Ultraviolet light and indoor air disinfection to fight pandemics: A technology long overdue

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This is the first of a two-part article. Part two can be read here.

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"We appeal to the medical community and to the relevant national and international bodies to recognize the potential for airborne spread of coronavirus disease 2019 (COVID-19). There is significant potential for inhalation exposure to viruses in microscopic respiratory droplets (microdroplets) at short to medium distances (up to several meters, or room scale), and we are advocating for the use of preventive measures to mitigate this route of airborne transmission."

— Letter to the World Health Organization by 239 scientists, July 6, 2020

Among the greatest failures, indeed crimes, of the COVID-19 pandemic, has been the coverup and distortion of the science of airborne transmission, the way in which SARS-CoV-2 spreads from person to person. As the fourth year of the pandemic begins, the vast majority of the world's population has virtually no understanding of this science and what measures must be taken to prevent viral transmission.

Implicated in this coverup are the World Health Organization (WHO), the US Centers for Disease Control and Prevention (CDC) and other public health agencies and governments throughout the world.

The principled stand taken by scientists like Drs. Jose-Luis Jimenez, Lidia Morawska, Donald Milton, Linsey Marr and their colleagues early in the pandemic to place front and center the issue of airborne transmission went unheeded by the world's top public health officials, as well as governments and corporations.

Instead, all of these institutions and their leaders have prioritized corporate profits over the health of society, rejecting the necessary public health measures and renovations to infrastructure that could dramatically slow and ultimately stop viral transmission globally.

While lip service on the role of airborne transmission has recently been given by figures such as White House COVID Response Coordinator Dr. Ashish Jha, no effort has been made to use the vast resources at their disposal to educate the public on this science. Concretely, nothing has been done to actually improve indoor air quality in the vast majority of public spaces.

Clearly acknowledging and educating society on the science of airborne transmission of not only COVID-19, but all respiratory pathogens, would require governments and businesses to clean the air in indoor spaces in order to protect the public.

The global burden of disease from respiratory pathogens

The need to address indoor air sanitization is, perhaps, the single most important public health concern in the modern era. It is as crucial as when Dr. John Snow recognized the cholera epidemic that was killing tens of thousands of English working class people in the mid-1800s was not a product of "miasma in the atmosphere," but simply of drinking contaminated water. It would take another 30 years before German physician Dr. Robert Koch isolated the bacterium *Vibrio cholerae* in 1883, proving Dr. Snow's theoretical and epidemiological work sound.

The overwhelming evidence and the consequent public health drive to address the threat posed by cholera meant that by the late 19th century, cholera epidemics came to an end in European and US cities, once water supply sanitation was improved. Yet, more than 140 years after Dr. Koch's discovery, unsafe water sources continue to kill 1.2 million people each year, especially in the poorest regions of the world, where they account for 6 percent of all deaths. This underscores the persistent and deep inequities that exist under capitalism.

With regards to respiratory viruses, the transmission of infectious viral particles via aerosols was not a new discovery during the COVID-19 pandemic. Decades of work by scientists internationally had repeatedly confirmed these modes of transmission for respiratory pathogens, such as tuberculosis, measles and SARS-CoV-1. In particular, just before the COVID-19 pandemic, numerous studies were published on the airborne transmission of influenza viruses.

Besides the more than 20 million excess deaths attributable to COVID-19 thus far, acute respiratory infections are among the three main causes of deaths and disability worldwide, accounting for nearly 4 million deaths per year. Most are caused by viruses such as RSV, influenza, rhinovirus and adenoviruses. These figures do not even begin to capture the deleterious impact of epidemics on health systems, as is currently occurring in crowded US emergency departments, ICUs and hospitals as a whole.

Pulmonary diseases caused by infectious pathogens and air pollution are further exacerbated by these same system failures in a vicious cycle.

Nearly 200 million people (4 percent of the global population) have chronic obstructive pulmonary disease, which kills roughly 3.2 million people each year. Asthma affects 350 million people and is the most common chronic disease of children. Pneumonia (a bacterial respiratory disease) kills 2.4 million each year and is the leading cause of deaths in those under the age of five and over 65. Additionally, 10 million people develop tuberculosis and 1.4 million die each year, second only to COVID-19 as the leading cause of infectious disease in 2021.

Early on in the COVID-19 pandemic, it was recognized that superspreader events occurred indoors in under-ventilated spaces, a hallmark of an airborne pathogen. Given the evidence that was available before and early on in the course of the pandemic, there was an urgent need to protect the population through innovations that could keep indoor spaces safe from airborne transmission.

An estimated 90 percent of a person's life is spent indoors. This means that the technology to ensure that hospitals, schools, factories and all public spaces are free of pathogens is necessary to secure the health and longevity of the population.

Ensuring occupied spaces are pathogen-free is crucial in efforts to eliminate COVID-19 and any future pandemic pathogen, as well as those that have been labeled as the common cold and flu viruses that sicken so many each year. Every knowledgeable scientist has said that there is no question about *if* another pandemic will occur, but *when*. Renovating indoor air infrastructure will be crucial to an elimination strategy and to protecting the lives of the population, present and future.

Vaccines and therapeutics aid in reducing the risks of developing severe and life-threatening disease should someone become infected. Though important adjuncts for a comprehensive approach, they are not preventive measures.

Respirators like N95s are also critical, but should serve as secondary layers of protection. The use of passive systems that do not rely on "personal initiative" have great value, and ensuring the continuous elimination of pathogens within enclosed spaces would be ideal. Throughout the world, air filtration and ventilation systems must be modernized and fitted with high-efficiency particulate air (HEPA) filters.

One of the most powerful "passive" technologies available, which has been almost entirely ignored throughout the pandemic, is far-ultraviolet (UV) irradiation, which can disinfect and inactivate pathogens on surfaces, as well as in water and in the air. This report will review the more than 100-year history of scientific research and real-world experience with the use of UV irradiation.

The history of ultraviolet light and infection control

Ultraviolet (UV) light ["beyond violet," the highest frequency of visible light] is a form of electromagnetic (EM) radiation, just below the visible light spectrum encompassing wavelengths from 10 nanometers (nm) to 400 nm. The UV radiation spectrum is divided into three main regions, termed UVA (315-400 nm), UVB (280-315 nm) and UVC (100-280 nm). Solar radiation, the light from the sun, encompasses three components of the electromagnetic spectrum: infrared, visible light and UV. When sunlight enters the atmosphere, all the UVC and most UVB is absorbed by the ozone, water, carbon dioxide and water vapor.

UVA accounts for approximately 95 percent of the UV radiation that reaches the Earth's surface. It is the cause of the initial tanning effect and burning associated with sun exposure, as well as skin aging and wrinkling, and studies indicate it can be a factor in developing skin cancer. Although UVB also has a physiological effect, it only penetrates the superficial skin layers and is responsible for delayed tanning and skin burns from too much sun exposure. Like UVA, it also speeds up the aging of our skin and can cause changes in the regenerative basal skin cells that lead to cancer.

Parts of the UVC spectrum are the most damaging type of UV radiation, but because it is completely filtered in the atmosphere, these light rays never reach the surface. Mercury lamps generate conventional germicidal UV (250 to 280 nm) and are placed in ceilings in conjunction with ventilation, as biophysical and experimental evidence suggests direct exposure to them can be hazardous.

UVC of 200-230 nm wavelengths can be generated by so-called "excimer lamps" that use simple molecules composed of only two atoms ("dimers" in chemistry). The formation of "excited dimers" produces a photon of UV light at a particular wavelength. For instance, a Krypton and Chlorine excimer lamp emits a 222 nm wavelength photon while a Krypton-Bromine lamp will generate a photon of 207 nm wavelength.

Interestingly, light in this narrow range of 200 to 230 nm has the potential to offer tremendous capacity to disinfect surfaces and spaces of viruses and bacteria while being safe to people exposed to it. Evidence for the safety of this range of UVC has been mounting for the last two decades. In particular, work done by Russian and Dutch scientists in early 2000 with short wavelength UVC (206 nm) and wound decontamination spurred the work by Manuela Buonanno, David Welch, David Brenner and colleagues at the Center for Radiological Research at Columbia University Medical Center in New York to begin examining the potential for such technology, leading them to coin the term "Far UVC" for this range of wavelengths.

UV technology, however, has been around for more than 100 years. The German chemist and physicist Johann Wilhelm Ritter made the first observation of ultraviolet radiation in 1801. After hearing about William Herschel's discovery of infrared radiation ("heat rays") in 1800, Ritter looked for its opposite, "cooling" radiation, at the other end of the visible spectrum. During his experiments, he noted that photographic paper impregnated with silver chloride transformed from white to black faster at the violet end of sunlight. He called these "chemical rays" ultraviolet radiation.

His work led to developing the first electrochemical cell, the dry cell battery, and the development of a storage battery. Ritter died in poverty and weakened health, most likely secondary to exposure to the chemicals he used in his experiments, in 1810, at the age of 36.

In the late 1870s, Arthur Downes and Thomas P. Blunt published a report in the scientific journal *Nature* about the antibacterial effects of the shorter wavelengths of sunlight. They placed solution-filled test tubes in sunlight and found it prevented the development of pathogenic bacteria. Soon after, they proved that the UV portions of light had germicidal properties.

Twenty-five years later, in 1902, the German ophthalmologist Ernst Hertel, building on the work done by his predecessors, determined that UVC light, rather than UVA or UVB, was most effective at killing microorganisms. Niels Ryberg Finsen, a Faroese-Icelandic physician and scientist, received the Nobel Prize in medicine in 1903 for his work on treating lupus vulgaris, a tuberculosis skin lesion, with concentrated light radiation.

As early as 1908, the city of Marseille, France used UVC to disinfect water supplies using mercury lamps that were known to emit ultraviolet light. By 1928, the ultraviolet irradiation of milk was introduced along with the disinfection of fruits and vegetables.

Fredrick L .Gates, working at the laboratories of the Rockefeller Institute for Medical Research in New York, investigated the use of mercury lamps against Staphylococcus aureus and Bacillus coli bacteria, varying the wavelengths used. He demonstrated that the "incident energy required to kill… the exposed" bacteria was most effective at the 265 nm wavelength. He also found that this wavelength corresponded to the absorption spectrum of nucleic acids, the genetic molecules of life, hinting at the idea that these were the targets that made UV at these wavelengths efficient disinfectants. At the time, DNA was yet to be discovered and its role in the process of life remained unknown.

A decade later, in 1944, Alexander Hollaender and John W. Oliphant, working at the Industrial Hygiene Research Laboratory and Division of Infectious Diseases at the National Institute of Health, continued Gates' work. They speculated, "It is quite possible that the high sensitivity of many agents at about 260 nm is based on the important function deoxyribose nucleic acid [DNA] plays in biological activities." The comprehension of the biological mechanism for UVC's action was a critical insight in utilizing it for its germicidal properties.

However, it was the contributions by American scientist and Harvard sanitary engineer Professor William Firth Wells (a World War I veteran) and his wife, Dr. Mildred Wells, that were the essential components in the understanding of the airborne nature of respiratory pathogens and the utility of UV light in disinfecting enclosed spaces.

The pioneering research of William and Mildred Wells

"The experiments described in this paper were undertaken in the fall of 1937, as a test of the hypothesis that the confined atmospheres of our habitations constitute the vehicle for the epidemic spread of contagion. Even though endemic incidence (person-to-person type of spread) may be due to any one of several modes of spread such as physical contact, direct hits by Flügge droplets [large-respiratory droplets], or air, the phenomenon of epidemic contagion (the dynamic network of person-to-group infection) is indicative of spread through the medium of a common source: air. If epidemic respiratory contagion can be controlled by radiant disinfection of air, then air must be such a vehicle of spread."

—Professor William F. Wells, Harvard Sanitary Engineer, 1942 study, "The Environmental Control of Epidemic Contagion"

Wells' work proceeded from that of German bacteriologist Carl Flügge, who showed that microorganisms expelled from the respiratory tract as droplets were essential for disease transmission.

In 1910, just two decades after the germ theory of disease had been recognized and accepted, American epidemiologist Charles Chapin wrote his seminal book, *The Sources and Modes of Infection.* Chapin's success with infection prevention led to conceptualizing "contact infection" as the primary source of transmission of disease. As Professor Jose Luis Jimenez and colleagues recently wrote, "He [Chapin] would go on to conflate close proximity with the actual mechanism of transmission, engendering a confusion that would muddy understanding for decades."

In 1934, in opposition to the erroneous conception of the droplet/contact transmission of respiratory pathogens put forth by Chapin, Wells noted:

> It would be incorrect to conclude [...] that air receiving infected droplets cannot convey such infections long distances. To do so would be to neglect a most important characteristic of liquid droplets, namely their tendency to evaporate. Evaporation causes the volume of water droplets to change, and this change becomes more rapid as the droplet decreases in size.

Wells hypothesized that these very small "droplet nuclei," what he called "aerosols," dried before they reached the ground and could remain in the air for an extended time, causing others to breathe them in. His theory of "droplet nuclei," as Nicholas Reed wrote in his 2010 article on the history of ultraviolet germicidal irradiation (UVGI) for air disinfection, "had been sparked by investigations into respiratory infections associated with dust-suppressive water sprays used in New England textile mills." The COVID-19 pandemic and the controversy surrounding the airborne nature of SARS-CoV-2 transmission has largely vindicated Wells' work posthumously.

The intersection of Wells' work on the mode of transmission of respiratory infections and the advancements being made in the use of UV radiation for disinfection was a critical milestone in public health and the understanding of the modes of disease transmission on a conscious level. But it failed to garner the critical mass in terms of influencing the powers that be and bringing the science forward and accepted on a social scale. History, however, always returns to these moments when the contradictions and fallacies that remain once again rear their head.

Indeed, Wells suspected that tuberculosis and measles were airborne, later proven to be correct. In 1935, he aerosolized the bacteria B. coli and exposed the organisms to UVC at 254 nm, demonstrating they could be effectively killed in a short time. In a manner, the experiment proved both the ability to convey the airborne character of pathogens and the utility of UV radiation to inactivate them.

In 1936, Dr. Deryl Hart used UVGI to disinfect hospital operating theaters at Duke University Hospital, resulting in a massive drop in postoperative infection rates from 11.6 percent to 0.24 percent. It is noteworthy that by the 1930s, Westinghouse Electric moved quickly, utilizing the talents of its research and development engineers, to create the first patented and commercially available UV lamps for use in health care settings.

This was a remarkable feat for its time as antibiotics were just being developed and hospital-acquired infections were oftentimes a grave prognosis. Even in the modern era of antibiotics, close to 2 million Americans develop such infections, and close to 100,000 die every year. Beside being among the top five killers in the US, they also lead to unnecessary annual costs of $28 to $45 billion. In emerging economies, such infection rates are three to 20 times higher than in Western countries.

Perhaps the most important work conducted by Wells, his wife and collaborator T. S. Wilder was an experiment conducted at Germantown Friends School (four years) and public schools of Swarthmore (one year), both in Pennsylvania, from 1937 to 1941.

Ultraviolet lights were installed in the ceilings of each of the four grades of the primary department, as well as the music room library, nature room, halls, lunchroom, restrooms and gymnasium. There were no ventilation systems other than windows. Air flow to the upper part of the rooms occurred through natural convection currents. The higher grades acted as controls and did not have UV lights in their classrooms, but did share common spaces. Details of rates of measles, mumps and chickenpox in the years before the experiment and during the study were available to the researchers and chosen as indices for review.

Remarkably, the primary classes with UV lights showed both a blunting and reduction of measles infections when compared to the upper classes. At the time, measles was the most infectious respiratory virus known. Likewise, the incidence of mumps and chickenpox was considerably reduced in the primary classrooms.

Wells and colleagues also remarked that in rural areas, schools acted as vectors for such infections, where susceptible children became infected while in class and then brought the disease home. In urban centers the larger opportunity for multiple exposures meant a more random pattern of infections. They highlighted that epidemic controls in schools alone in urban settings would be difficult but still important to consider.

Wells et al. added, "Incidence in diseases to which exposures are multiple within and without the school becomes a measure of susceptibility rather than exposure, and prevention will become manifest only when the last source of infection is eliminated." They pointed to the benefits of preventing childhood infections, especially in poorer districts where mortality is high.

Most importantly, the authors concluded:

> The results obtained in the experiments described here lend support to this hypothesis [the spread of epidemic contagion through the medium of confined atmospheres], and point to the immediate application of methods described to prevent the occurrence of contagious diseases [by radiant disinfection of air] …

Part two of this article can be read here.