing home patients.<sup>24</sup> There is some evidence to support this position. McClean, in 1957, installed UV lights in the main building of the Livermore (Calif) Veterans Affairs Hospital.<sup>33</sup> Of 209 patients in that building, the incidence of influenza was 2%. In comparison, in 396 patients living in neighboring, unirradiated control buildings, the incidence was 19%.

Although the practical clinical use of UV light as a means for disinfecting the air of respiratory viruses and bacteria is uncertain, the virucidal and bactericidal action, per se, is not in dispute. In vitro studies clearly demonstrate UV light to inactivate 99.99% of influenza virus aerosols.<sup>34</sup> UV irradiation is used commercially in wastewater and drinking water treatment<sup>35</sup> and is used to pasteurize fruit juices. Mercury vapor lamps emitting UV-C are routinely used to sterilize work areas and equipment in medical facilities and laboratories. UV-C has been found to be effective in sterilizing blood products.<sup>36</sup> The application of UV light as a bioterrorism defense has been raised elsewhere.<sup>37</sup>

The energy required for germicidal action, as well as adverse effects, is a product of radiation intensity and time. A few seconds of high-intensity radiation, or several hours of low-intensity radiation, may produce the same net amount of radiation and germicidal action.<sup>38</sup> Flooding a room above a height of 6.5 ft with high-intensity UV radiation has been found to keep skin and eye exposure well within the safety range.<sup>39</sup>

At germicidal UV wavelengths, adjacent thymine bases dimerize, rendering viral or bacterial DNA and RNA incapable of replication.<sup>40</sup> Germicidal lamps typically emit UV-C at  $16\,000\ \mu\text{W s/cm}^2$ .<sup>41</sup> Solar UV-C is held to be completely absorbed by the atmosphere's ozone and does not reach the earth's surface.<sup>42,43</sup> Recent evidence, however, demonstrates that UV-C does, in fact, penetrate through the atmosphere to sea level, at an intensity of  $.004\ \mu\text{W s/cm}^2$  ( $2.4 \times 10^{-7}\ \text{J/cm}^2$  over 60 s).<sup>44</sup>

It has long been a puzzle why, in temperate climates, influenza occurs in epidemics only in the winter months,<sup>45</sup> why epidemics cease before all those susceptible have been infected, and why influenza outbreaks have occurred simultaneously in geographic sites great distances from each other, where direct contact between those sites was not possible.<sup>3</sup> The mystery has been such that 1 reputable journal has published a theory arguing for viruses from space, via cosmic dust, as being responsible for influenza epidemics.<sup>46</sup>

The very minute amount of UV-C reaching the ground is likely insufficient to have a deleterious action on viral DNA and probably does not account for the seasonal occurrence of epidemics in the temperate climates. UV-B also has antiviral activity—much weaker than UV-C—but makes up 1% of the light spectrum that penetrates the earth's atmosphere. As such, it is exponentially more abundant than UV-C at ground level, by 6 orders of magnitude. A decrease in UV-B levels (from air pollution) has been theorized to be a factor in the avian influenza epidemic.<sup>47</sup>

Even if fully effective in rapidly sterilizing irradiated air, UV-C is no panacea. There is a time lag for complete air exchange to occur in treated rooms, albeit of less than 1 minute, and a single cough from an infected individual resets the time clock. That delay could be a window of opportunity for transmission of the virus.

## CONCLUSIONS

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The modalities proposed in this article, face masks and UV-C light, are clearly an inferior strategy compared with an effective vaccine and antiviral agents for influenza A. What is offered here is a plan B, should plan A fail. The tactic proposed is one of “block and burn”—masks to block and UV irradiation to burn the viral pathogen. The focus is on attacking the virus in the environment, rather than in the patient.

These measures may work, but supporting clinical data are limited. Further studies, however, should not be difficult or particularly expensive to carry out. For instance, vis-à-vis disposable masks, the same techniques used in routine fit testing could be undertaken for masks in which the margin is coated with a gel. A positive result, compared with uncoated controls, would provide presumptive validation for the strategy. In high-risk situations (e.g., entering the room of a patient with cavitary tuberculosis), such an application is likely warranted even without supporting data. Unless one speculates that application of petroleum jelly may denature the mask or cause slippage, there is little reason not to attempt to seal the leak. As for a possible pandemic, as noted earlier, disposable masks would soon be in short supply. Reusable elastomeric masks are likely a wiser strategy and should be stockpiled in sufficient number to allow for distribution to health care and other essential workers.

UV light also warrants reexamination. Disregarding the prospect of avian flu transforming into a 1918-style pandemic and disregarding the specter of a deliberately bioengineered influenza virus,<sup>48</sup> we still have the near certainty of annual flu epidemics that result in a yearly average of 36 000 deaths in the US alone.<sup>1</sup> The effectiveness of influenza vaccine varies from year to year, predicated on the degree of antigenic similarity between the vaccine and the circulating virus. Even if well matched, effectiveness is incomplete. Among the elderly in nursing homes, “vaccine can be 50–60% effective in preventing influenza related hospitalization, and 80% effective in preventing death, although the effectiveness in

preventing influenza illness ranges from 30% to 40%”.<sup>49</sup> Installation of UV lights in nursing homes and hospitals could be a significant adjunct. It should not be difficult to install UV lights in such situations and to compare the incidence of influenza to controls.

The modalities discussed here, face masks and UV light, have been largely overlooked. They are modest and far from the cutting edge of science. Nonetheless, they offer the potential of mitigating a potentially uncontrollable pandemic. It is our hope that this brief review stimulates research interest and draws the attention of policymakers to allow for wider implementation of their use as public health measures.

## Acknowledgments

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The authors thank Joan B. Goode, Jonathan Schwartz, Gerd Eckstein, PhD, Aysel Gezik, Jacqueline Bowles, MD, Giulia Michelini, MD, Wendell Ching, MD, Arthur Gomez, MD, Sami Zakzook, MD, Diane Suzuki, MD, Eric Cheng, MD, Jitendra Kuckreja, PA-C, Ronald Tomas, MD, Rumi Cader, MD, and Shirley Oles.

**Human Participant Protection** No approval was required.

## Notes

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Peer Reviewed

**Contributors** All authors contributed to the writing of this article.

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