Ultraviolet Far-UV (222nm): A Promising Approach for the Disinfection of Hospital and indoor Occupied Public Spaces.

Warrag Saed[1], Agnan M M[2]
[1,2] Department of Medical Microbiology,
Faculty of Medical Technology, University of Nalut, Libya.
Corresponding author: E. mail: s_warrag@yahoo.com
Mobile: 00218/917139889

Abstract:

Hospital-associated infections have led to a significant increment of morbidity and mortality among patients. Ultraviolet irradiation C (UVC) has emerged as an effective strategy for microbial control in hospitals and indoor public spaces. This review article highlights the current information regarding UV-C and Far-UV Technology disinfection capabilities and applications. UVC is commonly applied for air, surface, and water disinfection. UV irradiation (100 to 400 nm) is fractionated into four main regions by their wavelength and energy: Far-UV from 200 to 235 nm, short wave ultraviolet (UV-C) from 200 to 280 nm, UV-medium wave (UV-B) from 280 to 315 nm, and UV long wave (UV-A) from 315 to 400 nm. UV-C devices such as, Robots, Mercury-vapor lamps and diodes(UVC-LEDs) has the ability to disinfect airports and transport stations. However, overexposure to UV-C radiation can cause erythema, or sunburn like lesions on the skin, and photo keratitis in the eyes. Hence, for the application of UV-C light, safety is one of the primary considerations. Published studies on the effectiveness of UV-C radiation on surfaces and the surrounding environment showed that for bacterial inactivation it was more than 99.9% within 15 minutes, and the reduction in *C. difficile* spores was 99.8% within 50 minutes. A recent study showed 87.4 %, 99.9 % and a total inactivation of SARS-CoV-2 after 1, 10 and 20 s of treatment by UVC-LED (280 nm; 37.5 mJ/cm^2), respectively. In rooms occupied by patients with MRSA, UV-C irradiation of approximately 15 minutes duration resulted in a decrease in total CFUs per plate (mean, 384 CFUs vs 19 CFUs; $P < .001$), in the number of samples positive for MRSA (81 [20.3%] of 400 plates vs 2 [0.5%] of 400 plates; $P < .001$), and in MRSA counts per MRSA-positive plate (mean, 37 CFUs vs 2 CFUs; $P < .001$). Far-UV-C(222nm) can eliminate pathogens including COVID-19 and other viral diseases without causing any health risks in spaces with simultaneous human presence. The Far-UV-based devices/lights can be administered to be used as an adjunctive procedure to the standard chemical methods in public indoor spaces such as hospitals, health clinics, schools, sport centers and public transport to minimize the risk of pathogens contamination and propagation, saving costs by reducing manual cleaning and equipment maintenance provided by manpower.

Key words: Ultraviolet radiation, disinfection, UV-C devices ,Light sources, bacteria

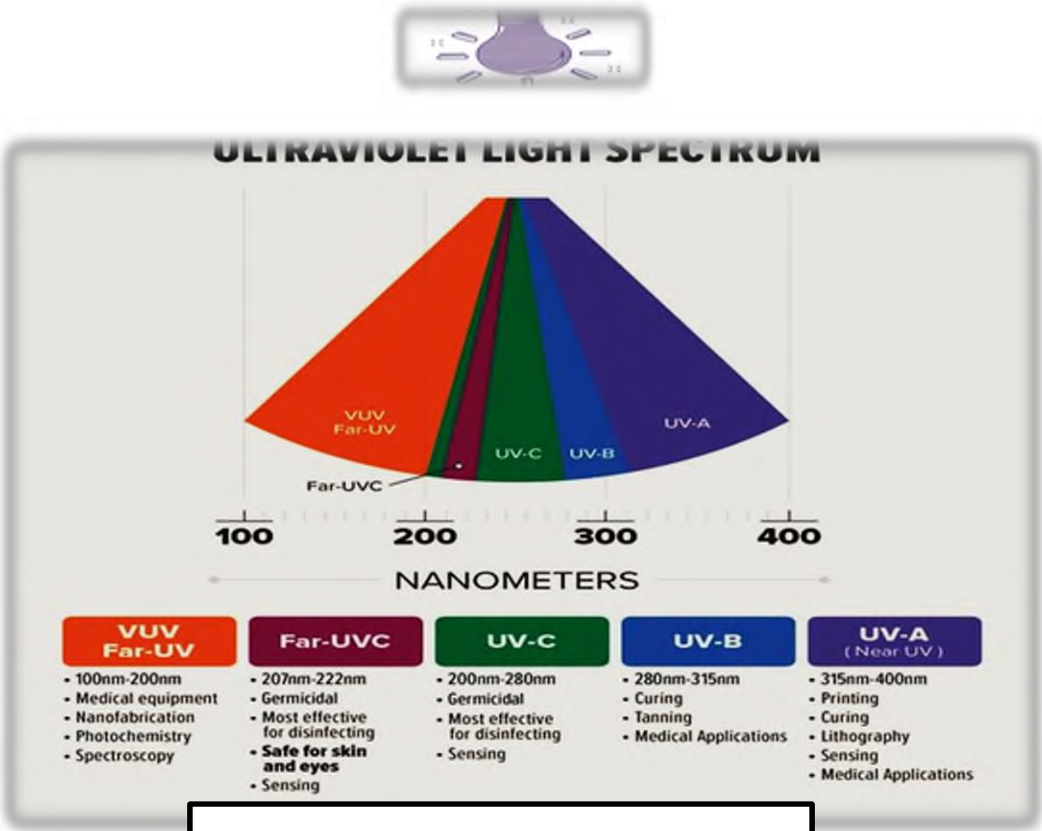
Introduction

Ultraviolet irradiation C (UVC) is a well-known and well-understood technology that could successfully inactivate pathogens, including viruses and bacteria. Therefore, an increased use of UVC-based devices has the potential to reduce the risks of airborne diseases and the dissemination of pathogens on surfaces of public spaces. Ultraviolet irradiation C **(UVC)** has emerged as an effective strategy for microbial control in indoor public spaces. UVC is commonly applied for air, surface, and water disinfection. The SARS-CoV-2 pandemic led to an exponential interest in developing UVC-based devices for indoor space disinfection in addition to conventional preventive measures and the use of traditional disinfectants.

UV irradiation (100 to 400 nm) is fractionated into four main regions by their wavelength and energy: UV from 100 to 200 nm, short wave ultraviolet (UVC) from 200 to 280 nm and 222nm(Far-UV) , UV-medium wave (UVB) from 280 to 315 nm, and UV long wave (UVA) from 315 to 400 nm **[7].** These systems could not only be a powerful strategy to mitigate disinfection issues on hospital surfaces but are also promising for the food and water industry **[1].** Hospital-associated infections have led to a significant increment of morbidity and mortality among patients. As a result, the public health had concentrated on preventing the transmission of infection using environmental controls **[2].** Due to the increase in hospital-associated infections, multidrug- and extensive drug-resistant microorganisms, and the pandemic of new viral strains, specifically, the severe acute respiratory syndrome coronavirus (SARS-CoV) in 2003, the swine influenza virus H1N1 in 2009, and the recent SARS-CoV-2 pandemic since December 2019, studies on environmental cleaning and disinfection techniques had been conducted in order to prevent transmission of the infections and to control the pandemic. Both air purification techniques and surface cleaning techniques had been reported as effective disinfection methods, including the non-thermal plasma (NTP), thermal treatment, antimicrobial material-embedded filters, ultraviolet lights, and photo catalysis. **[3-6].**

Microbial disinfection

The microbial inactivation process by UVC irradiation is mainly based on the occurrence of photochemical reactions caused by UV light on the genetic material (DNA or RNA) of microorganisms **[8].** The adenine-thymine bond is broken resulting in the formation of a covalent linkage between two adenines named pyrimidine dimer. These dimers (e.g. cyclobutane pyrimidine dimers – CPDs) disrupt the normal assembly of nucleic acids, which consequently affect the correct transcription and replication of RNA and DNA, respectively **[9]**. For that reason, the mode of action of UVC light on microorganisms is called “inactivation” and not “killing” **[8].** Environmental surfaces may play an important role in transmission of healthcare-associated pathogens such as *Clostridium difficile*, methicillin-resistant *Staphylococcus* *aureus* (MRSA), and vancomycin-resistant *Enterococcus* (VRE) Patients may acquire these pathogens through direct contact with contaminated surfaces or healthcare workers' hands may transmit pathogens from contaminated surfaces to susceptible patients **[10-15].** Ultraviolet germicidal irradiation (UVGI) is commonly used to disinfect air, water, and various kinds of surfaces due to its high efficiency and relatively low cost. In addition, the use of ultraviolet light for inactivating bacteria and viruses is well established. A shortwave ultraviolet C (UV-C) radiation, 100-280 nanometer (nm), is commonly used in UVGI as their wavelengths are strongly absorbed by bio aerosols. The radiation can damage microorganisms' deoxyribonucleic acid (DNA) and ribonucleic acid, leading to the inactivation of bacteria or virus. In the last decades, an increasing number of studies have demonstrated the UV-C light germicidal ability and its application in healthcare-related settings, e.g., on the ambulance, in operative rooms, and in hospital rooms. However, overexposure to UV-C radiation can cause erythema, or sunburn like lesions on the skin, and photo keratitis in the eyes. Hence, for the application of UV-C light, safety is one of the primary considerations**[16,17,18,19]**. The effectiveness of UV-C radiation in reducing the counts of vegetative bacteria on surfaces was more than 99.9% within 15 minutes, and the reduction in C. difficile spores was 99.8% within 50 minutes. In rooms occupied by patients with MRSA, UV-C irradiation of approximately 15 minutes duration resulted in a decrease in total CFUs per plate (mean, 384 CFUs vs 19 CFUs; $P < .001$), in the number of samples positive for MRSA (81 [20.3%] of 400 plates vs 2 [0.5%] of 400 plates; $P < .001$), and in MRSA counts per MRSA-positive plate (mean, 37 CFUs vs 2 CFUs; $P < .001$). This UV-C device was effective in eliminating vegetative bacteria on contaminated surfaces both in the line of sight and behind objects within approximately 15 minutes and in eliminating C. difficile spores within 50 minutes.**[20]** . Tru-D device was effective in killing *C. difficile* spores, MRSA, and VRE inoculated onto surfaces in the laboratory and in hospital rooms. Disinfection of hospital rooms with Tru-D reduced the frequency of positive MRSA and VRE cultures by 93% and of *C. difficile* cultures by 80% on frequently touched surfaces. These findings are consistent with unpublished data from another research group that are available online **[21]**. The device was effective in reducing contamination in sites not easily amenable to manual application of disinfectant (e.g., the undersurface of bedside tables) and on portable equipment. The housekeeping staff considered the device to be easy to use and to integrate into their routine cleaning practices. These results suggest that the Tru-D device is a promising new environmental disinfection technology that could be a useful adjunct to routine cleaning measures in healthcare facilities**.** The biological effects of UV radiation of different wavelengths (UVA, UVB and UVC) were assessed by [23} in nine bacterial isolates displaying different UV sensitivities. Biological effects (survival and activity) and molecular markers of oxidative stress [DNA strand breakage (DSB), generation of reactive oxygen species (ROS), oxidative damage to proteins and lipids, and the activity of antioxidant enzymes catalase and superoxide dismutase] were quantified and statistically analyzed in order to identify the major determinants of cell inactivation under the different spectral regions. Survival and activity followed a clear wavelength dependence, being highest under UVA and lowest under UVC. The generation of ROS, as well as protein and lipid oxidation, followed the same pattern. DNA damage (DSB) showed the inverse trend. Multiple stepwise regression analysis revealed that survival under UVA, UVB and UVC wavelengths was best explained by DSB, oxidative damage to lipids, and intracellular ROS levels, respectively.**[22].** Fig.(1) and (2).

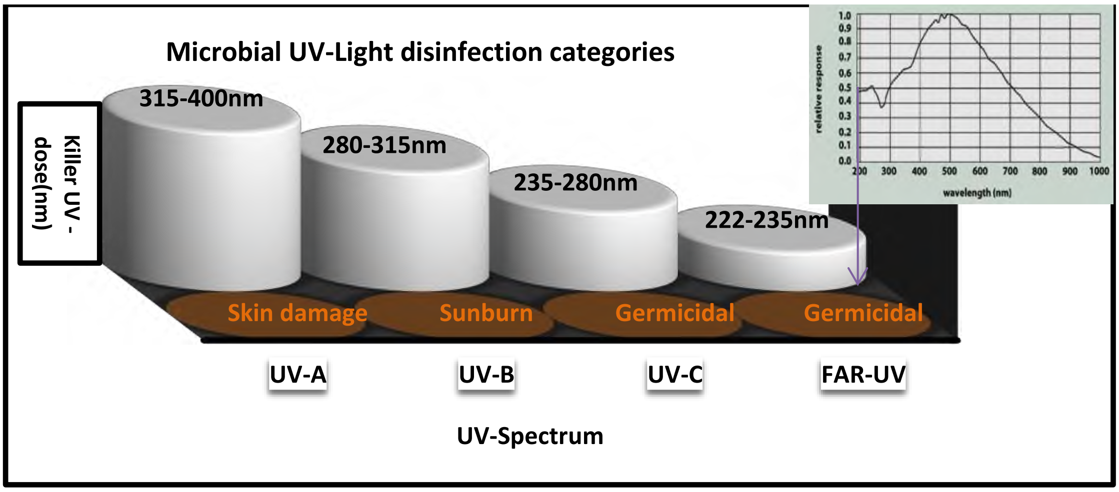


Medical and health applications of UV lights

Figure(1). Ultraviolet light sources UVC and its efficacy

Source: Google images of wavelength dependence by UV-radiation on bacteria

.



Figure(2). Microbial UV-light disinfection and efficacy.

The aim of this study was to collect and analyze the results published to date on the impact of far-UVC in the spectral region between 200 and 235 nm on microbial disinfection efficacy in indoor spaces and its effect on animal and human cells, skin and eyes

Methods

This study was based on the descriptive research to investigate the background of UVC and Far-UVC application and future prospects to improve the disinfection strategies in hospitals and public occupied places and to ascertain the underlying patterns of the some current research data to validate the existing disinfection procedures for healthy environment..

Data analysis:

UV-Devices and light sources

UV-C emerges as an alternative to harmful and (eco)toxic chemical disinfectants. Far-UV-C (222nm) can eliminate pathogens in spaces with simultaneous human presence. Autonomous UV-C-based devices/robots reduce manual work and process costs. No consensus exists on UV-C safety and human exposure. figure(3) A,B,C

UV-C (200-280 nm) is most traditionally referred to as germicidal UV with ability to kill bacteria, viruses, mold, and fungi. While UV-C is most traditionally referred to as germicidal UV, UV-B wavelengths have also demonstrated effectiveness against certain bacteria. UV-A (320-400 nm) and UV-B (280-320nm) light causes oxidation of proteins and lipids causing cell death. Broad band UV lamps have also been shown to inhibit photo-reactivation, the process that can result in self-repair of damaged microbes.(UV-C irradiation different UVC doses from distinct UVC sources cause different antimicrobial effects, depending on the target microorganisms. Thus, UVC tolerance may be species-dependent. In general, Gram-negative bacteria seem to be more susceptible to UVC radiation than vegetative Gram-positive bacteria, yeast, bacterial spores, molds, and viruses **[23].** A wide range of light sources have been used under UVC wavelengths: mercury-vapor UVC lamps; UVC light-emitting diodes (UVC-LEDs); continuous and pulsed xenon arc lamps; excimer lamps: krypton chloride excimer (KrCl) lamps and krypton-bromide excimer (KrBr) lamps and micro plasma lamps **[24]**, **[25].**

Mercury-vapor UVC lamps.

Mercury-vapor lamps can be divided into three classes, namely low-pressure (254 nm), medium-pressure (220-580 nm), and high-pressure lamps (220-1000 nm) **[26]** The conventional UVC light at 254 nm with 30–40 % power efficiencies generated by low-pressure mercury-vapor lamps remains the most common disinfection unit source due to the electrical efficiency and low cost**[27]**.

UVC light-emitting diodes (UVC-LEDs).

To overcome the potential environmental and health warns of mercury, UVC-LEDs (emitting between 255 and 280 nm) have emerged as an alternative solution with efficiencies more than nine times higher than the conventional mercury-vapour UVC lamps (254 nm) when used for water disinfection. A recent study showed 87.4 %, 99.9 % and a total inactivation of SARS-CoV-2 after 1, 10 and 20 s of treatment by UVC-LED (280 nm; 37.5 mJ/cm^2), respectively **[28]**. UVC LED ranging between 16 J/s and 18 J/s were found to reduce *P. aeruginosa*, *S. aureus* and *E. coli* colonies on the stethoscope membrane after >240 h and 2900 cycles of use **[29]**.

Pulsed UVC light

Pulsed UVC light has a broad spectrum (200-1000 nm with a peak at 254 nm) emitted from a xenon flash lamp that is delivered in a series of pulses (100 ns to 2 ms). Pulsed UVC light represents a fast and residue-free technology with higher light energy and intensity and deeper penetration than the alternative UVC light sources**[30]**.

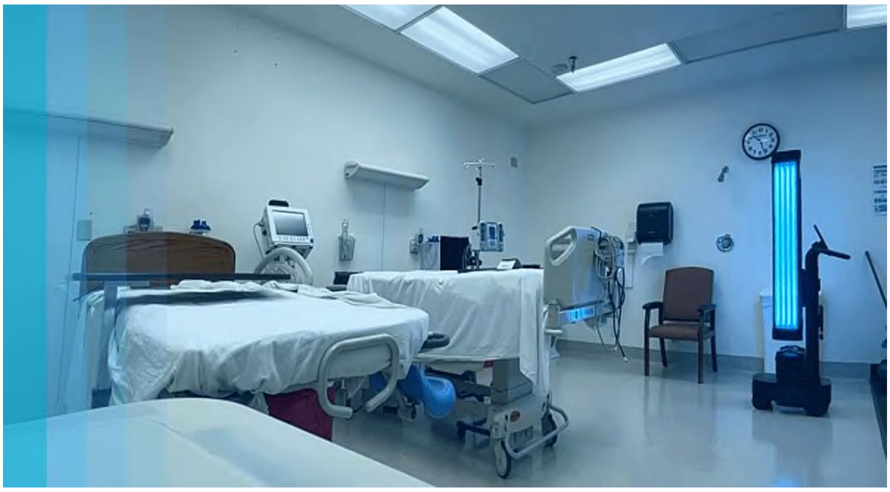
Excimer lamps: far-UVC light

Excimer lamps, namely xenon-bromide - XeBr (285 nm), krypton-bromide - KrBr (207 nm) and krypton-chlorine - KrCl (222 nm), could inactivate a wide range of pathogens. For example, xenon lamps inactivated *E. coli*, hepatitis A virus, Murine NoV-1 and SARS-CoV-2 in suspension and on food-contact surfaces **[31].** The most commonly used excimer lamps for UVC disinfection are these of KrCl that emit light at 222 nm, being recognized as far-UVC technology.

UVC technological devices: robots.

The adoption of automatic UVC technological devices (robots) during the Covid-19 pandemic gave support to fight the spread of pathogens in enclosed areas where contact between people was frequent, particularly in hospitals work offices, schools, shopping centers, and airports**[32], [33]**. These devices already played a significant role in avoiding manual supervision and maneuvering of the disinfection treatment, helping to mitigate the potential spread of pathogens. Among different purposes for UVC robots, most of them are used to fight microbial spread in hospital environments and even in ambulances fig(A, B, C, and D). Xenex Disinfection Services recently developed a pulsed-xenon disinfection system to reduce the load of SARS-CoV-2 on hard surfaces and N95 respirators **[34]**. The use of this system resulted in log reductions up to 4.12

and 4.79 of SARS-CoV-2 after 5 min in hard surfaces and N95 respirators, respectively. Other applications for UVC robots include the sterilization of liquids and packaging using pulsed UVC light. An example is Pure Bright, which uses flash lamps filled with inert gases (xenon, krypton) causing 4.8-7.2 log reductions of different viruses with a dose of 1.0 J/cm^2 **[35].** Figure(**3**)



Figure(**3**).UV-C technological devices : robots

Data concerned with SWOT analysis comparing strengths, weakness, opportunities and threats between Far-UVC and UVC lights indicated that: Far-UVC is Stronger at inactivation of bacteria and viruses compared to 254nm light source, and safer to use in public occupied spaces Table(1).

Table (1). A SWOT analysis comparing strengths, weaknesses, opportunities, and threats between Far-UVC and UVC lights .

Strengths	**Weakness**
- Multiple target inactivation mechanism of DNA and cell membrane damage - Without mercury environmental and health concerns. - Stronger at inactivation of bacteria and viruses compared to 254nm light source. - Safe for use in the presence of humans and animals. - This does not apply to Far-UVC LEDs. -Longer lifespan of lamps compared to mercury vapor lamps at 254nm.	- Controversial information about its pathogen disinfection compared to 254nm lights were it only inactivates DNA. - Limited available data on its long-term health effects. - Ozone production. - On longer human presence it has the potential to cause skin, eye and cell damage. - Mercury vapor lamps are readily available worldwide in all wattages - Limited availability of lamps and fixtures due to its relatively new technology , higher energy consumption and costs.
Opportunities	**Threats**

- Potential for future technology and effectiveness development of 222nm light sources. - Increased demand for effective and safe disinfection techniques in public spaces. - Opportunity for market business to provide safer environment for customers and employees in public spaces.	- Safety concerns due to limited research and data on long-term health effects. - Competition from established 254nm mercury vapor lamps. - Economic downturns that may decrease demand for disinfection products and services.

Table(2). Comparison between UVC/ Far-UVC light sources and chemical disinfection Source:(Elgujja,et.al.2020/ available at:www.jnsmonline.org).

UVC/FAR-UVC light sources	**Traditional disinfection (H2O2)**
- Rapid contact time, for example, 15 min for vegetative bacteria Has a sporicidal activity after longer exposure of up to 50 min. - Plug and play: Does not require closing the HVAC system, nor sealing the room. - Eco-friendly, with no residue, irritants. -Low recurrent running costs. - Microbial cells cannot develop resistance to this technology, and it can be used in public spaces while there is a heavy movement of people in all directions . - can be used in general public occupied spaces such as hospitals. airports, railway stations ,universities, clubs sport centers etc.…… without any health risks.	- Cannot be used in an occupied room. - It is labor-intensive as it requires closing the HVAC system and sealing the doors to prevent its escape. - Has a sporicidal activity It cannot be routinely used, but only as part of the terminal cleaning after the patient has vacated the room. - Expensive. - Time-consuming: requires about 2.5 to 5 h Its effectiveness dependents on specific use parameters (e.g,. concentration, contact time, etc.).

FAR-UV APPLICATION

Ultraviolet irradiation C (UVC) has emerged as an effective strategy for microbial control in indoor public spaces. UVC is commonly applied for air, surface, and water disinfection. Unlike common 254 nm UVC, far-UVC at 222 nm is considered non-harmful to human health, being safe for occupied spaces, and still effective for disinfection purposes. Therefore, and allied to the urgency to mitigate the current pandemic of SARS-CoV-2, an increase in UVC-based technology devices appeared in the market with levels of pathogens reduction higher than 99.9 %. This environmentally friendly technology has the potential to overcome many of the limitations of traditional chemical-based disinfection approaches. The novel UVC-based devices were thought to be used in public indoor spaces such as hospitals, schools, and public transport to minimize the risk of pathogens contamination and propagation, saving costs by reducing manual cleaning and equipment maintenance provided by manpower. However, a lack of information about UVC-based parameters and protocols for disinfection, and controversies regarding health and environmental risks still exist. In this review, fundamentals on UVC disinfection are presented. Furthermore, a deep analysis of UVC-based technologies available in the market for the disinfection of public spaces is addressed, as well as their advantages and limitations. This comprehensive analysis provides valuable inputs and strategies for the development of effective, reliable, and safe UVC disinfection systems. **Figure (4)**

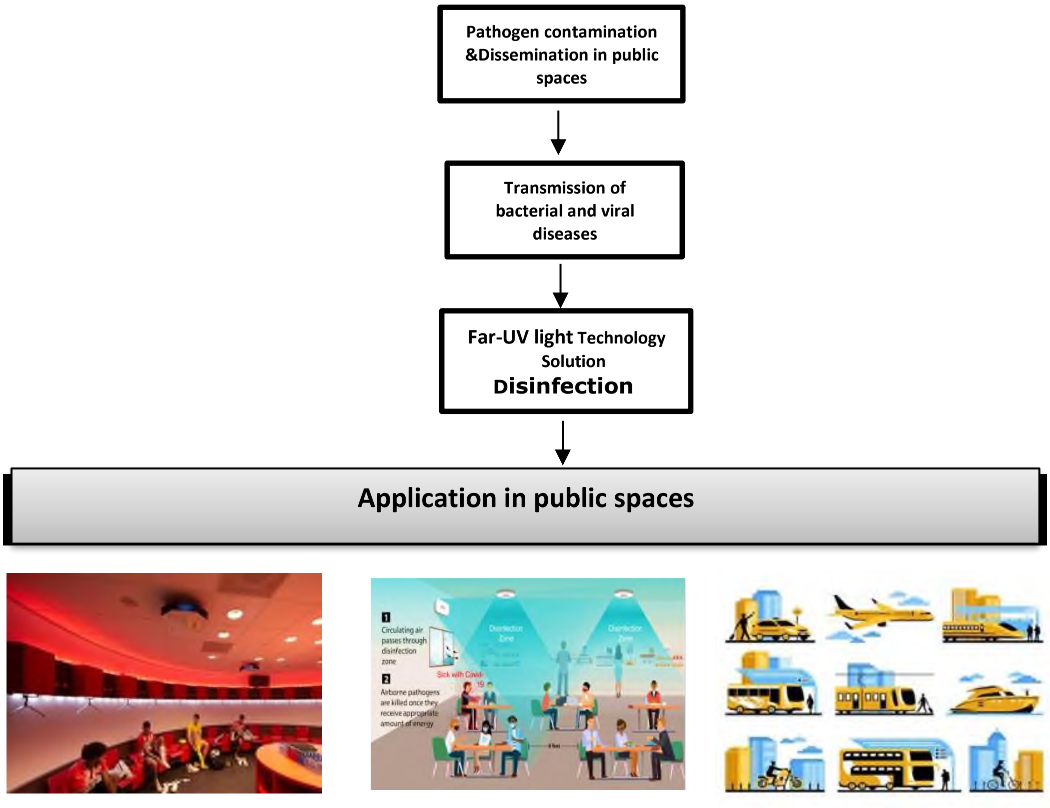


Figure (4).: future Far-UVC disinfection technology safety application in public occupied spaces and services.

Safety Aspects of Human Exposure to Far UV-C Radiation.

Multiple recent studies of health effects from Far UV-C exposures of the eye and skin indicate that the wavelengths below about 230 nm are substantially safer than longer UV-C wavelengths. These experimental observations are consistent with biophysical considerations regarding the much shorter penetration depth of Far UV-C radiation as compared with longer wavelength UV-C radiation. The biophysical background here is that UV-C radiation at wavelengths less than about 230 nm is strongly absorbed by all proteins (particularly through the peptide bond) and by other biomolecules, and so its ability to penetrate living tissue is quite limited. This phenomenon is quantified by wavelength dependent measurements. These considerations and experimental results have led to proposals to modify safety guidelines for human exposure in the Far UVC spectral region, including for whole-room exposure in occupied settings (see below).

The promising reports on the effects of far-UVC on cells, tissue and pathogens – including coronaviruses – give reason to hope that this radiation might become a very important tool in the fight against airborne pathogens and especially SARS-CoV-2 in the current pandemic.

Discussion and Conclusions

Based on the evidence in the published literature and the collation of expert knowledge by the authors, the following conclusions can be drawn: Far UV-C technology is currently dominated by one source type, the KrCl* lamp. Although alternate devices exist, they are not yet practically viable for disinfection applications. Though commonly referred to as 222 nm lamps, a KrCl* lamp will emit polychromatic radiation across a wide segment of the UV-C range; optical filters may be needed to limit substantial emissions to the Far UV-C range. Far UV-C is an effective viral disinfectant, with particular suitability as a technology response to transmission of SARS-CoV-2 via air and surfaces, The efficacy of Far UV-C against viral pathogens is at least as high as that of conventional UVGI, and benefits from the long history of this technology as a disinfectant in a wide range of settings. The rate of ozone generation by these sources is orders of magnitude lower than for conventional "ozone generating" UV lamps. Reasonable application of these sources for continuous, room-scale disinfection could be achieved while maintaining ozone concentrations below regulated values; however, it is also reasonable to consider applications where ambient ozone concentrations would exceed these values.

It is the responsibility of lamp manufacturers and those installing such systems to properly communicate and assess the potential ozone hazard of these systems.

The majority of the presented studies conclude that human and animal cells can tolerate far-UVC doses of 150 mJ/cm^2 for 207 nm irradiation – and probably even much higher ones for 222 nm – without damage such as dimer formation, erythema or increased cell death. This irradiation dose is much higher than 1.7 mJ/cm^2, the only 222 nm dose published to date for a 3 log-reduction of coronaviruses in aerosols, and still many times above the previously mentioned 10 mJ/cm^2 for a one log-reduction of 2/3 of the pathogens in Table 2.

Conclusion:

-The material in this Report suggests that there is sufficient evidence for immediate consideration of this technology during this world-wide health crisis.

-Far UV-C offers a promising technology to reduce surface and airborne disease transmission in occupied spaces, including COVID-19 ,other viral diseases and bacterial pathogens, when it is properly designed, engineered, and applied.

-The Far-UV-based devices/lights can be administered to be used as an adjunctive procedure to the standard chemical methods to minimize the risk of pathogens contamination saving costs by reducing manual cleaning and equipment maintenance provided by manpower.

Other important advantages are:- - The prevention of surgical site infections by far-UVC irradiation – as suggested by Buonanno, M *et al* (35)– seems to be very attractive for future application Microbial cells cannot develop resistance to this technology. -can be used in general public occupied spaces such as hospitals. airports, railway stations ,universities, clubs and sport centers etc……. and other public places with heavy people movements in all directions without any health issues or risks.

Recommendation

- There should be future studies on the feasibility acceptability and efficacy of Far-UVC in long –term care settings.
- further studies are also required on the information regarding the safety of this kind of radiation to determine the necessary doses for pathogen decontamination compared with exposure time (seconds, minutes and hours) or fixing a timer system to ascertain safety on longer exposure in public occupied places.

References

(1)
D.J. Anderson, R.W. Moehring, D.J. Weber, S.S. Lewis, L.F. Chen, J.C. Schwab, P. Becherer, M. Blocker . Effectiveness of targeted enhanced terminal room disinfection on hospital-wide acquisition and infection with multidrug-resistant organisms and *Clostridium difficile*: a secondary analysis of a multicenter cluster randomized controlled trial with crossover
Lancet Infect. Dis., 3099 (2018), pp. 1-9, 10.1016/S1473-3099(18)30278-0

(2) Xu Z, Wu Y, Shen F, Chen Q, Tan M, Yao M. Bio aerosol science, technology, and engineering: past, present, and future. *Aerosol Sci Technol*. 2011; **45**(11): 1337- 1349.

(3) Casini B, Tuvo B, Cristina ML, et al. Evaluation of an ultraviolet C (UVC) light-emitting device for disinfection of high touch surfaces in hospital critical areas. *Int J Environ Res Public Health*. 2019; **16**(19): 3572.

(4) 3Yu BF, Hu ZB, Liu M, Yang HL, Kong QX, Liu YH. Review of research on air-conditioning systems and indoor air quality control for human health. *Int J Refrig*. 2009; **32**(1): 3- 20.

(5) Kim J, Jang J. Inactivation of airborne viruses using vacuum ultraviolet photo catalysis for a flow-through indoor air purifier with short irradiation time. *Aerosol Sci Technol*. 2018; **52**(5): 557- 566.

(6) Khan et al., 2022.
M. Khan, M. McDonald, K. Mundada, M. Willcox
Efficacy of ultraviolet radiations against coronavirus, bacteria, fungi, fungal spores and biofilm Hygiene, 2 (2022), pp. 120-131, 10.3390/hygiene2030010.

(7) M. Raeiszadeh, B. Adeli
A critical review on ultraviolet disinfection systems against COVID-19 outbreak: applicability, validation, and safety considerations
ACS Photonics (2020), 10.1021/acsphotonics.0c01245

(8) M. Buonanno, D. Welch, I. Shuryak, D.J. Brenner
Far-UVC light (222 nm) efficiently and safely inactivates airborne human coronaviruses Sci. Rep., 10 (2020), pp. 1-8, 10.1038/s41598-020-67211-2

(9) Goodman ER, Platt R, Bass R, Onderdonk AB, Yokoe DS, Huang SS. Impact of an environmental cleaning intervention on the presence of methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant enterococci on surfaces in intensive care unit rooms. *Infect Control Hosp Epidemiol.* 2008;**29**:593–599. doi: 10.1086/588566. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

(10) Boyce JM, Pittet D. Guideline for hand hygiene in health-care settings: Recommendations of the Healthcare Infection Control Practices Advisory Committee and the HICPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. *Infect Control Hosp Epidemiol.* 2002;**23**(Suppl):S3–S40. doi: 10.1086/503164. [PubMed] [CrossRef] [Google Scholar]

(11) Bhalla A, Pultz NJ, Gries DM, Ray AJ, Eckstein EC, Aron DC, Donskey CJ. Acquisition of nosocomial pathogens on hands after contact with environmental surfaces near hospitalized patients. *Infect Control Hosp Epidemiol.* 2004;**25**:164–167. doi: 10.1086/502369. [PubMed] [CrossRef] [Google Scholar]

(12) Boyce JM, Potter-Bynoe G, Chenevert C, King T. Environmental contamination due to methicillin-resistant *Staphylococcus aureus* (MRSA): possible infection control implications. *Infect Control Hosp Epidemiol.* 1997;**18**:622–627. doi: 10.1086/647686. [PubMed] [CrossRef] [Google Scholar]

(13) Eckstein BC, Adams DA, Eckstein EC, Rao A, Sethi AK, Yadavalli GK, Donskey CJ. Reduction of *Clostridium difficile* and vancomycin-resistant Enterococcus contamination of environmental surfaces after an intervention to improve cleaning methods. *BMC Infect Dis.* 2007;**7**:61. doi: 10.1186/1471-2334-7-

61. [PMC free article] [PubMed] [CrossRef] [Google Scholar].

(14) Hayden MK, Bonten JM, Blom DW, Lyle EA, van de Vijver D, Weinstein RA. Reduction in acquisition of vancomycin-resistant *Enterococcus* after enforcement of routine environmental cleaning measures. *Clin Infect Dis.* 2006;**42**:1552–60. doi: 10.1086/503845. [PubMed] [CrossRef] [Google Scholar].

(15) 5Reed NG. The history of ultraviolet germicidal irradiation for air disinfection. *Public Health Rep*. 2010; **125**(1): 15- 27.

(16) McDevitt JJ, Rudnick SN, Radonovich LJ. Aerosol susceptibility of influenza virus to UV-C light. *Appl Environ Microbiol*. 2012; **78**(6): 1666- 1669.

(17) Yin R, Dai T, Avci P, et al. Light based anti-infectives: ultraviolet C irradiation, photodynamic therapy, blue light, and beyond. *Curr Opin Pharmacol*. 2013; **13**(5): 731- 762.

(18) World Health O, International Programme on Chemical S. Ultraviolet radiation : an authoritative scientific review of environmental and health effects of UV, with reference to global ozone layer depletion / published under the joint sponsorship of the United Nations Environment Programme, the International Commission on Non-Ionizing Radiation Protection and the World Health Organization, 2nd edn. Geneva: World Health Organization; 1994.

(19) Rutala William A. Martin S. Favero Lectureship, Disinfection and Sterilization: Successes and Failures.
http://www.unc.edu/depts/spice/dis/dsFaveroLectjune09.pdf

(**20)**William A. Rutala 2015. (room decontamination) / 02-january Cambridge university press .

(21) H. Singh, S.K. Bhardwaj, M. Khatri, K. Kim, N. Bhardwaj
UVC radiation for food safety: an emerging technology for the microbial disinfection of food products Chem. Eng. J., 417 (2021), Article 128084, 10.1016/j.cej.2020.128084

(22) M. Guettari, I. Gharbi, S. Hamza
UVC disinfection robot Environ. Sci. Pollut. Res., 28 (2021), pp. 40394-40399

(23) Ana L Santos. (wavelength dependence) PubMed/PMID: 23090570 DOI:10.1007/s00203-012-04847-5

(24) M. Raeiszadeh, F. Taghipour. Microplasma UV lamp as a new source for UV-induced water treatment: protocols for characterization and kinetic study Water Res., 164 (2019), 10.1016/j.watres.2019.114959.

(25) N. Demeersseman, V. Saegeman, V. Cossey, H. Devriese, A. Schuermans Shedding a light on ultraviolet-C technologies in the hospital environment J. Hosp. Infect., 132 (2023), pp. 85-92, 10.1016/j.jhin.2022.12.009.

(26) J. Hadi, M. Dunowska, S. Wu, G. Brightwell Control measures for SARS-CoV-2: a review on light-based inactivation of single-stranded RNA viruses Pathogens, 9 (2020), p. 737.

(27) H. Inagaki, A. Saito, H. Sugiyama, T. Okabayashi Rapid inactivation of SARS-CoV-2 with deep-UV LED irradiation Emerg. Microbes Infect. (2020), pp. 1-8, 10.1080/22221751.2020.1796529.

(28) M. Ploydaeng, N. Rajatanavin, P. Rattanakaemakorn UV-C light: a powerful technique for inactivating microorganisms and the related side effects to the skin Photodermatol. Photoimmunol. Photomed., 37 (2021), pp. 12-19, 10.1111/phpp.12605

(29) J. Jean, R. Morales-rayas, M. Anoman, S. Lamhoujeb Inactivation of hepatitis A virus and norovirus surrogate in suspension and on food-contact surfaces using pulsed UV light (pulsed light inactivation of food-borne viruses) Food Microbiol., 28 (2011), pp. 568-572, 10.1016/j.fm.2010.11.012

(30) F. Graeffe, Y. Luo, Y. Guo, M. Ehn Unwanted indoor air quality effects from using ultraviolet C lamps for disinfection Environ. Sci. Technol. Lett. (2023), 10.1021/acs.estlett.2c00807

(31) U. Robots .UVD Robots https://uvd.blue-ocean-robotics.com/applications (2021) accessed 1.22.23.

(32)S.E.S. Drph, R.C. Jr, K.J. Alfson, H.M.S. Bs, C. Jinadatha, W.R. Jarvis, P. Sampathkumar, R.F. Chemaly, F. Khawaja, M.P. Pharmd, S. Jackson, K.S. Kaye, R.M. Rodriguez, M.A. Stibich Deactivation of SARS-CoV-2 with pulsed-xenon ultraviolet light: implications for environmental COVID-19 control Infect. Control Hosp. Epidemiol., 1–4 (2020), 10.1017/ice.2020.399.

(33) R. Mandal, X. Mohammadi, A. Wiktor, A. Singh, A.P. Singh Applications of pulsed light decontamination technology in food processing: an overview Appl. Sci., 10 (2020), 10.3390/app10103606.

(34) Buonanno, M.; Ponnaiya, B.; Welch, D.; Stanislauskas, M.; Randers-Pehrson, G.; Smilenov, L.; Lowy, F. D.; Owens, D. M.; Brenner, D. J., Germicidal Efficacy and Mammalian Skin Safety of 222- nm UV Light. Radiat. Res. 2017, 187 (4), 483-491.

(35) Buonanno, M.; Randers-Pehrson, G.; Bigelow, A. W.; Trivedi, S.; Lowy, F. D.; Spotnitz, H. M.; Hammer, S. M.; Brenner, D. J., 207-nm UV light - a promising tool for safe low-cost reduction of surgical site infections. I: in vitro studies. PLoS One 2013, 8 (10), e76968.