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ULTRAVIOLET TECHNOLOGY IN THE TIME OF EPIDEMICS

MINA PENCHEVA[1], VERA GLEDACHEVA[1], GEORGI VASILEV[2], DIMITRIOS MALOGIANNIS[3], CHARILAOS XENODOCHIDIS[1]*

[1]Department of Medical Physics and Biophysics, Faculty of Pharmacy, Medical University of Plovdiv
[2]Student of Medicine at the Medical University of Plovdiv, Bulgaria
[3]Student of Dental Medicine at the Medical University of Plovdiv, Bulgaria
** Corresponding author: H.Ksenodohidis@mu-plovdiv.bg*

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Abstract: Since the outbreak of the COVID-19 epidemics, the priority worldwide was to minimize the spread of the virus. Ultraviolet (UV) light has proven a trustworthy solution against various ranges of health disorders and in the inactivation of viruses. Wavelengths between 254 nm and 265 nm from the electromagnetic spectrum are used for the deactivation of viruses, bacteria and fungi. In that sense, UV light can be proven efficient against SARS-CoV-2 transmission due to its germicidal effect. UVC light can damage the virus ribonucleic acid (RNA) and hence prevent its replication. Likewise, the development of a disease can be avoided. This study aims an objective assessment of UV light implementation in SARS-CoV-2 disinfection. We have performed a vast review of the articles. The search engines included were PubMed, Medline (EBSCO & Ovid), Google Scholar, Science Direct, Scopus and Bio-Medical. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2009 guidelines were used for review writing. The literature review showed that many authors employed UV lamps and Light-emitting Diodes (LED) UV instruments for experimental purposes emitting radiation at a range between 254 nm and 365 nm. The online findings have shown approximately 99.9% viral inactivation. Factors such as power density of the light source, source-virus distance and time exposure to UV light played a crucial role in the final outcome. All of them have been discussed in the current work.

INTRODUCTION

UV light has proven a powerful tool for disinfection and sterilization. The UV range is divided into three zones: UVA, UVB, and UVC, each of which has a different effect on biological structures (Cutler and Zimmerman, 2011). UVC zone refers to electromagnetic waves with a wavelength between 100 and 280 nm and is known for its germicidal effect. It is established that the absorbed amount of radiation, known as UV dose, is directly related to the destruction of microorganisms. Microorganisms can be damaged via photooxidation and photo-induced reactions, which have as a common characteristic the absorption of UV photons either by nucleic acids or photosensitizers. Generally, nucleic acids are made of monosaccharides and nucleobases. Regarding the monosaccharides, the maximum absorption of UV photons is at 200 nm wavelength (λ), whereas for the nucleobases is at 265 nm (Kesavan & Sagripanti, 2014; Ortiz-Mateos, 2020). In other words, UVC light can damage the virus RNA and hence prevent its replication leading to its inactivation (Raeiszadeh & Adeli, 2021). On December 31, 2019, a new human pathogen, later named Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), which is a member of the *Coronaviridae* family, caused an outbreak. The virus was notified for the first time in Wuhan, China (Coronaviridae Study Group of the International Committee on Taxonomy of Viruses, 2020) and the symptoms were defined as coronavirus disease (COVID-19) (Huang et al., 2020). Three months later (March 11, 2020), and after the report of 118,319 infections and 4292 deaths, the World Health Organization (WHO) declared that SARS-CoV-2 infection had become a pandemic.

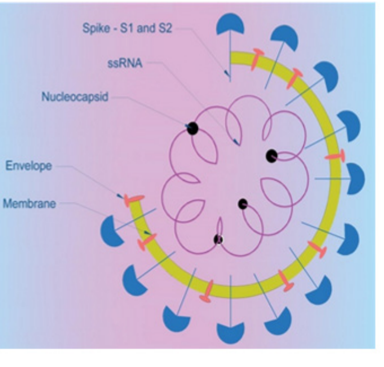

Figure 1.Structural representation of SARS-COV-2

To control the spread of SARS-CoV-2 governments had implemented severe restrictions concerning transportation within, from and towards 113 countries (World Health Organization 2019, 2020). Regarding the viral genome, it is composed of a single strand of RNA (Figure 1), and the diameter of the viral particles also known as virions is around 120 nm (Cascella et al., 2020;

Encyclopaedia Britannica, 2020). Up to date findings suggest that the virus causes a highly contagious respiratory disease which is characterized by symptoms of fever, cough, and muscle ache, often with progressive difficulty in breathing. The genome of SARS-CoV-2 has been detected in clinical specimens such as nasopharyngeal swabs, sputum, bronchoalveolar lavage fluid, fibrobronchoscope brush biopsy, stool, ocular fluid, and blood (Wang et al., 2020; Cheng et al., 2004; Peng et al., 2020). However, according to current evidence, the virus is most commonly transmitted from infected persons through respiratory droplets and contact routes at a distance of 1–1.5 m from the contagious individual (Huang et al., 2020). Indeed, the possibility of contagion is greater when it comes to direct contact of the mucosae or conjunctiva with infected surfaces, like skin or objects that have been exposed to infected droplets, sputum, or sneeze (Peng et al., 2020).

This study aims at the objective assessment of UV light implementation in SARS-COV-2 disinfection. Here, we present a literature data analytics in which we discuss various physical parameters of the employed light sources and the level with which they affect the inactivation of various viruses while the epicenter of our interest is on SARS-COV-2 and less on the other types of coronaviruses.

MATERIALS AND METHODS

Over 3 months, we performed a vast review of the articles. The included search engines were PubMed, Medline (EBSCO & Ovid), Google Scholar, Science Direct, Scopus and Bio-Medical. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2009 guidelines were used for review writings. Our research was based on the effect of UV-light and UV technology on SARS-COV-2. The findings are presented quantitatively in tables for better comprehension of the received information. We focused mainly on the physical characteristics of the UV radiation that affected the virus. These were: time exposure to UV light, the irradiance of the light source and distance source-SARS-COV-2. For the enrichment of data, we used the International Clinical Trials Registry Platform and the ClinicalTrials.gov registry (https://clinicaltrials.gov/).

RESULTS AND DISCUSSION

The data we have accumulated demonstrated a correlation between the UV irradiance, distance and time exposure of the virus to the type of the UV source. The UV technology was tested in three different viruses that belong to the coronavirus family. Namely, these were the Middle Eastern respiratory syndrome coronavirus (MERS-CoV), SARS-associated coronavirus (SARS-CoV) and SARS-COV-2. In particular, Bedell et al. conducted studies on samples with the MERS-CoV. The results showed 99.99% viral inactivation when the distance light source-virus was 1.22 m after 5 min irradiation though the UV irradiance was not reported (Table 1) (Bedell et al., 2016). Similarly, Keil and colleagues achieved a reduction of MERS-CoV in undetectable levels in human plasma products with the use of UV light. However, there is no information on the time exposure, distance or UV dose (Table 1) (Keil et al., 2016). Concerning SARS-COV, Ansaldi et al. used UV light with λ at 254 nm and UV irradiance of 40 mW/cm². They managed to fully inactivate the virus after 2 min exposure to UV radiation. It is worthy to mention that they didn't reveal the source-virus distance (Table 1) (Asnaldi et al., 2004). Moreover, studies on human aerosolized coronavirus have shown 99.9% inactivation of HCoV-229E under the influence of UVC light with λ at 222 nm. The reported results were the outcome of 100 μW/cm² UV irradiance, while the irradiation of the virus lasted for 20 s at a distance of 22 cm (Table 1) (Buonanno et al., 2020). Another study that came to light showed that UVC light (λ = 254 nm) with the power intensity at 2.9 mW/cm² inactivated 100% HCoV-NL63 after viral exposure for 1 min to UV radiation at 254 nm, whereas the distance between emitter and virus was measured at 50 cm (Table 1) (Khaiboullina et al., 2020).

Table 1. Parameters of the employed UV light that affect inactivation of MERS-CoV, SARS-CoV, SARS-CoV-2

Authors	exposure time to UV radiation	distance light source-virus	Irradiance	Viral inactivation
Mers - CoV				
Bedell et al.	5 min	1.22 m	not reported	99.99%
Keil et al.	not reported	not reported	not reported	99.99%
SARS-CoV				
Asnaldi et al.	2 min	not reported	40 mW/cm^2	99.99%
Buonanno et al.	20 s	22 cm	100 μW/cm^2	99.99%
Khaiboullina et al.	1 min	50 cm	2.9 mW/cm^2	100%
SARS-COV-2				
Sabino et al.	49.42 s	30 cm	2.2 mW/cm^2	99.99%
Inagaki et al.	10 s	2 cm	3.75 mW/cm^2	99.99%
Storm et al.	4 s (for wet virus) 9 s (for dry virus)	not reported	0.849 mW/cm^2	99.99%

SARS-CoV-2 or the human CoV-19 is the newest form of the coronaviruses family. Many authors have studied the UV effect on inactivating SARS-CoV-2. More specifically, Sabino and colleagues reported 99.99% inactivation of SARS-CoV-2 after irradiation for 49.42 s with UVC light (254 nm) at a 30 cm light source-virus distance with the irradiance of 2.2 mW/cm^2 (Table 1) (Sabino et al., 2020). With the use of LED UV, Inagaki et al. reported 99.9% viral inactivation when the samples were exposed for 10 s to UV radiation, while the reported irradiance was 3.75 mW/cm^2 at 2 cm distance source-virus (Table 1) (Inagaki et al., 2020). In 2020, the National Emerging Infectious Diseases Laboratories at Boston University tested the efficacy of UVC light sources against SAR-CoV-2. Tests revealed a viral reduction in undetectable levels in a dry environment for about 9 s and 4 s in a wet when the surface of the material inoculated with SARS-CoV-2 was irradiated with UV light. The tests were undertaken in laboratory conditions and while surface disinfection takes seconds, normal disinfection cycles are measured in minutes. Concretely, the authors reached a reduction in undetectable levels of viral infectivity (99.9%) at a light intensity of the UV source of 0.849 mW/cm^2 with the peak λ at 254 nm (Table 1) (Storm et al., 2020).

Recently, authors reported another correlation between the abovementioned physical parameters of the UVC light with the virus concentration. Concretely, in samples with different multiplicity of infection (MOI) and more specifically with 0.05, 5, and 1000 MOI, the authors achieved total viral inactivation with the use of a low-pressure mercury lamp emitting UVC (254 nm) light at a distance of 250 mm source-dwell filled with the virus. Notably, in the case of 5 MOI, viral inactivation was detected at 3.7 mJ/cm^2, whereas in samples with 1000 MOI, the authors observed inactivation at a dose of 16.9 mJ/cm^2 (Biasin et al., 2021). These findings confirmed the correlation between viral concentration and UV dose.

Unfortunately, the number of diseased cases has dramatically increased since WHO declared the ongoing pandemic (https://www.statista.com/page/covid-19-coronavirus). The slogan: "stay at home alone" turned out to be insufficient and so all the preventative measures until now. This fact made scientists and politicians think of alternatives that will lead humanity back to "normal". Hopefully, UV technology proves to be a trustworthy solution in dissolving the spread of SARS-CoV-2. The pooled literature data is the proof of the above allegation. The reason for the included parameters in all these studies is to retrieve a deeper understanding of the coronaviruses' inactivation and the employed light sources. Interestingly, all authors reported a 99.99% viral reduction in Table 1 but the main differences were irradiance, time exposure and distance emitter-virus. Regarding SARS-CoV-2, data illustrated in Table 1 demonstrates that, at a small distance and for a shorter irradiation time, there is higher absorbance of UV photons by the virus RNA. According to Bolton and colleagues, intercellular components such as proteins, DNA and RNA have an absorbance peak at the UVC range (Bolton et al., 2008). UV photons break the adenine – thymine bonds forming pyrimidine dimers, which are essentially the bond of two adenines. These genomic changes put an end to RNA's replication and thus the nucleic acid is inactivated (Raeiszadeh & Adeli, 2020). Another fact that must be taken into consideration is that single-stranded viruses (in particular SARS-CoV-2) cannot recover from the detrimental effect of UV radiation (Tseng & Li, 2005). Therefore, UVC light is indeed dangerous for the human skin even at low doses. Taking all these findings into account, we recommend that direct exposure to the UVC range should be avoided. Subsequently, disinfection in hospitals must occur in the absence of patients or personnel. The last statement is in agreement with a report made by WHO and the International Commission Non-Ionizing Radiation Protection indicating that UV technology should be applied only during the human absence due to its mutagenic and cataractogenic effect (https://www.who.int/publications/i/item/cleaning-and-disinfection-of-environmental-surfaces-inthe-context-of-covid-19). Additionally, the maximum UV dose that the human body can absorb via reflection is 3 mJ/cm^2 according to the European Agency for Safety and Health at Work (for a time interval of 8 h).

Up to date, the accumulated evidence indicates that the efficacy of UV technology on airborne pathogens is higher than this on microbes on surfaces. This is due to the fact that in air microbes are more exposed to UV radiation. Subsequently, they are exposed to a higher UV irradiance that of the surface-borne microbes, which seem to be in a sense ”protected” (Kowalski, 2009). In another inquiry, authors reported less efficacy of UVC light on dirty surfaces that had not been preliminary disinfected, which confirms the direct relationship between the effectiveness of a UV emitter and dirty/dusty surfaces (Anderson et al., 2013).

CONCLUSIONS

In conclusion, what taught us about the ongoing pandemic is that we can rely on UV technology. Nowadays UV light sources find wider application not only in hospitals and health care facilities but also in public areas (Chiappa et al., 2021). Despite the proven effects on viruses, protocols that standardized the parameters for the daily usage of UV-based technologies are yet to be formulated. Even more, all the aforementioned studies were conducted in laboratory conditions. Our research on the already published data indicates that authors cannot reach a consensus regarding the time of exposure, wavelength, distance source-object, dose or irradiance of the exploited UV source, which can be exploited on a daily basis without harming living organisms and simultaneously killing pathogens and allergens. Nonetheless, in healthcare settings, one of the effective ways to deal with the dissemination of viruses is the ultraviolet germicidal irradiation systems. Yet, the reported findings are far from adequate to make a conclusion on the functional parameters of these systems.

If people are to have the confidence to return to offices, then greater attention must be given to keeping them safe. This is where UVC lighting makes a real difference with its extraordinary power to disinfect. It is truly a technology for the “new normal” (McDevitt et al., 2012). For the time being, we anticipate that because of the increased scientific interest in such technology, UV light will be an integral part of our daily life. As for future pandemics, we deeply believe that we will be better prepared.

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Conflict of interest statement: The authors declare no conflict of interest.

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