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Ultraviolet-C decontamination of a dental clinic setting: required dose and time of UVC light

Utilização de radiação ultravioleta-C para descontaminação de um consultorio odontológico: tempo e dose de UVC necessária

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ABSTRACT

Viruses can spread to the environment, and it can be challenging to clear it. A direct approach to limit airborne transmission of pathogens in dental clinic offices is to inactivate viruses within a short time of their production and block the person-to-person transmission routes in dental clinics. For this, we can use chemical substances on surfaces and germicidal ultraviolet light (UV), typically at 254 nm, for complementary disinfection of surfaces and air contaminated by aerosols produced by high-speed handpiece or ultrasound scaler. Based on the literature review and the similarity of Sars-Cov-2 with other previously studied corovaviruses, COVID-19 is sensitive to UV irradiation that can break the genome of this virus, inactivating it. In our study, we performed the calculation of the time required to decontaminate a dental care room between each patient change. We can conclude that the use of UVC can be incorporated into the dental care routine to reduce cross contamination.

KEYWORDS

UVC-decontamination; Sterilization; Ultraviolet light; Dentistry; Sars-Cov-2.

RESUMO

Os vírus podem se espalhar para o meio ambiente e pode ser um desafio eliminá-lo. Uma abordagem direta para limitar a transmissão aérea de patógenos nos consultórios de clínicas odontológicas é inativar os vírus o mais rápido possivel após sua produção e bloquear as rotas de transmissão de pessoa para pessoa nas clínicas odontológicas. Para isso, podemos usar substâncias químicas para limpar as superfícies e luz ultravioleta (UV) germicida (UV), normalmente a 254 nm, para desinfecção complementar de superfícies e ar contaminado por aerossóis produzidos pelo altarotação ou ultrassom periodontal. Com base na revisão de literatura e na semelhança do Sars-Cov-2 com outros corovavirus previamente estudados, o COVID-19 é sensível à irradiação UV que podem quebrar o genoma desse vírus, inativando-o. Em nosso estudo, realizamos o cálculo de tempo necessário para descontaminar uma sala de atendimento odontológico entre cada troca de paciente. Podemos concluir que a utilização de UVC pode ser incorporada à rotina de atendimento odontológico para reduzir a contaminação cruzada entre atendimentos.

PALAVRAS-CHAVE

Descontaminação UVC; Esterilização; Luz ultravioleta; Odontologia; Sars-Cov-2.

INTRODUCTION

Dental offices produce a high amount of aerosol during several different types of standard clinical procedures, especially with high-speed dental use, for example. For this reason, dental offices are high-risk settings of cross-infection among patients, dentists, and health professionals during regular clinical situations [1]. Surface disinfection of equipment and noncritical surfaces is commonly performed by the crew that manually applies a liquid disinfectant to surfaces with a disposable wipe, mop, or cloth. The reduction on environment-mediated infection transmission by effective environmental disinfection in healthcare facilities is essential.

Novel germicidal ultraviolet light devices are currently at the forefront of increasing automated technologies due to the well-documented efficacy of ultraviolet-C (UVC) irradiation for killing bacteria, fungi, yeasts, viruses, and persistent spores [2].

UVC has the property of ionization, thus acting as a potent mutagen, which can cause immune-mediated disease and cancer in adverse cases. Ultraviolet radiation is not known to contribute to visual perception but to mainly damage multiple structures. High dose exposure to ultraviolet radiation causes direct cellular damage, which has an essential role in the development of cancer [3].

The mechanism of killing of microorganisms by UVC is primarily due to the inactivation of desoxyribonucleic acid (DNA) and ribonucleic acid (RNA) through the absorption of photons resulting in the formation of pyrimidine dimers from thymine and cytosine [4].

The radiation of the sun includes in its radiation waves like radio, infrared, visible light, x-rays, gamma-ray, cosmic rays, and ultraviolet radiation. The ozone layer that overlays the Earth filters about 100% of UVC radiation, so the UVC radiation can only be obtained for use through special lamps.

The germicidal effect of this type of energy was first reported by Downs & Blunt at the end of the 19th century, precisely in 1878. Due to problems of equipment reliability, technology, among others, the use of UV was abandoned at the time.

The ultraviolet radiation used to inactivate microorganisms is usually obtained through special lamps, commercially called germicidal lamps that are low-pressure lamps and short wave ultraviolet, designed for high yield of UVC rays of 253.7 nm peak.

Ultraviolet light consists of light with wavelengths between 40 and 390 nm, subdivided into three wavelength bands, called UV-A (400 to 320 nm), UV-B (320 to 290 nm) and UV-C (290 to 100 nm), with the 300 to 220 nm region called germicidal region (with a peak at 253.7 nm) that is used to disinfection of air, water or surfaces, and sterilization of certain thermosensitive materials.

Units and terminology for the health effects of UV on animals and humans are the same as for germicidal effects of UV on microbes. UV exposure is quantified in terms of irradiance, preferably measured in units of W/m^2. Cumulative UV exposure is quantified in terms of the exposure dose, preferably measured in units of J/m^2 or mJ/cm^2.

Coronavirus disease 2019 (COVID–19) was first reported in December 2019 and was declared by the World Health Organization as an international public health emergency [5].

The Covid-19 virus has not yet been specifically tested for its UVC susceptibility but many other tests on related coronaviruses, including the SARS-CoV (severe acute respiratory syndrome coronavirus) and MERS-CoV (Middle East respiratory syndrome coronavirus), have concluded that they are highly susceptible to ultraviolet inactivation [6]. UVC has been reported reducing contamination on N95 respirators with high-level disinfection with an extended cycle [7].

The UVC dose required for a 99% viral reduction on surfaces for double-stranded RNA and double-stranded DNA viruses is respectively 10.57 mJ/cm^2 and 16.2 mJ/cm^2 that was more resistant to UVC than single-stranded RNA and single-stranded DNA viruses respectively 6.5 mJ/cm^2 and 8.34 mJ/cm^2 [8].

Coronaviruses contain a single-stranded RNA viruses (+ssRNA) genome surrounded by a corona-like helical envelope [9].

Upon this moment, over a hundred genome sequences of SARS-CoV-2 were published, and these suggest there are two types: Type I came from an unknown location, and Type II came from the Wuhan seafood market in China [10]. The genome of SARS-CoV-2 consists of 29.751 base pairs and is about 80% homologous with SARS viruses [11]. Coronaviruses have a size range of 60nm to 140 nm, with a mean size of 0.10 microns [12].

The range of D90 values for coronaviruses is 0.7 to 24.1 mJ/cm^2 [13, 14]. Otherwise, an energy density of 30 mJ/cm^2 can adequately represent the ultraviolet susceptibility of the SARS-CoV-2 (COVID-19) virus.

Dental care settings carry the risk of 2019-nCoV infection because the dental procedure involves face-to-face communication with patients, frequent exposure to saliva, and blood, and the handling of sharp instruments [15].

The pathogenic virus can be transmitted in dental settings through inhalation of aerosols microorganisms that can remain suspended in the air some hours, or direct contact with oral fluids and blood, contact of conjunctival, nasal, or oral mucosa with droplets and aerosols containing microorganisms generated from an infected individual, and indirect contact with contaminated instruments or surfaces. Infections could be present through any of these conditions involved in an infected individual in dental clinics and hospitals, especially during the outbreak of COVID-19 [16].

Confirmed modes of viral transmission of Coronaviruses are primarily but not exclusively contact with contaminated environmental surfaces and aerosols [17].

A viral pathogen like COVID-19 can survive at room temperature (22^{o}C; Relative humidity: ~65%) on aerosols for at least 3 hours, and on a variety of surface materials commonly encountered in dental offices like stainless steel (7 days), plastic (7 days), cardboard (3 days), glass (4 days), banknotes (4 days), cloth (2 days), wood (2 days) and paper (3 hours) [17-19]. As explained above, cleaning failures in the dental room can increase the risk of cross-contamination during patient care.

Despite being commercially common equipment using UVC for sterilization of water, air, food, rooms, among others, the literature is still very scarce, especially in the application suggested in this work.

The objective of the present study is to present the required amount of UVC light to decontamination use in the dental clinic setting.

MATERIALS AND METHODS

Figure 1 shows the layout of a model room of dimensions L (length) x W (width) x H (height) to be sterilized [34]. We can note that in this configuration, there are two lamps of length l, placed a distance d from the walls of the room.

The location of any point source on the lamp is (X, d, H), where (L-l)/2 < X < (L+l)/2. The distance between the luminous point and any point (x, y, z) in the volume of the room is:

$$r = (X - x)^2 + (d - y)^2 + (H - z)^2 \tag{1}$$

A point of light radiates isotropically in a sphere, so the radiation intensity reaching a point x, y, z in the room is:

$$I_{ponto} = \frac{P/l}{4\pi r} \tag{2}$$

where P/l is the power of each point of light.

To calculate the intensity of light that reaches each point of the room's volume, irradiated by one lamp, we have:

$$I = \int_{(L-l)/2}^{(L+l)/2} \frac{P/l}{4\pi r} \tag{3}$$

Using Eq. (3), a radiation map can be made for any plane xy, xz ou yz in the room.

Python 3.6 [35] and some libraries from python ecosystem namely: IPython 6.2, Jupyter 4.4 , numpy 1.6, pandas 0.23 [36] and matplotlib 3.1 [37] were used for numerical evaluation of equation eq. 3.

We used in this study a lamp OSRAM PURITEC HNS(OSRAM GmbH, Wilmington, MA, USA) with 90 cm length and 22 mm diameter, with 55 W total power that emits 18 W UVC power at 254nm, with nominal voltage of 83 V, current of 0.77 A, luminous intensity of 7800 cd, connection base G13 and approximately life of 9000 h.

In the example, we used two lamps (55 W OSRAM PURITEC HNS) of low pressure that emit mercury line radiation mainly in the short-wave ultraviolet range at 254 nm, about 85% of maximum effectiveness, about 85% of maximum effectiveness, and are ozone-free (Figure 2).

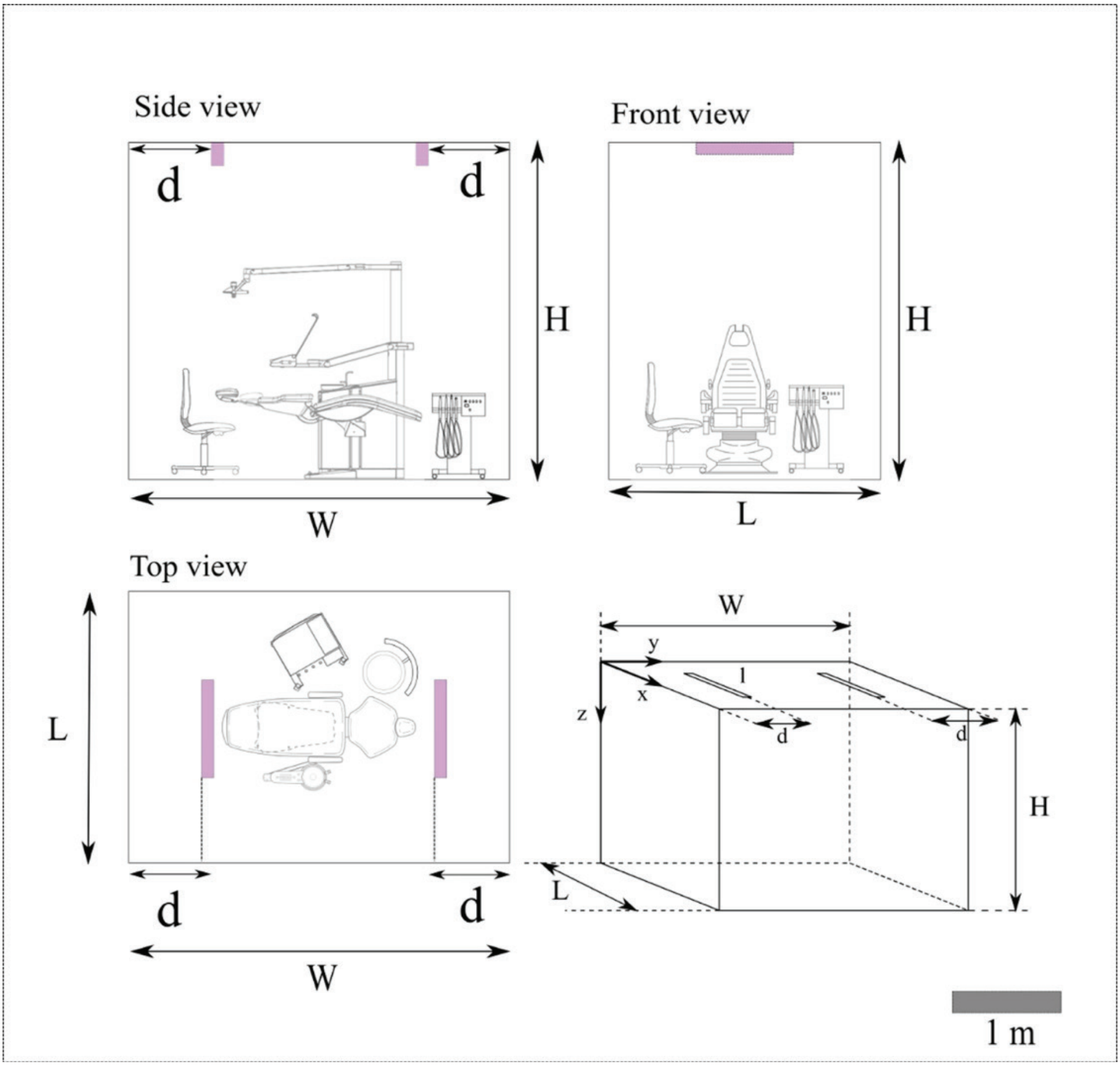

Figure 1 - Layout of a dental office room to be sterilized using two UVC lamps at the ceiling.

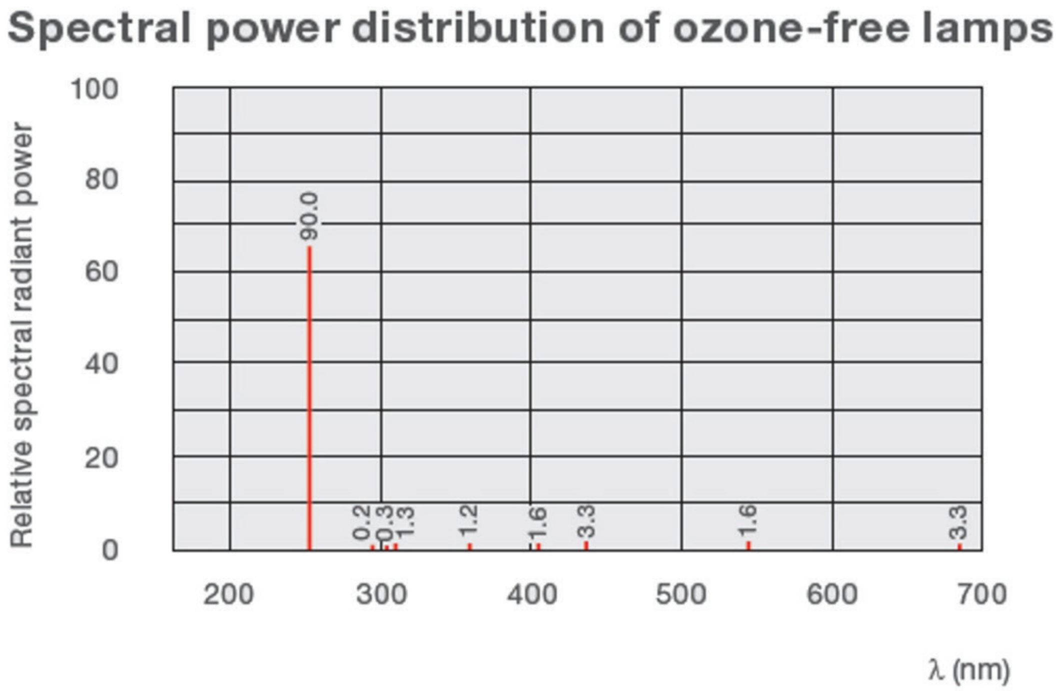

Figure 2 - Shows the spectral power distribution of ozone-free lamps (Osram product datasheet).

RESULTS

Figure 3 shows the example of calculation for a room of dimensions H = 3.10 m, L = 2.50 m, and W = 3.50 m for the floor level. Each of the lamps has 18 W of UVC power and length l = 0.9 m. The exposure time is 20 minutes. Each of the lamps is located at a distance d = 0.5 m from the walls. Figure 3a) shows the situation where only the left lamp is on and Figure 3b) shows the situation where only the right lamp is on. In both situations, we can see from the intensity bar that the intensity is less than 30 mJ/cm^2. Thus, both situations are insufficient. When the two lamps are used simultaneously, we have the situation shown in figure 3c. For this, a new intensity matrix is calculated, which is actually the original matrix rotated around the y/2 axis. The total intensity for each point is calculated by adding the two matrices. We can see that the sum of the intensities. We can see by the intensity bar that the intensity values are about 30 mJ/cm^2 with a much more uniform distribution.

Figure 4 shows a comparison of intensities between different heights (or different xy planes). We have as examples the intensity distribution for the half-height of the room (figure 4a, z = H/2= 1.55 m), for a workbench (figure 4b, z = 0.8 m), for a dental chair water unit (figure 4c, z = 0.7 m) for a dental chair and dental stool (figure 4d, z = 0.6 m). For all described heights, it can be observed that there is more than enough sterilization dose.

Note from figures 3c and 4 that there is enough radiation uniformity to dispose all the required equipments at 30mJ/cm^2 freely. For 40mJ/cm^2 the time required is 26 minutes irradiation. In addition, for more common rooms with about 2.54 m height, the same configuration applies, and the irradiation time for 40mJ/cm^2 is about 20min. (Figure 5)

The UV sterilization system was easily assembled using parts purchased from local businesses at a low cost. However, the system needs validation by the National Sanitary Agency of Brazil (ANVISA) to ensure applicability for the dental office.

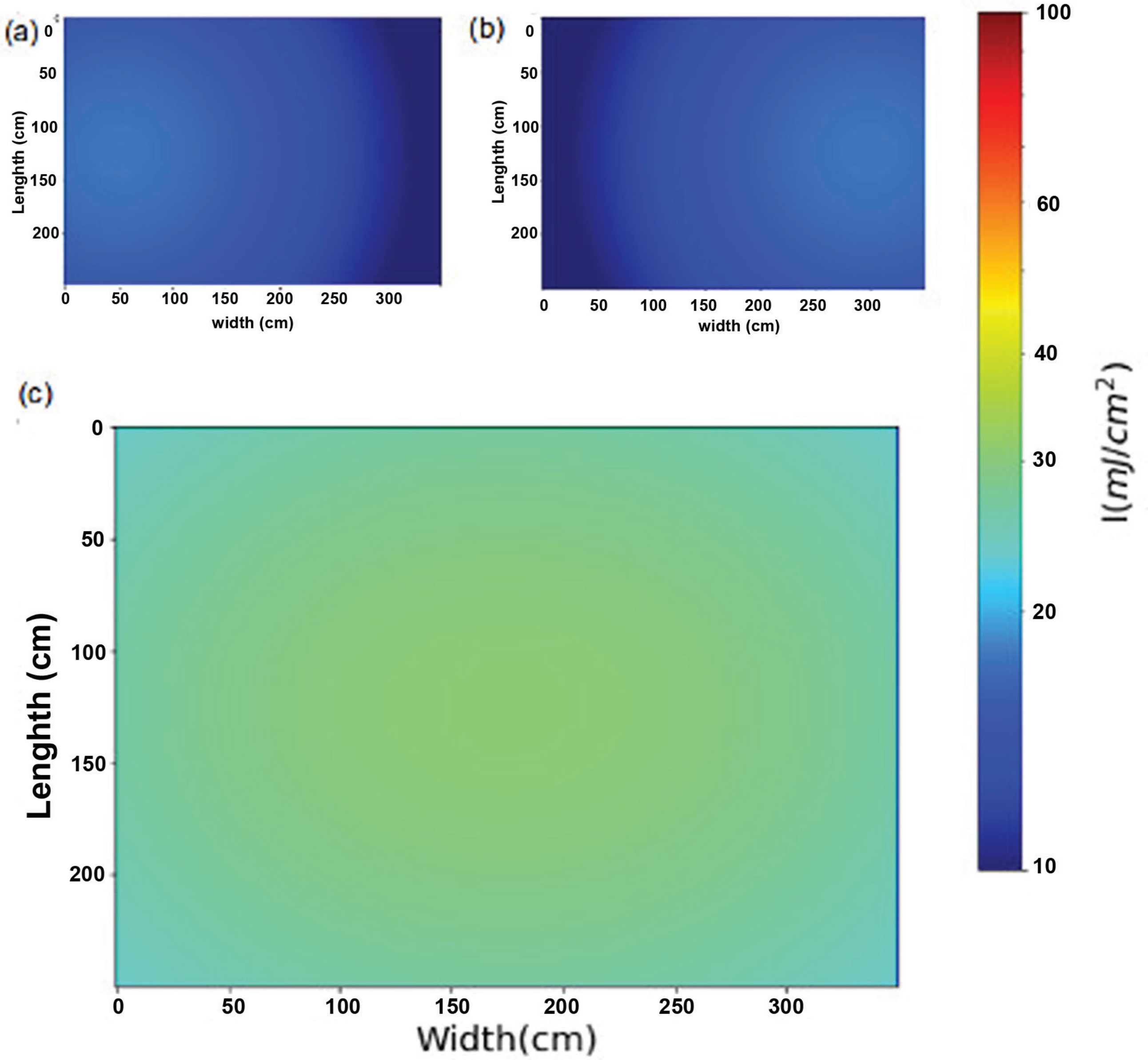

Figure 3 - Shows the example of calculation for a room of dimensions H = 3.10 m, L = 2.50 m, and W = 3.50 m for the floor level, where (a) and (b) corresponds to only one lamp on and (c) both lamps on.

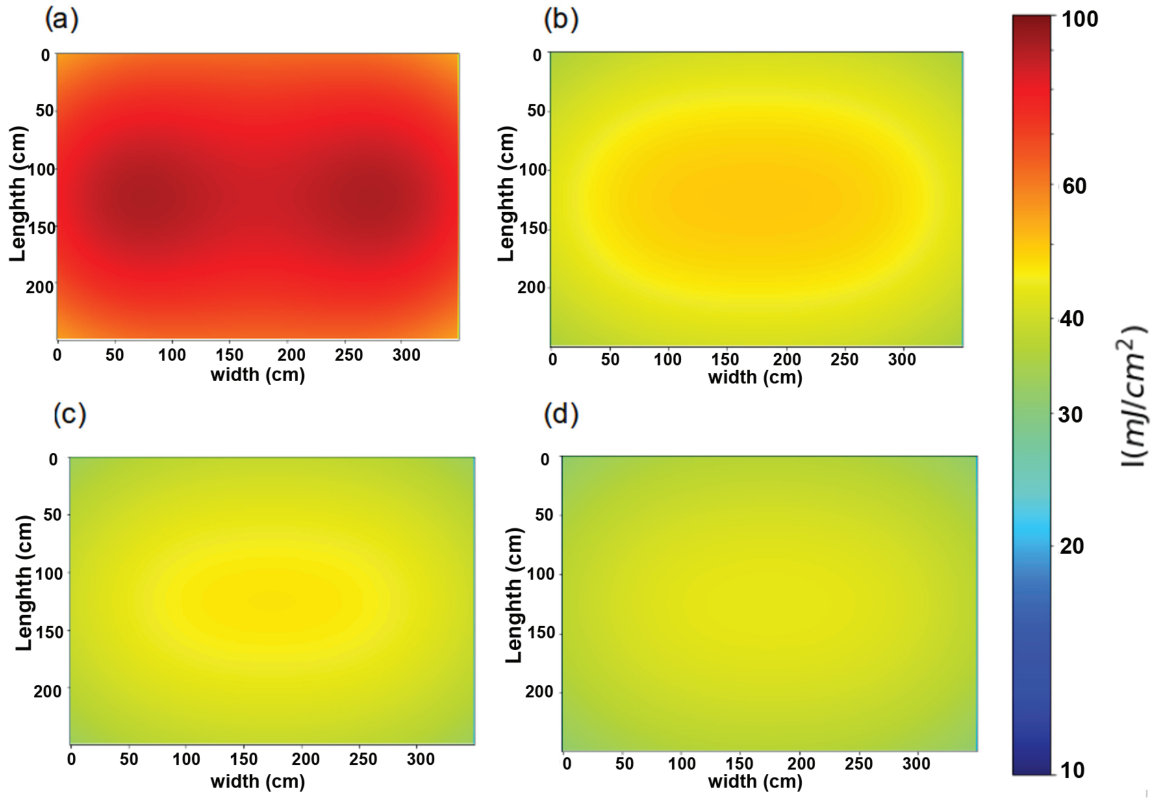

Figure 4 - An example of calculation for model room with 3.10m height for 18W UVC irradiation for 20 minutes: (a) half height (z = H/2 = 1.55 m), (b) workbench height (z = 0.8 m), (c) dental chair water unit (z = 0.7 m) and (d) dental chair and dental stool (z = 0.6 m).

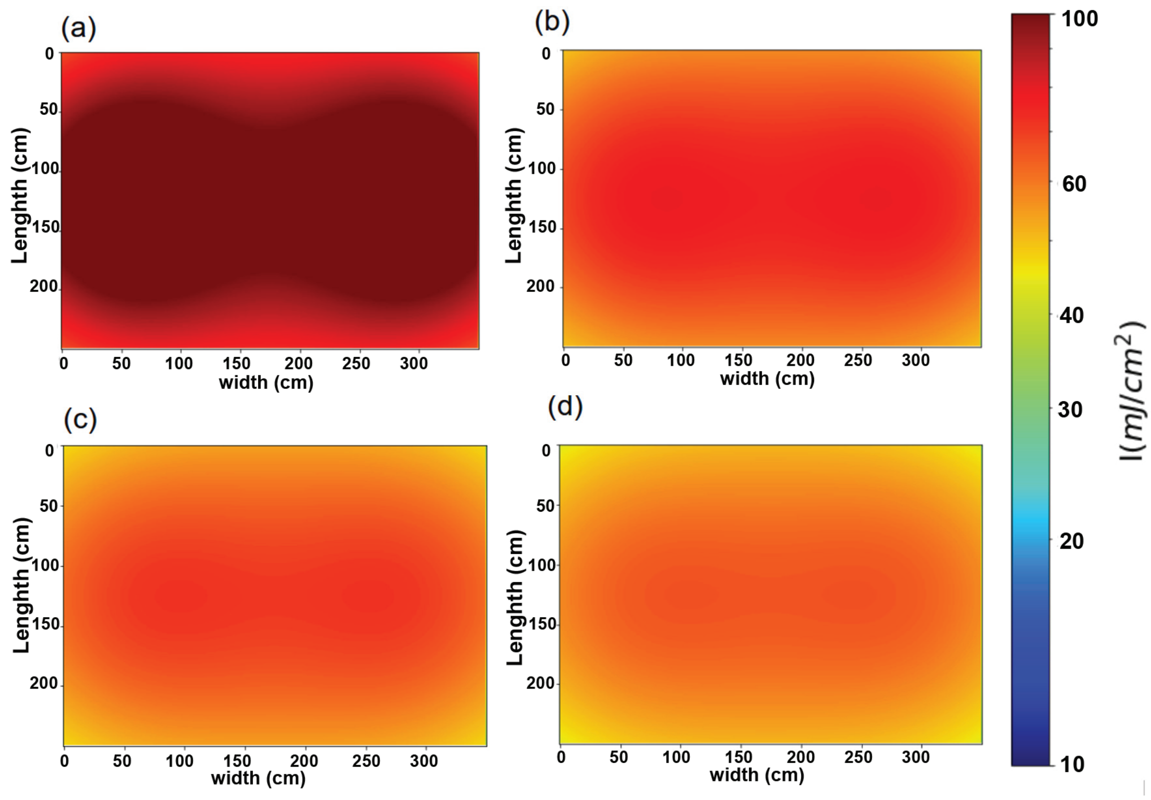

Figure 5 - An example of calculation for model room with 2.54m height for 18W UVC irradiation for 20 minutes: (a) half height (z = H/2 = 1.27 m), (b) workbench height (z = 0.8 m), (c) dental chair water unit (z = 0.7 m) and (d) dental chair and dental stool (z = 0.6 m).

DISCUSSION

It has been reported that for SARS-CoV-2, the salivary gland could be a major source of the virus in saliva with a 91.7% positive rate of SARS-CoV-2 in patients' saliva. This suggests that COVID-19 transmitted by asymptomatic infection may originate from infected saliva [20].

Among several personal protective measures for the dental professionals it has been described mouth rinse before dental procedures with oxidative agents such as 1% hydrogen peroxide or 0.2% povidone to reduce the salivary load of oral virus; rubber dam isolation special management of medical waste, and disinfection of the clinic settings [20]. Dental office public areas, such as bathrooms and waiting area, should also be frequently cleaned and disinfected, including door handles, chairs, and desks.

Studies dated 1968 showed the effects of ultraviolet radiation on nucleic acids [21].

The UVC light is absorbed by ribonucleic acid (RNA) and desoxyribonucleic acid (DNA) in cells and microbes, which induces changes (apoptosis) in the DNA and RNA structures that result in their inability to replicate [2] by the formation of pyrimidine dimers. A dimer consists of two adjacent pyrimidines (two thymines, two cytosines, or one thymine and one cytosine) joined by the DNA strand. The formation of a dimer prevents the affected bases from pairing with the bases in the complementary DNA chain, preventing replication and transcription [22]. As pyrimidines are more sensitive to radiation than purine bases, the mutagenic and lethal effects of radiation in biological systems are attributed to photochemical transformations of pyrimidine bases [21].

Studies conducted with various UVC equipment illustrate the efficacy of UVC irradiation in the decontamination of hospital rooms [23,24]. The UVC light has a disinfection rate of up to 4 log10, which is 99.99% eradication of, for example, one of the more resistant bacteria, *Clostridium difficile* spores that need about 38.5 mJ/cm^2 to be inactivated [24-26].

The D90 range values for coronaviruses is 0.7 to 24.1 mJ/cm^2 [13,14]. Otherwise, an energy density of 30 mJ/cm^2 can adequately represent the ultraviolet susceptibility of the SARS-CoV-2 (COVID-19) virus.

The result of the intensity and duration of exposure to UVC is directly related to the amount of inactivation that is proportional to the UVC dose received. The received dose in an area is not necessarily the same as the emitted dose of UVC [26,27].

The use of UVC can be effective in inactivating pathogenic microorganisms commonly found in dental office settings. However, some details must be observed and individualized for each setting: (1) Area and volume of the dental office setting; (2) Power of the UVC emitting lamp; and (3) positioning of UVC emitting lamps. With these specifications, the calculation of the time must be done to obtain the dose necessary for the inactivation of the microorganisms. In order for it to be satisfactory, the time for dosing should not be too long, allowing it to be done between possible uses of the ambulatory room, if the time is too long, the increase in the power of the lamp (s) should be considered or increase in the number of lamps.

The most critical applications of ultraviolet radiation are the destruction of airborne microorganisms [14], inactivation of microorganisms present on surfaces [13] or suspended in liquids [14], and protection and disinfection of products of unstable composition that cannot be treated by conventional sterilization methods.

Because of the high amount of photons delivered by the ultraviolet radiation, is related to the inverse-square-law, where the propagation of light intensity is inversely proportional to the square of the distance.

This means that objects near to the light source will have higher exposure and, therefore, a short time for disinfection compared to objects further away. The reflection rate of ultraviolet radiation is reduced, then shadowed areas will require a longer time to reach the adequate level of disinfection as an area in a direct line and on the same distance from the light source [28].

Factors known to influence the delivery of lethal doses of UVC irradiation are the distance from the device [27,29], time of radiant exposure [29,30], and absence of organic material on surfaces [31] because it can absorve UVC energy.

Since UVC decontamination technology is being increasingly used in health care, it is crucial to have access to tools that offer quality control and assurance that the decontamination process has been adequate. Different instruments are available to measure the received ultraviolet light doses, like UVC radiometers and different kinds of chemical dosimeters. Even though electronic devices are accurate, they can be too expensive and difficult to be used as a routine in a clinical setting [29].

Sodium hypochlorite has corrosive effects on some materials, its efficacy is dependent on correct application by housekeeping staff, additionaly, it can irritate the eyes and respiratory tracts of cleaning staff and patients, and the [30].

Hydrogen peroxide vapor and hydrogen peroxide dry mist have been shown to be highly effective in the elimination of *C. difficile* spores [30,32]. However, these systems are relatively expensive, dedicated staff is required, and up to several hours may be required to complete room disinfection [30, 32]. In contrast, after the initial purchase of the UVC device, the cost of operating and maintaining them is minimal (i.e., electricity and annual bulb replacement), dedicated staff is not essential, and a three $\log_{10}$ CFU reduction in *C. difficile* spores can be achieved in less than an hour. Additionally, UVC may be less damaging to surfaces than bleach and does not produce emissions that are harmful or irritating to operators like hydrogen peroxide vapor.

It is important to highlight that dental office must be empty to UVC decontamination since it has been published a case report of an accidental exposure to UV radiation produced by germicidal lamp causing several health problems of acute UV injury and two healthcare workers continued having significant clinical signs for over two years [33].

To the best of our knowledge, this article describes, for the first time, the UVC light amount calculation for a coadjuntive non-destructive approach of decontamination of dental clinic setting during the Covid-19 pandemic.

CONCLUSION

We found that a novel UVC assembly was effective in deliver the adequate dose of UVC been capable to be reduce de COVID-19 spread on dental offices. The assembly can be important to allow dentists and patients to be safe during clinical appointments. We can conclude that the use of UVC can be incorporated into the dental care routine to reduce cross-contamination.

We recommend that additional studies be performed in health care settings to evaluate the efficacy of the device in reducing the transmission of pathogens.

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