

## The Paradoxical Role of far-Ultraviolet C (far-UVC) in Inactivation of SARS-CoV-2: The Issue of Droplet Size

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### ABSTRACT

The Omicron variant is spreading at a rate we have never observed with any previous variant. A lot of efforts have been taken to inactivate SARS-CoV-2, especially the omicron variant. Specific wavelength ranges of electromagnetic radiation can be exploited to inactivate coronaviruses. Previous studies show that 222-nm far-Ultraviolet C (far-UVC) light inactivates airborne influenza virus efficiently. Considering the similar genomic sizes of all human coronaviruses, other human coronaviruses, such as SARS-CoV-2, would be expected to be inactivated by far-UVC with a similar efficacy. Taking this into account, it is concluded that exposure to far-UVC can be introduced as a safe method that significantly reduces the ambient level of airborne coronaviruses in crowded places. Biomolecules, particularly proteins, strongly absorb ultraviolet radiation at a wavelength of around 200 nm. Given this consideration, far-UVC has a limited ability to permeate biological materials. Thus, for example, in only around 0.3 mm of tissue, the intensity of 200-nm UV radiation is decreased by half, compared to tissue penetration of about 3 mm at 250 nm. This paper aims to answer the key question of whether far-UVC can penetrate SARS-CoV-2 inside inhalable respiratory droplets (with diameters up to 100  $\mu$ m).

### Keywords

Ultraviolet Rays; COVID-19; SARS-CoV-2; Disinfection; Pneumonia

### Introduction

Ultraviolet (UV) radiation, as a form of electromagnetic radiation, has biological impacts. As the biological impacts of UV radiation shift enormously with wavelength, the UV spectrum is classified into three sections: UVA, UVB, and UVC. UV radiation wavelength ranges from 100 to 400 nm, and the classification of UV spectrum differs based on the discipline involved and is arbitrary to some extent. UV wavelength sections are regularly characterized as UVA 400-320 nm, UVB 320-290 nm, and UVC 290-200 nm. In the case of far UVC, the wavelength ranges from 207 to 222 nm [1].

Due to the rapid spread of SARS-CoV-2, especially new variants like Omicron, by asymptomatic carriers [2], investigating practical mitigation technologies for inactivation of the airborne virus in public places and limiting transmission by air is of high importance [1]. UV radiation has a direct antimicrobial effect [3], and the effectiveness of this range

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of electromagnetic radiation against various airborne virus strains has long been identified [4].

The purpose of this study is to show whether far-UVC is efficient or not in completely inactivating coronaviruses that reside in respiratory droplets.

## Material and Methods

This article is written by authors in a two-step process. Information about the classification of the UV spectrum, biological impacts of UV radiation, the germicidal effect of UV radiation, various ways of transmitting infectious microorganisms, and SARS-CoV-2 characteristics have been gathered as the first step of the study. In the second phase of the study, all authors have discussed the facts collected and compared them; finally, the authors have achieved the results and conclusions.

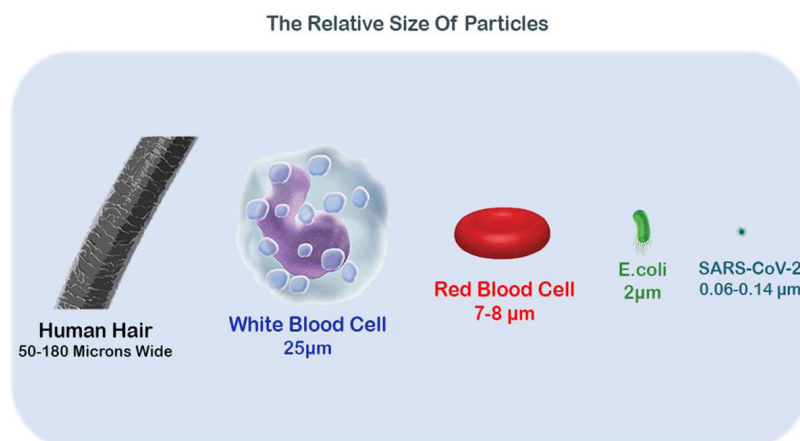
## Results

Various sources of UV radiation are accessible, but some are more common. A low-pressure mercury-vapor arc lamp which emits UV with wavelengths around 254 nm is the most common source of UV radiation used for germicidal applications, and xenon lamp technology which emits a broad UV spectrum has been used lately [5]. Direct exposure of

skin and eye to conventional germicidal UV lamps has health hazard consequences, so using them for disinfecting occupied public places is impossible although utilizing these lamps for disinfection of unoccupied places is possible. Based on the studies conducted to date far-UVC light is capable of killing microorganisms as well as conventional germicidal UV light; besides, it does not cause any health hazards [6-9].

Briefly, not reaching living human cells in our skin or eyes is because, in biological materials, far-UVC light has a limited range. In other words, far UVC can be absorbed in the stratum corneum of our skin or the ocular tear layer. Since viruses (and even bacteria) are quite small, penetration of far-UVC light to these microorganisms and subsequently killing them is feasible (Figure 1). As a result, far-UVC light, like other UVC light regions, has the same germicidal action yet poses no health risks to humans [6-9].

The authors' review of the literature to determine the advantages and disadvantages of far-UVC has led to the following results. First, far-UVC light can be emitted by using inexpensive excimer lamps [6-9]. Then, this range of UV wavelength light acts as an anti-microbial technology efficiently [1]. The last point is that far-UVC light is a safe way of disinfecting



**Figure 1:** The relative size of SARS-CoV-2 compared to E. coli, red blood cell (RBC), white blood cell (WBC), and human hair

occupied public places [6].

Some studies validate this theory by showing that far-UVC light can even be used as a disinfectant against different strains of coronaviruses. A study showed that doses as low as 1.2 to 1.7 mJ/cm<sup>2</sup> of 222 nm far-UVC inactivates 99.9% of the airborne human coronaviruses. Since all human coronaviruses possess identical genomic sizes, which plays a crucial role in radiation sensitivity, far-UVC light shows adequate inactivation effectiveness against all human coronaviruses, such as SARS-CoV-2 [1]. Moreover, some other studies state that far-UVC light can kill microorganisms efficiently just like UV light but is safer than UV light [6-8].

## Discussion

There are several ways of transmitting infectious microorganisms from one person to another. One of these ways is the transmission of microorganisms by respiratory droplets. Patients produce droplets when they breathe, speak, cough, or sneeze. Attached pathogens to the droplets infect vulnerable populations within a close range and short period. Then the susceptible population will be infected, and lead to the further spread of the disease.

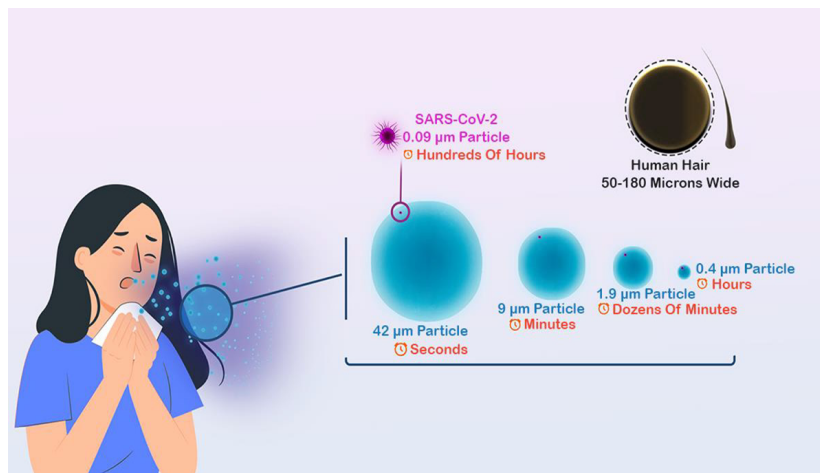
Despite the penetration of far-UVC light in microbes (<1 μm), its penetration in a typi-

cal mammalian cell is limited, and it cannot penetrate human cells [10-12]. Additionally, all tissues with a stratum corneum will stop this light's penetration [7, 8]. The lifetime of a droplet with a diameter ranging from 10-100 μm is in the order of seconds at a relative humidity of 60%. As time passes, small droplets quickly evaporate and form droplet nuclei, which due to their small sizes may remain airborne for a long time (Figure 2). When evaporation of the droplets decreases, the settling times will be decreased [13].

The volume of droplets ranges from 0.001 to 12 cm<sup>3</sup> (breathing), 0.001-1.2 cm<sup>3</sup> (speaking), and 0.001-5.5 cm<sup>3</sup> (coughing) [14]. According to the findings of another study, the total average size distribution of droplet nuclei was 0.58-5.42 μm, and 82 percent of droplet nuclei were centered in the 0.74-2.12 μm range. The entire average size distribution of coughed droplets by test subjects was 0.62-15.9 μm [15].

## Conclusion

While it is widely claimed that far UVC can inactivate coronaviruses, it would be of crucial importance to consider the ability of far UVC to reach viruses inside large droplets, particularly those covered with components such as salivary proteins. Moreover, it should



**Figure 2:** The relative size of respiratory fluid particles and their average lifetime

be noted that for similar ambient conditions (e.g., temperature, ventilation air flows, light intensity, and air quality) humidity strongly affects the effectiveness of far-UVC because large droplets in an environment with higher rates of humidity do not rapidly evaporate to form droplet nuclei.

### Authors' Contribution

M. Karimpour, SMJ. Mortazavi, A. Ghadimi-Moghadam, and JJ. Bevelacqua designed the manuscript. All authors have contributed to the gathering of the data, interpretation of the findings, and writing/reviewing of the current manuscript and read, modified, and approved the final version of the manuscript.

### Conflict of Interest

None

### References

1. Buonanno M, Welch D, Shuryak I, Brenner DJ. Far-UVC light (222nm) efficiently and safely inactivates airborne human coronaviruses. *Sci Rep*. 2020;**10**(1):10285. doi: 10.1038/s41598-020-67211-2. PubMed PMID: 32581288. PubMed PMCID: PMC7314750.
2. Bai Y, Yao L, Wei T, Tian F, Jin DY, Chen L, Wang M. Presumed Asymptomatic Carrier Transmission of COVID-19. *JAMA*. 2020;**323**(14):1406-7. doi: 10.1001/jama.2020.2565. PubMed PMID: 32083643. PubMed PMCID: PMC7042844.
3. Kowalski W. Ultraviolet germicidal irradiation handbook: UVGI for air and surface disinfection. Springer; 2010.
4. Budowsky EI, Bresler SE, Friedman EA, Zheleznova NV. Principles of selective inactivation of viral genome. *Arch Virol*. 1981;**68**(3-4):239-47. doi: 10.1007/BF01314577. PubMed PMID: 7271457.
5. Naunovic Z, Lim S, Blatchley ER 3rd. Investigation of microbial inactivation efficiency of a UV disinfection system employing an excimer lamp. *Water Res*. 2008;**42**(19):4838-46. doi: 10.1016/j.watres.2008.09.001. PubMed PMID: 18848711.
6. Buonanno M, Ponnaiya B, Welch D, Stanislauskas M, Randers-Pehrson G, et al. Germicidal Efficacy and Mammalian Skin Safety of 222-nm UV Light. *Radiat Res*. 2017;**187**(4):483-91. doi: 10.1667/RR0010CC.1. PubMed PMID: 28225654. PubMed PMCID: PMC5552051.
7. Buonanno M, Randers-Pehrson G, Bigelow AW, Trivedi S, Lowy FD, et al. 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. doi: 10.1371/journal.pone.0076968. PubMed PMID: 24146947. PubMed PMCID: PMC3797730.
8. Buonanno M, Stanislauskas M, Ponnaiya B, Bigelow AW, Randers-Pehrson G, Xu Y, Shuryak I, Smilenov L, Owens DM, Brenner DJ. 207-nm UV Light-A Promising Tool for Safe Low-Cost Reduction of Surgical Site Infections. II: In-Vivo Safety Studies. *PLoS One*. 2016;**11**(6):e0138418. doi: 10.1371/journal.pone.0138418. PubMed PMID: 27275949. PubMed PMCID: PMC4898708.
9. Ponnaiya B, Buonanno M, Welch D, Shuryak I, Randers-Pehrson G, Brenner DJ. Far-UVC light prevents MRSA infection of superficial wounds in vivo. *PLoS One*. 2018;**13**(2):e0192053. doi: 10.1371/journal.pone.0192053. PubMed PMID: 29466457. PubMed PMCID: PMC5821446.
10. Lorian V, Zak O, Suter J, Bruecher C. Staphylococci, in vitro and in vivo. *Diagn Microbiol Infect Dis*. 1985;**3**(5):433-44. doi: 10.1016/0732-8893(85)90082-3. PubMed PMID: 4028668.
11. Coohill TP. Virus-cell interactions as probes for vacuum-ultraviolet radiation damage and repair. *Photochem Photobiol*. 1986;**44**(3):359-63. doi: 10.1111/j.1751-1097.1986.tb04676.x. PubMed PMID: 3786457.
12. Metzler DE. Biochemistry (2 Volume Set): The Chemical Reactions of Living Cells. Elsevier; 2003.
13. Li H, Leong FY, Xu G, Kang CW, Lim KH, Tan BH, Loo CM. Airborne dispersion of droplets during coughing: a physical model of viral transmission. *Sci Rep*. 2021;**11**(1):4617. doi: 10.1038/s41598-021-84245-2. PubMed PMID: 33633316. PubMed PMCID: PMC7907382.
14. Zhang H, Li D, Xie L, Xiao Y. Documentary Research of Human Respiratory Droplet Characteristics. *Procedia Eng*. 2015;**121**:1365-74. doi: 10.1016/j.proeng.2015.09.023. PubMed PMID: 32288921. PubMed PMCID: PMC7128962.
15. Yang S, Lee GW, Chen CM, Wu CC, Yu KP. The size and concentration of droplets generated by coughing in human subjects. *J Aerosol Med*. 2007;**20**(4):484-94. doi: 10.1089/jam.2007.0610. PubMed PMID: 18158720.