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News & Highlights

Ultraviolet Light Fights New Virus

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In the fight against the coronavirus disease 2019 (COVID-19) pandemic, an old weapon has re-emerged [1]. More than a century after Niels Finsen won the 1903 Nobel Prize for discovering that ultraviolet (UV) light could kill germs [2], UV light is surging in popularity as a method for disinfecting hospital rooms and other public spaces.

"Pathogens have evolved, but our tools to clean the environment have not," said Mark Stibich, chief science officer and co-founder of San Antonio, TX-based Xenex. "We need a new tool to fight them, not just a mop and bucket."

Xenex's disinfecting robot, called LightStrike (Fig. 1), can kill 99.99% of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in 2 min at a distance of 1 m [3]. UV light will not replace the mop and bucket, but it complements chemical disinfectants by targeting germs in a proven and different way.

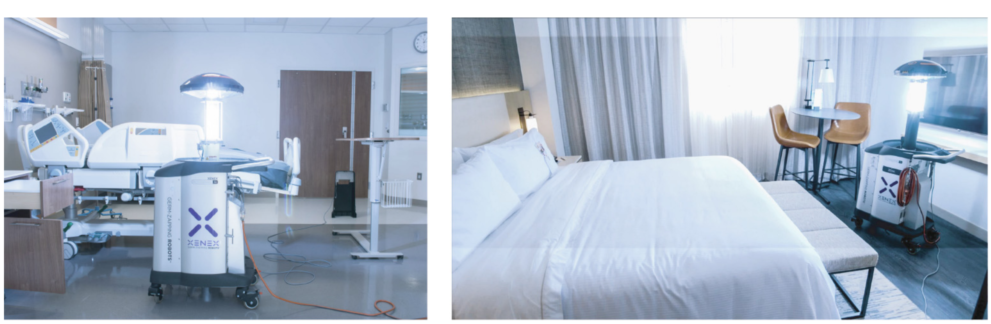
Xenex is one of at least 30 companies making UV disinfection equipment. And not just for hospitals. Another company, Dimer UVC Innovations of Los Angeles, CA, USA, markets a cart with UV lamps, called GermFalcon (Fig. 2), that it claims can disinfect a whole airplane in 3 min [4]. UV light is also being used to disinfect and re-use hospital face masks [5].

UV light is generally divided into three classes, based on the wavelength of the light. All of them are invisible to the human eye. The longest wavelengths are UVA (315–400 nm) and UVB (280–315 nm), which are found in ordinary sunlight. These are the rays that can cause sunburn if one stays outside too long without protection. UVA and UVB light rays have limited germ-killing ability because viruses and bacteria have had millions of years to adapt to them.

But UVC light (200–280 nm) is completely absorbed by our atmosphere and never reaches the surface of the earth [6]. Therefore, UVC light is just as novel to SARS-CoV-2 as the virus is to humans. According to the International Ultraviolet Association, it is generally accepted that a dose of 40 $mJ\cdot cm^{-2}$ of 254 nm light will kill at least 99.99% of "any pathogenic microorganism" [6,7].

At present there are many different designs for UV disinfection systems. Some systems consist of just a bare lightbulb and a timer, while others are mobile robots that can reach hard-to-access places [8]. Two of the major design choices are the wavelength of light and the method of delivery. By far the most common wavelength for germicidal light is 254 nm, produced by low-pressure mercury lamps. These lamps are easy and cheap to manufacture because they use essentially the same technology as a fluorescent light bulb. A fluorescent bulb actually produces UV light inside the bulb. But the phosphor deposited on the glass surface of the bulb absorbs that light and re-emits it at longer wavelengths that humans can see. To make a UV lamp, the glass is replaced with a material transparent to UV light, such as fused quartz.

However, 254 nm may not be the optimal wavelength for killing all viruses. Experts believe that different wavelengths disable viruses in different ways [9,10]. The 254 nm light damages the viral deoxyribonucleic acid (DNA) or ribonucleic acid (RNA) so that the



(a) (b)

Fig. 1. The Xenex LightStrike, shown here set up inside (a) a hospital room and (b) a hotel room, is stationary during use, but the "head" moves up and down, and its xenon lamp pulses many times a second with UV light that spans the spectrum from 200 to 315 nm. Credit: Xenex, with permission.

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Fig. 2. The GermFalcon is a UV disinfection device that can be wheeled up and down an airplane aisle. It requires an operator, who is protected by a UV light shield, to push it. Credit: Dimer UVC Innovations, with permission.

virus cannot reproduce. Shorter wavelengths, like 207–222 nm (sometimes called "far UVC") are believed to damage the proteins on the surface of the virus that it needs to attach to human cells. Thus, the curve that describes the viral killing ability of UVC light has a double-humped shape, with a peak at shorter wavelengths and another around 265 nm.

The Xenex system is designed to take advantage of both virus-killing methods, by producing light from a pulsed xenon source that spans the whole spectrum from 200 to 315 nm. Because xenon is an inert gas, xenon-stimulated bulbs can be disposed of more easily than ones containing toxic mercury. According to the company, more than 500 healthcare facilities around the world are currently using Xenex robots for whole-room disinfection.

Disinfection with far-UVC lamps remains largely experimental but could have an intrinsic advantage. Initial evidence suggests that far-UVC light does not penetrate beyond the outer dead layer of skin cells or the liquid film on eyes in healthy people [10,11]. Thus, it cannot cause skin cancer or cataracts, like UVA and UVB. It also seems not to cause temporary skin burns and eye damage ("welder's flash") like standard UVC. This presumably depends on the intensity of exposure; whether intense exposure to destroy pathogens on the hands, for example, would be safe is unknown.

However, doctors may need some convincing to accept that some kinds of UV light may be safe to human eyes. "I would like to see more research on longer term exposure before I am convinced," said Karl Linden, a professor of environmental engineering at the University of Colorado in Boulder, CO, USA. If it can be proven safe at the incidental exposure involved, far UVC light might prove ideal for disinfecting spaces that always have people in them, like a 24-hour market; they could perhaps also be used to provide constant disinfection in hospitals.

No matter what wavelength is used, germicidal light has another problem to overcome: If a surface is in shadow, it will not be disinfected. Shadows abound in a typical hospital room, with multiple surfaces and objects that jut out at odd angles from the floor, walls, and ceiling. In one recently published study, when a standard UVC lamp was placed in the center of the room and operated according to the manufacturer's instructions, some places like the wardrobe and the sink were partly or completely in shadow, and did not receive the full dose of 40 $mJ \cdot cm^{-2}$ needed to assure 99.99% disinfection [12].

For this reason, many systems have to be moved to a few different places to thoroughly disinfect a room with UVC light. This means a housekeeper has to enter the room, position the lamps, leave the room, turn them on for 5 min or so, then re-enter the room, reposition the device, and so on. It is a laborious process. To address this shortcoming, UVD Robots, a company based in Odense, Denmark, has developed a UV system that moves around the room autonomously, eliminating the need for manual repositioning. According to a UVD Robots spokesperson, the company recently sold "a three-digit number" of their robots to Sunay Healthcare Supply (also in Odense) for use in China, and these robots are now available to 2000 Chinese hospitals [8]. The company says its robots are being used in more than 50 countries in all six inhabited continents.

If UV disinfection is so good, why has it taken so long to be embraced by hospitals, and why is it virtually unknown to other businesses (outside of wastewater treatment, where it has been used for decades)? It has a lot to do with human perceptions, said Edward Nardell, a professor of environmental health, immunology, and infectious diseases at the Harvard T.H. Chan School of Public Health in Cambridge, MA, USA. "The first barrier is fear. Everyone has heard doctors say that we should not be exposed to too much UV. That UVC penetrates skin and eyes poorly is too nuanced a difference. Lack of familiarity is a second reason. Engineers and architects do not hear about germicidal light in their training. It is an orphan discipline."

UV light may also suffer from a quirk of history [1]. In the 1940s and 1950s, antibiotics came into wide use, giving many doctors the impression that the war against microbes was won. UV light, therefore, was not only an orphan technology but also seemed obsolete. However, that complacency began to unravel in the 1980s, when drug-resistant bacteria emerged, particularly tuberculosis (TB). Nardell said that a partial solution to disrupt hospital transmission of TB, an airborne pathogen, used louvered UVC lamps to disinfect the air near the ceiling, which was then circulated to the rest of the room. But that strategy did not affect pathogens that depend on surface-based transmission. Hospital-acquired infections remain a major problem globally, affecting an estimated seven to ten of every 100 hospitalized patients [13]. Many of the pathogens that cause these infections are multi-drug resistant and difficult or impossible to cure with drugs, so it makes sense to try to kill them before they can enter the body. Thus, before 2020, hospitals were the main customers for whole-room UV disinfection.

But now COVID-19 has arrived and changed everything. "With the new coronavirus, the demand outside hospitals has soared," said Stibich. "We've deployed at hotels, offices, anywhere there is a high perceived risk, or they want extra assurance. As countries re-open, these other areas are going to be important, too. We want to make sure they are as safe as possible."

References

[1] Reed NG. The history of ultraviolet germicidal irradiation for air disinfection. Public Health Rep 2010;125(1):15–27.

[2] The Nobel Prize in Physiology or Medicine 1903 [Internet]. Stockholm: Nobel Prize; c2020 [cited 2020 May 15]. Available from: https://www.nobelprize.org/prizes/medicine/1903/summary.

[3] Manganello K. Xenex LightStrike robot destroys SARS-CoV-2 (coronavirus) in 2 minutes [Internet]. San Antonio: Xenex; 2020 Apr 30 [cited 2020 May 15]. Available from: https://xenex.com/resources/news/xenex-lightstrike-robot-destroys-sars-cov-2-coronavirus-in-2-minutes/.

[4] Moore SK. Flight of the GermFalcon: how a potential coronavirus-killing airplane sterilizer was born [Internet]. New York: IEEE Spectrum; 2020 Mar 9 [cited 2020 May 15]. Available from: https://spectrum.ieee.org/tech-talk/aerospace/aviation/germfalcon-coronavirus-airplane-ultraviolet-sterilizer-news.

[5] Mackenzie D. Reuse of N95 masks. Engineering 2020;6(6):593–6.

[6] Bolton JR. UV FAQs [Internet]. Chevy Chase: International Ultraviolet Association; [cited 2020 May 15]. Available from: https://iuva.org/UV-FAQs.

[7] Malayeri AH, Mohseni M, Cairns B, Bolton JR. Fluence (UV dose) required to achieve incremental log inactivation of bacteria, protozoa, viruses, and algae [Internet]. Chevy Chase: IUVA News; [cited 2020 May 15]. Available from: https://iuvanews.com/stories/092816/fluence-required-achieve-incremental-log-inactivation-bacteria-protozoa-viruses-algae.shtml.

[8] Ackerman E. Autonomous robots are helping kill coronavirus in hospitals; [Internet]. New York: IEEE Spectrum; 2020 Mar 11 [cited 2020 May 15]. Available from: https://spectrum.ieee.org/automaton/robotics/medical-robots/autonomous-robots-are-helping-kill-coronavirus-in-hospitals.

[9] Beck SE, Rodriguez RA, Hawkins MA, Hargy TM, Larason TC, Linden KG. Comparison of UV-induced inactivation and RNA damage in MS2 phage across the germicidal UV spectrum. Appl Environ Microbiol 2016;82(5):1468–74.

[10] Buonanno M, Ponnaiya B, Welch D, Stanislauskas M, Randers-Pehrson G, Smilenov L, et al. Germicidal efficacy and mammalian skin safety of 222-nm UV light. Radiat Res 2017;187:493–501.
[11] Welch D, Buonanno M, Grilj V, Shuryak I, Crickmore C, Bigelow AW, et al. Far-UVC light: a new tool to control the spread of airborne-mediated microbial diseases. Sci Rep 2018;8:2752.
[12] Lindblad M, Tano E, Lindahl C, Huss F. Ultraviolet-C decontamination of a hospital room: amount of UV light needed. Burns 2019;46(4):842–9.
[13] Heath care-associated infections fact sheet [Internet]. Geneva: World Health Organization; [cited 2020 May 15]. Available from: https://www.who.int/gpsc/country_work/gpsc_ccisc_fact_sheet_en.pdf.