Southeast Europe Journal of Soft Computing ISSN 2233 – 1859
Available online: http://scjournal.ius.edu.ba

Vol 10, No. 1, March 2021, pp. 30-37

Review of the Effectiveness of UV-C for Disinfection of High Touch Objects

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Article Info

Article history:

Article received on 1 March 2021

Received in revised form 5 March 2021

Keywords:

Healthcare; UV germicidal irradiation (UVGI); infections; decontamination; filtering facepiece respirator (FFR)

ABSTRACT: General wellbeing dangers like bioterrorism, multi-and unnecessary medication safe tuberculosis, pandemic flu, and outrageous intense respiratory problem have heightened attempts to use environmental measures to deter infection spread that is entirely or partly airborne. UV germicidal irradiation (UVGI) is one such control that has gained renewed recognition following quite a while of under-implementation and negligence. With renewed interest, however, come new concerns, especially about effectiveness and protection. Proof shows that the condition of the patient care system has a significant effect on the risk of hospital-acquired infections among hospitalized patients. The new launch of its use for surface decontamination has piqued the attention of medical facilities. Nonetheless, the worldwide scattering of the novel Covid-19 (SARS-CoV-2) brought about a shortage of filtering facepiece respirators (FFR) among medical services experts. This has raised the issue of whether FFRs can be safely sanitized for reuse without endangering primary strength or viability by utilizing UV light. There is a long history of studies reasoning that, when utilized appropriately, UVGI can be both sound and successful in sanitizing surfaces, keeping away from the spread of various airborne microorganisms.

1. INTRODUCTION

UV germicidal irradiation (UVGI) is a well-established decontamination method that can be used to avoid the dissemination of some infectious diseases. Low-pressure mercury (Hg) discharge lamps, which emit shortwave ultraviolet-C (UV-C), 100–280 nanometer (nm) radiation, are widely used in UVGI applications. Microbes are destroyed or inactivated by UV-C radiation because it destroys their deoxyribonucleic acid (DNA) [1]. Surface sanitization is hindered by micro shadows and absorptive protective layers, but UVGI can be used to decontaminate water, air, and surfaces. While ultraviolet (UV) light is well-known for its antimicrobial activity, there is some debate regarding its relative efficacy in surface disinfection.

There is as of now convincing proof that contaminated surfaces in medical centre settings raise the danger of hospital-acquired illnesses spreading to different patients [2].

The old theory that the atmosphere should not lead to infection transmission is rapidly losing legitimacy, as a plethora of research shows that a new patient is at risk of inheriting pathogens left behind in a room by the previous resident. As a result, current literature indicates that increased outdoor surface cleaning and decontamination will minimize the rate of healthcare associated infections [2]. During the most recent COVID-19 pandemic, UV surface disinfection drew a lot of interest, and several items reached the market [3].

UV surface disinfection devices have been used in various public regions with contrasting measures of dirtied surface probabilities, going from facilities and medical services centers to eateries just as a diner. It is also recommended that UVC disinfectors be commonly used to restrict virus spread after public places reopen [4].

However, a lack of awareness for crucial parts of UV sanitization, among the overall population as well as among certain UV surface sterilization producers, has resulted in the misuse of this exciting technology [5]. Unfortunately, questionable and nonscientific efficiency statements by some UV device designers and manufacturers are common.

This study expands on the use of UV exposure to clean polluted media. The authors aim to offer an analytical basic study and theoretical basis of UV exposure prerequisites for sanitization, execution approval techniques for UV frameworks on the surface as well as FFR, and fear of backlash for UV radiation utilization.

2. METHODS

An electronic writing survey was led inside the Google Scholar, Science Direct, and ASM databases for publications written in English until December 2020 using the following keywords: UVGI, healthcare-associated diseases, UV disinfection, N95 FFR, and portable equipment. This is essential to provide a thorough analysis of the effectiveness of using ultraviolet C as a decontamination tool.

3. RESULTS

Our thesis only examined studies about the basic principles of UVGI for decontamination, its efficacy in surfaces and N95 masks of disinfection artifacts, and the protection considerations of the use of UV-C illumination.

3.1. Fundamentals of UV Decontamination

For many decades, UV decontamination has become a proven technology for pathogen disinfection both on surfaces and in air and water 6-[7]. [7]. A particular UV exposure spectrum between 200 and 280 nm, known as the UVC, is widely used as a UV radiation germicidal range. Since the microbial intercellular components (such as RNA, DNA, and protein) absorb UVC photons sensitively [8,] the UVC spectrum has a more adverse impact on microbial cells, as shown in Figure 1.

Absorbed UVC photons do serious harm to the molecular structures of the microorganisms (nucleic acid and microorganism proteins) by keeping them from procreate and exist in the shape of adenine Thymine, as seen in Figure 2, which collapsed and shaped the cell's inability to replicate pyrimidine dimer, a covalent connection. As a result, "inactivation" is the effect of UV illumination on microorganisms rather than "death." While the effectiveness of UV radiation is well established in viral infectivity and virion nucleic acid, an increased environmental UV dose can increase the rate of viral mutation [9].

Also, in the existence of abnormalities, the virus will replicate, but the reactions on viral genes can vary [10]. The deadly effect of UV-induced nucleic acid (DNA or RNA) destruction is based on where the modifications occur within the viral genetic [11]. Besides, certain transformations have minimal recognizable infection sway since they are turned around by the host's nucleic acid repair framework. Since certain viral qualities have a specific task to carry out, most of the transformations diminish infection infectivity. Some mutations, however, may result in the development of more pathogenic viruses. For example, inside the virus structure, a novel receptor-binding protein may be synthesized, allowing the virus to infect a certain cell type in the host. Any UV-resistant virus strains are also expected to appear, perhaps as a result of developing a thicker capsid structure to shield the nucleic acid from UVC damage [11].

UVC sources such as low and medium pressure mercury UV lamps [12], UV light-emitting diodes (UV-LEDs) [13], and far-UVC (200240 nm) radiating excimer and microplasma lamps [14] have been used in academic and industrial research. Figure 3 shows the distribution of spectral power (SPD) from different UVC sources. It is important to remember that UV-LEDs in the UVC region [15]-[16] emit different high wavelengths from 255 to 285 nm, and the SPD of the 270 nm of UV-LED is a piece of evidence shown through Figure 1.

UV decontamination is an energy-based procedure in which the applied UV dosage through the disinfecting device determines the inactivation ratio. The UV dosage (mJ cm2) is measured by multiplying the irradiance or fluence rate gave to microbial cells (mW/cm2) by the exposure time (s) [8]. Consequently, for UV-prompted responses, revealing active information as a component of UV measurement instead of time is the most solid methodology [17].

As opposed to water therapy, decontamination of bio-contaminated air and surfaces may be believed to be more simple and predictable treatments of UV radiation [18]. However, for a UV air or surface disinfector to obtain a valid inactivation rating, such as 99.99 percent, many considerations must be considered, which can be

separated into two categories: intrinsic microbe features and end medium applications.

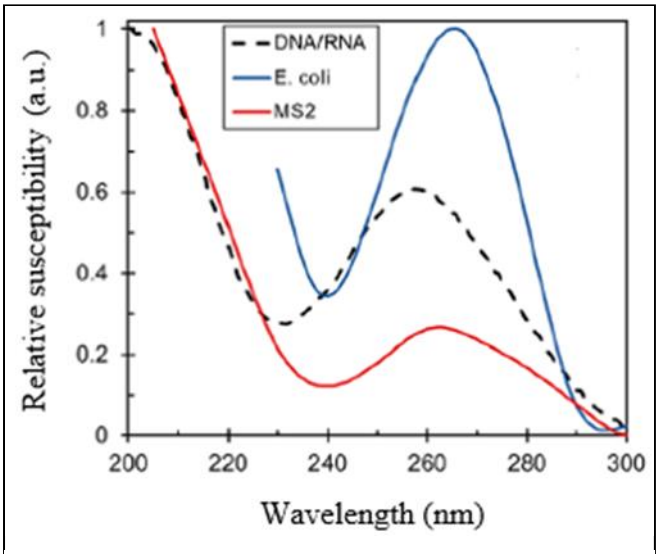

Figure 1: Significant UV resistance of general RNA or DNA as well as MS2 and E. coli virus over the anti-microbial zone from reported values [19]

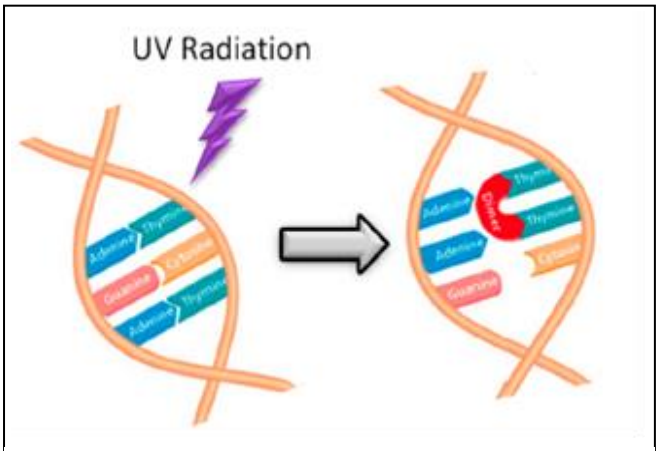

Figure 2: Thymine dimerization model for UV exposed DNA

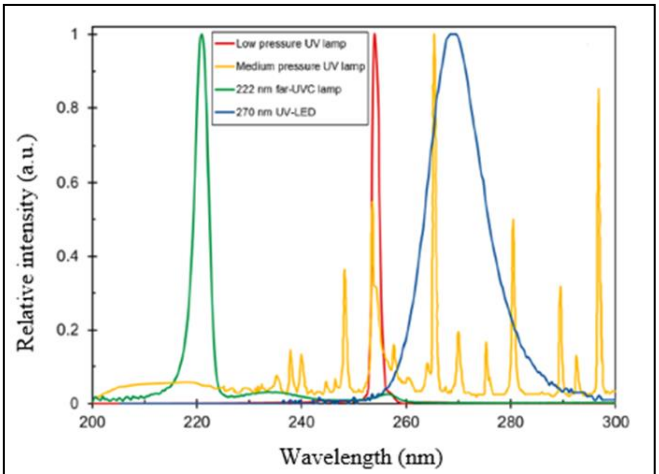

Figure 3**:** Samples for various germicidal UV origins of spectral power distribution (SPD).

3.2. 'No Touch' Methods for Decontaminating Surfaces

Several findings have shown that outdoor surfaces and artifacts are often badly cleaned or disinfected and may play a part in the spread of pathogens associated with healthcare. Furthermore, while action to increase cleanliness has shown efficiency, numerous surfaces remain inadequately washed and, in this way, possibly defiled. As a result, several new methodologies for decontaminating outdoor surfaces (i.e., 'no contact' methods) have been established (Table 1) [20]-[25].

There is already a significant body of evidence showing the efficacy of 'no contact' systems for terminal room sanitization. These methods can be divided into two categories: instruments that use UV light and systems that produce hydrogen peroxide [20]-[25]. UV-C systems are used to relay precise wavelengths (254nm ranges) to areas for microbial bacteria (e.g. 12,000 mWs/cm2) or spores (22,000–36,000 mWs/cm2), with UV pulses releasing large UV spectrum in brief spells [22]. Currently, there are two big hydrogen peroxide networks [21]. First, there are H2O2 vapor systems, which distribute a heat-generated vapor of 30–35 percent (w/w) aqueous H2O2 through a high-speed air stream to accomplish homogeneous dispersion in an encased climate. Second, the pressure-generated aerosol is emitted by aerosolized H2O2 systems [21]. The most often used applications in healthcare use a formulation containing 5–6 percent H2O2 and less than 50ppm platinum. A unidirectional nozzle is used to introduce aerosolized droplets into an enclosure.

Many trials have been conducted to evaluate the efficacy of UV systems in inactivating organisms immunized onto diverse test surfaces and afterward put in an ordinary patient room [20], [23], and [24]. To

healthcare-associated decide the level of inactivation, the inoculating doses were generally greater than 4-log10. MRSA, C. difficile, VRE, and Acinetobacter spp. were the most widely tested pathogens, and they were epidemiologically relevant healthcare-associated pathogens. According to these tests, UV can destroy more than 3-log10 vegetative species in 5–25 minutes, in any case, it takes additional time and energy to kill a spore-framing creature like C. difficile.

Both publications have shown that indirect and overt UV viewing has resulted in fewer killings. The use of UV reflecting paint on the walls has been shown to shorten the time it takes to destroy the pathogen. [26]-[27]. Furthermore, various experiments have tested the efficacy of UV systems in decontaminating real healthcare center rooms after the release of a patient colonized or defiled with a multidrug-safe microorganism [20], [23]-[24]. MRSA, VRE, Acinetobacter, and Clostridium difficile were among the pathogens tested. Cycle times for vegetative bacteria varied from 10 to 25 minutes, while C. difficile cycle times ranged from 10 to 45 minutes. In all cases, the level of healthy surface sites following therapy was less than 11%, and in certain cases, it was less than 1%. The log10 reductions recorded were always greater than 2. Given the generally low bioburden on defiled surfaces in the patient rooms, the diminishing in surface rate is a preferable proportion of UV adequacy over the reduction in log10.

Table 1. 'No touch' methodology for decontamination of surfaces

Room decontamination methodologies for terminal room decontamination	
Ultraviolet light devices	**Hydrogen peroxide systems**
1. UV-C 2. UV-pulsed xenon	1. Hydrogen peroxide vapor (30-35%H2O2) 2. Aerosolized hydrogen peroxide systems(5-6% H2O2 plus silver

3.3. Effectiveness of UVGI in Decontaminating N95 FFR

The new coronavirus (SARS-CoV-2) has a global threat to public health and is especially vulnerable to healthcare staff due to its frequent contact with affected patients. Doctors also verified that the personal protective device (PPE) that they felt better protected during the 2003 SARSCoV-1 outbreak was NIOSH-certified Face Respirator N95, removing 95% of airborne particles [28 - 29]. Similarly, US Centers for Disease Control and Prevention (CDC) formally suggests N95 FFRs be used to treat patients with coronavirus disease (COVID-19) [30]. Sadly, PPE shortage is a big problem and COVID-19 is no different [31-32]. As a result, FFR price controls have become a rising priority in many hospitals around the world.

Decontaminating and reusing existing FFR masks may be one solution to expanding their use. This has raised if FFRs can be reused safely without sacrificing their durability or efficacy [33]. Previously FFR decontamination procedures were examined: Bleach, autoclaving, ethanol, microwaving, hydrogen peroxide, and UV light [34-36]. UVGI (ultraviolet germicidal irradiation) with shortwave ultraviolet-C light (UV-C, usually 245 nm) has a long practice of sterile uses in medication and is utilized for health center air sanitization [37]. In recent audits, UV-C light is getting progressively basic for microbial cleaning of items from toothbrushes to stethoscopes [38]-[40], also, its versatility renders it ideal for huge scope cleaning all through a pandemic.

We found several studies that focused on enhancements of aerosol penetration after UVGI. NIOSH has developed a 95 percent filter efficiency standard (i.e. a 5 percent filter penetration) for N95 FFR [41]. The five reports published on aerosol penetration followed NIOSH monitoring guidelines. The implementation of several separate UVGI protocols on some FFR models resulted in a marginal improvement in filter performance, and all FFRs tested retained the normal filter efficiency of 95%. A new study on N95 decontamination and reuse from N95 FFR manufacturer 3M stresses the vital value of ensuring the filter performance does not influence the disinfection process [42]. The research additionally contains the discoveries of an interior examination, which found that 3M N95 FFRs held a channel execution of 95% after delayed UVGI exposure (5-10 UV-C cycles) however needed more detail to gauge a complete UVGI measurement. Notwithstanding channel proficiency prerequisites, NIOSH has created wind current obstruction norms for N95 FFRs. To meet endorsement prerequisites, N95 FFRs should show a pinnacle normal inward breath of 35 mm (343.2 Pa) and an exhalation protection from wind current of 25 mm (245.1 Pa) H2O pressure [43]. Testing is conducted using a filter tester at 85 L/min of constant airflow. Three experiments were identified in this study that examined airflow filtration using uniform testing protocols following UVGI. None of the seven FFRs studied in the three studies demonstrated significant variations in airflow filtration after UVGI, and all FFRs met NIOSH airflow criteria.

While the capacity and fit of the FFR are significant, another undeniable factor for assessing UVGI boundaries is their capacity to prevent unsafe substances from the veil surface. The seven decontamination findings demonstrate that UV-C light contact can essentially diminish the measure of practical N95 FFR viral microorganisms and consistently result in log reductions of 2 and 3 at cumulative dose levels of >20,000 J/m2. Nevertheless, it should be remembered that these two tests were carried out in a lab and don't address certifiable conditions. It is shown that the UVGI disinfection effect can be stronger in the actual world. A study overflowed the mask surface with more infection than expected after an actual case of infection. However, 12 of the 15 masks tested showed a viral load reduction of three logs. [44]. Note that without a significant decrease in all 15 masks, the form and content of the mask ought to be considered as elements that can impact the viability of UVGI sanitization. The log reduction of Cardinal N95-ML to 0.1 0.2 was recorded by a study compared to 2.9 0.2 and >4.8 for the other masks checked [45] due to a high-security layer of external masks that lowered the number of UV-C filters accessing mask layers.

All in all, there is strong proof of N95 FFR sustainability after a single UVGI loop. The penetration of aerosol and airflow filtration is critically measured, and the control arm used in their construction in all research studies conducted on FFR function. There is lower evidence for UVGI's effectiveness in mask decontamination. Given the clear findings in the experiments and the use of a control group in the design of the analysis, results evaluators were not blinded. Besides, much of today's literature is laboratory-focused and does not constitute circumstances in the modern world.

3.4. Safety Considerations of UV Light

UV has different impacts on the physiology of the tissue, with implications immediately and afterward. The actuation of a course of the medium layer in the skin, adding to burn from the sun, is perhaps the most obvious intense impacts of UV on the skin. UV radiation is often referred to as a "true carcinogen" because it is both a mutagenic and a non-specific harmful agent, and a cancer initiator and promoter. UV and skin pigmentation raise both the chance of skin cancer [46]. Moreover, if the eye is presented to an excess of UV radiation, it is probably going to cause retinal injury, erythema of the eyelid, solar retinopathy, photokeratitis, and cataracts[47].

Hazardous UV harm to human skin or eyes requires both primary irradiation and indirect exposure by surface UV reflection. Secondary damage from UV-reflective surfaces must be a critical concern when developing UV surface disinfection systems. PTFE, titanium, and stainless-steel surfaces, for example, will reflect up to 95 percent, 90 percent, and 50 percent of UVC radiation, respectively. The maximum limit value (TLV) for the exposure to human UV is a "effective" UV dose (irradiance exposure duration) of 3 mJ cm2 in 8 hours, based on laws provided by different organizations such as the American Cancer Society, the American Conference of Governmental Industrial Hygienists and the European Agency for Safety and Health at Work. The term "efficient" is critical in this regulation and is decided dependent on the most extreme affectability of the natural eye, which was found to be around 270 nm [48]. This wavelength is used to compare the ability of other UV wavelengths to evoke a biological response. The spectral efficacy of 254 nm UVC rays, for example, is 0.5, which means that 6 mJ cm2 of 254 nm UVC will have the same effect as 3 mJ cm2 of 270 nm UVC (TLV for human exposure). The TLV values over the UVC area are taken from the US Navy Environmental Health Center's Ultraviolet Radiation Guide [48] and are illustrated in Figure 4. As the UV dose rises to the TLV, intense reactions of a sunburn can occur which results in the "cells of sunburn" on the skin. A variety of safety precautions, for example, an infant lock and movement sensor just as the making of a mask for the UV exposure zone could essentially lessen the danger of people exposure just as the utilization of fitting PPE, for example, UV safeguard lenses and gloves.

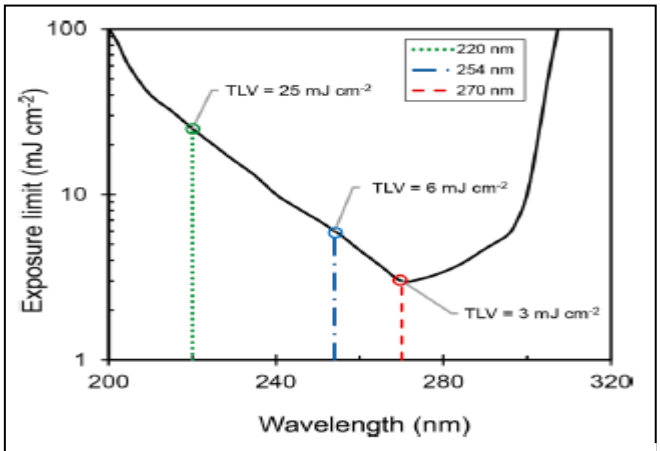

Figure 4: UVC spectrum threshold limits values (TLV) derived from research for person UV radiation. [48]

Even if the vendor has the most efficient device, the user's vigilance will eventually decide the effectiveness of the UV sterilization for similar operational wellbeing conditions. Handheld UV sanitization gear, for instance, ought not to be utilized for hand or wound disinfection.

The common population may in any case be unconscious of what amount of time it requires to illuminate any given surface structure, at what frequency, and with what wellbeing safety measures. As a result, UV surface disinfection units require a detailed operating manual to be supplied with the package. Ground folds and crevices often necessitate additional visibility. Thus, the minimum required exposure duration for portable UV surface decontaminators must be provided in product recommendations, comparable to current hygiene standards that recommend the utilization of synthetic wipes for determining spans going from 1 to 10 minutes to appropriately treat routinely contacted surfaces.

Finally, UV irradiation is believed to degrade the components that are irradiated (i.e., polymers). By creating revolutionaries on a surface level that can meddle with the infection and incite in situ transformation, such oxidation can separate the material design and abbreviate the life expectancy of the illuminated material. Thus, the applied measurement of UVC energy ought to be adjusted to arrive at healthy degrees of biocidal adequacy while avoiding unnecessary energy that would degrade the surfaces over their expected lifespan [49].

4. CONCLUSION

The point of this review paper is to give an investigation outcome of the utilization of UV radiation to disinfect polluted media. We have spoken about the technical basics of UV dose rules for sanitization, conventions for execution approval of UV frameworks on surfaces and FFR, and security issues when utilizing UV radiation. The improved use of air and surface disinfection sterilization devices attests to the need for clean and simple disinfection methods for the general public. Without a grounded convention and directions for approving purchaser UV sanitization items, an immense number of UV-based disinfection gadgets with unsure efficacies against microorganisms and an absence of security proof offered genuine conversation starters concerning whether those items are prepared for use by inexperienced consumers. This 'no contact' technology, on the other hand, nosocomial viruses are destroyed on inoculated tests and genuine condition surfaces and appliances in the patient rooms. More than enough clinical preliminaries have now shown that HAIs are reduced to a minimum for one of these technologies. More well-equipped experiments (e.g., randomized controlled preliminaries) to decide the degree to which these innovations can alleviate disease infections. Simple comparative analyses with various systems can be highly helpful. Finally, cost–benefit analysis must be performed.

CONFLICT OF INTEREST

Nothing to declare

REFERENCES

[1] N. G. Reed, “The history of ultraviolet germicidal irradiation for air disinfection,” Public Health Rep., vol. 125, no. 1, pp. 15–27, 2010,

[2] A. Elgujja, H. Altalhi, and S. Ezreqat, “Review of the efficacy of ultraviolet C for surface decontamination,” J. Nat. Sci. Med., vol. 3, no. 1, p. 8, 2020,

[3] Shining a Light on COVID-19. Nat. Photonics. 2020, 14, 337.

[4] García de Abajo, F. J.; Hernández, R. J.; Kaminer, I.; Meyerhans, A.; Rosell-Llompart, J.; Sanchez-Elsner, T. Back to Normal: An Old Physics Route to Reduce SARS-CoV-2 Transmission in Indoor Spaces. ACS Nano 2020, 14, 7704.

[5] M. Raeiszadeh and B. Adeli, “A Critical Review on Ultraviolet Disinfection Systems against COVID-19 Outbreak: Applicability, Validation, and Safety Considerations,” ACS Photonics, 2020,

[6] Kowalski, W. Ultraviolet Germicidal Irradiation Handbook: UVGI for Air and Surface Disinfection; Springer: Berlin Heidelberg, 2009.

[7] Adeli, B. Not If, But When: UV LED Beverage Disinfection. IUVA News 2020, 10−11.

[8] Bolton, J. R.; Cotton, C. A. The Ultraviolet Disinfection Handbook; American Water Works Association, 2008.

[9] Norval, M. The Effect of Ultraviolet Radiation on Human Viral Infections. Photochem. Photobiol. 2006, 82, 1495.

[10] Cornelis, J. J.; Su, Z. Z.; Rommelaere, J. Direct and Indirect Effects of Ultraviolet Light on the Mutagenesis of Parvovirus H-1 in Human Cells. EMBO J. 1982, 1, 693.

[11] NORVAL, M.; EL-GHORR, A.; GARSSEN, J.; VAN LOVEREN, H. The Effects of Ultraviolet Light Irradiation on Viral Infections. Br. J. Dermatol. 1994, 130, 693.

[12] Craik, S. A.; Weldon, D.; Finch, G. R.; Bolton, J. R.; Belosevic, M. Inactivation of Cryptosporidium Parvum Oocysts Using Medium and Low-Pressure Ultraviolet Radiation. Water Res. 2001, 35 (6), 1387−1398.

[13] Song, K.; Taghipour, F.; Mohseni, M. Microorganisms Inactivation by Wavelength Combinations of Ultraviolet Light- Emitting Diodes (UV-LEDs). Sci. Total Environ. 2019, 665, 1103−1110.

[14] Raeiszadeh, M.; Taghipour, F. Microplasma UV Lamp as a New Source for UV-Induced Water Treatment: Protocols for Characterization and Kinetic Study. Water Res. 2019, 164, 114959.

[15] Saifaddin, B. K.; Almogbel, A. S.; Zollner, C. J.; Wu, F.; Bonef, B.; Iza, M.; Nakamura, S.; Denbaars, S. P.; Speck, J. S. AlGaN Deep- Ultraviolet Light-Emitting Diodes Grown on SiC Substrates. ACS Photonics 2020, 7, 554

[16] Song, K.; Mohseni, M.; Taghipour, F. Application of Ultraviolet Light-Emitting Diodes (UV-LEDs) for Water Disinfection: A Review. Water Res. 2016, 94, 341−349.

[17] Bolton, J. R.; Mayor-Smith, I.; Linden, K. G. Rethinking the Concepts of Fluence (UV Dose) and Fluence Rate: The Importance of Photon-Based Units - A Systemic Review. Photochem. Photobiol. 2015, 91, 1252

[18] Gora, S. L.; Rauch, K. D.; Ontiveros, C. C.; Stoddart, A. K.; Gagnon, G. A. Inactivation of Biofilm-Bound Pseudomonas Aeruginosa Bacteria Using UVC Light Emitting Diodes (UVC LEDs). Water Res. 2019, 151, 193.

[19] Chen, R. Z.; Craik, S. A.; Bolton, J. R. Comparison of the Action Spectra and Relative DNA Absorbance Spectra of Microorganisms: Information Important for the Determination of Germicidal Fluence (UV Dose) in an Ultraviolet Disinfection of Water. Water Res. 2009, 43, 5087.

[20] Weber DJ, Rutala WA, Anderson DJ, et al. Effectiveness of UV devices and hydrogen peroxide systems for terminal room decontamination: focus on clinical trials. Am J Infect Control 2016; 44 (5 Suppl):e77–e84.

[21] Otter JA, Yezli S, Perl TM, et al. The role of 'no-touch' automated room disinfection systems in infection prevention and control. J Hosp Infect 2013; 83:1–13.

[22] Canadian Agency for Drugs and Technologies in Health, Ottawa (ON). Non manual techniques for room disinfection in healthcare facilities: a review of clinical effectiveness and guidelines [Internet]; 2014 April.

[23] Barbut F. How to eradicate Clostridium difficile from the environment. J Hosp Infect 2015; 89:287–295

[24] Doll M, Morgan DJ, Anderson D, Bearman G. Touchless technologies for decontamination in the hospital: a review of hydrogen peroxide and UV devices. Curr Infect Dis Rep 2015; 17:498.

[25] Rutala WA, Weber DJ. Disinfection and sterilization in health-care facilities: an overview and current issues. Infect Dis Clinic N Am 2016.

[26] Rutala WA, Gergen MF, Tande BM, Weber DJ. Rapid hospital room decontamination using ultraviolet (UV) light with a nanostructured UV-reflective wall coating. Infect Control Hosp Epidemiol 2013; 34:527–529.

[27] Rutala WA, Gergen MF, Tande BM, Weber DJ. Room decontamination using an ultraviolet-C device with short ultraviolet exposure time. Infect Control Hosp Epidemiol 2014; 35:1070–1072.

[28] Bałazy, A, Toivola, M, Adhikari, A, Sivasubramani, S, T, R & Grinshpun, S. Do N95 respirators provide 95% protection level against airborne viruses, and how adequate are surgical masks? American Journal of Infection Control 2006; 34: 49-56

[29] Tan, N, Goh, L & Lee, S. Family physicians' experiences, behavior, and use of personal protection equipment during the SARS outbreak in Singapore: do they fit the Becker Health Belief Model? Asia Pacific Journal of Public Health 2006; 18: 49–56.

[30] Centre for Disease Control and Prevention. Strategies for optimizing the supply of N95 respirators: Conventional capacity strategies., https://www.cdc.gov/coronavirus/2019-ncov/hcp/respirators-strategy/conventional-capacity-strategies.html; [Accessed March 28. 2020]

[31] Patel, A, D'Alessandro, MM, Ireland, KJ, Burel, WG, Wencil, EB & Rasmussen, SA. Personal Protective Equipment Supply Chain: Lessons Learned from Recent Public Health Emergency Responses. Health Secur 2017; 15: 244-252.

[32] Srinivasan, A, Jernign, DB, Liedtke, L & Strausbaugh, L. Hospital preparedness for severe acute respiratory syndrome in the United States: views from a national survey of infectious diseases consultants. Clin Infect Dis 2004; 39: 272-274.

[33] Bauchner, H, Fontanarosa, PB & Livingston, EH. Conserving Supply of Personal Protective Equipment-A Call for Ideas. JAMA 2020.

[34] Heimbuch, BK, Wallace, WH, Kinney, K, Lumley, AE, Wu, CY, Woo, MH et al. A pandemic influenza preparedness study: use of energetic methods to decontaminate filtering facepiece respirators contaminated with H1N1 aerosols and droplets. American Journal of Infection Control 2011; 39: e1-9.

[35] Lin, TH, Tang, FC, Hung, PC, Hua, ZC & Lai, CY. Relative survival of Bacillus subtilis spores loaded on filtering facepiece respirators after five decontamination methods. Indoor Air 2018; 31: 31.

[36] Viscusi, DJ, Bergman, MS, Eimer, BC & Shaffer, RE. Evaluation of five decontamination methods for filtering facepiece respirators. Annals of Occupational Hygiene 2009; 53: 815-827.

[37] Reed, NG. The history of ultraviolet germicidal irradiation for air disinfection. Public Health Rep 2010; 125: 15-27.

[38] Agrawal, SK, Dahal, S, Bhumika, TV & Nair, NS. Evaluating Sanitization of Toothbrushes Using Various Decontamination Methods: A Meta-Analysis. J Nepal Health Res Counc 2019; 16: 364-371.

[39] Napolitani, M, Bezzini, D, Moirano, F, Bedogni, C & Messina, G. Methods of Disinfecting Stethoscopes: Systematic Review. Int J Environ Res Public Health 2020; 17:

[40] Ahmed, I, Fang, Y, Lu, M, Yan, Q, El-Hussein, A, Hamblin, MR et al. Recent Patents on Light-Based Anti-Infective Approaches. Recent Pat Antiinfect Drug Discov 2018; 13: 70-88.

[41] National Institute for Occupational Safety and Health. NIOSH Guide to the Selection and Use of Particulate Respirators, https://www.cdc.gov/niosh/docs/96-101/default.html; 1996 [Accessed March 27, 2020]

[42] 3M. Disinfection of Filtering Facepiece Respirators, https://multimedia.3m.com/mws/media/1816576O/disinfection-of-disposable-respiratorstechnical-bulletin.pdf; 2020 [Accessed March 27, 2020]

[43] 2. Code of Federal Regulations (42 CFR 84.180). Airflow resistance tests., [Accessed March 29, 2020]

[44] Mills, D, Harnish, DA & Lawrence, C. Ultraviolet germicidal irradiation of influenza contaminated N95 filtering facepiece respirators. American journal of infection control,2018.

[45] Fisher, EM & Shaffer, RE. A method to determine the available UV-C dose for the decontamination of filtering facepiece respirators. Journal of applied microbiology 2010.

[46] D'Orazio, J.; Jarrett, S.; Amaro-Ortiz, A.; Scott, T. UV Radiation and the Skin. Int. J. Mol. Sci. 2013, 14, 12222.

[47] Van Kuijk, F. J. G. M. Effects of Ultraviolet Light on the Eye: Role of Protective Glasses. Environ. Health Perspect. 1991, 96, 177.

[48] D'Orazio, J.; Jarrett, S.; Amaro-Ortiz, A.; Scott, T. UV Radiation and the Skin. Int. J. Mol. Sci. 2013, 14, 12222.

[49] Jo, H.; West, A. M.; Teska, P. J.; Oliver, H. F.; Howarter, J. A. Assessment of Early Onset Surface Damage from Accelerated Disinfection Protocol. Antimicrob. Resist. Infect. Control 2019.