DOI: 10.17058/reci.v15i3.20108

ORIGINAL ARTICLE

Development and evaluation of equipment for disinfection by ultraviolet radiation in healthcare environments

Desenvolvimento e avaliação de equipamentos para desinfecção por radiação ultravioleta em ambientes de saúde

Desarrollo de equipo para la desinfección por radiación ultravioleta en entornos sanitarios

Aline Teichmann[1] ORCID 0000-0002-8019-7063
Demis Pessatto Faqui[1] ORCID 0009-0001-8551-9893
Eduardo Dullius[1] ORCID 0009-0002-5744-4406
Gilson Augusto Helfer[1] ORCID 0000-0002-3256-8069
Nayanna Dias Bierhals[1] ORCID 0000-0002-3010-8317
Maitê Souza Magdalena[1,2] ORCID 0000-0001-9561-896X
Andréia Rosane de Moura Valim[1] ORCID 0000-0001-9611-3103
Jane Dagmar Pollo Renner[1] ORCID 0000-0003-0649-7081
Janine Koepp[1] ORCID 0000-0003-4873-7696
Mari Ângela Gaedke[1] ORCID 0000-0002-3032-081X
Adilson Ben da Costa[1] ORCID 0000-0003-3009-7459

[1]Universidade de Santa Cruz do Sul, Santa Cruz do Sul, Rio Grande do Sul, Brasil.
[2]Hospital Santa Cruz, Santa Cruz do Sul, Rio Grande do Sul, Brasil.

Endereço: Avenida Independência, 2293, Universitário, Santa Cruz do Sul, Rio Grande do Sul, Brasil.
E-mail: adilson@unisc.br

Submitted: 16/12/2024
Accepted: 14/05/2025

Layout Version

ABSTRACT

Background and Objectives: In hospitals, where there is a high circulation of microorganisms, complementary technologies are essential to improve disinfection. This study aimed to develop a technology adapted to our reality, produced and tested by our research group, safe, easy to operate and with low construction cost so that it can be used in health environments such as hospitals with limited resources. **Methods:** After research, 55W lamps, T8 - G13 - 909 mm with emission of ultraviolet radiation at 254 nm were chosen as the UVC source. The “Torre UVC” application was created using the Android Studio IDE. Power measurements taken with a radiometer were used to assess the efficiency of the UVC tower and determine the appropriate doses. The efficiency of the tower against some clinically important microorganisms was evaluated. **Results:** The UVC tower was constructed with an aluminum frame and 8 lamps, allowing remote operation. The app was designed for easy and intuitive use. The efficiency tests conducted with the radiometer demonstrate an exponential decrease in radiation dosage as objects or surfaces move away from the tower. The tower effectively inhibited microbial growth (bacteria and fungi) even with low doses of UVC radiation (12 mJ/cm²) and reduced the viral load of the SARS-CoV-2 positive sample. **Conclusion:** It was possible to develop a safe and easy to operate technology with low construction costs that can be used in healthcare environments with satisfactory results in the disinfection of microorganisms.

Keywords: *Decontamination. Disinfection. Ultraviolet Rays. UV Light. NonIonizing Radiation.*

RESUMO

Justificativa e Objetivos: Em hospitais, onde há alta circulação de microrganismos, tecnologias complementares são essenciais para melhorar a desinfecção. Este estudo teve como objetivo desenvolver uma tecnologia adaptada à nossa realidade, produzida e testada pelo nosso grupo de pesquisa, que seja segura e fácil de operar, com baixo custo de construção para que possa ser utilizada em ambientes de saúde com recursos limitados. **Métodos:** Após a investigação, lâmpadas de 55W, T8 - G13 - 909 mm com emissão de radiação ultravioleta a 254 nm foram escolhidas como fonte de UVC. O aplicativo "Torre UVC" foi criado usando o Android Studio IDE. Para verificar a eficiência do equipamento e determinar as doses a serem utilizadas, foram realizadas medições de potência através de radiômetro. Foi avaliada a eficiência da torre frente a alguns microrganismos clinicamente importantes. **Resultados:** A Torre UVC foi construída com uma estrutura de alumínio e 8 lâmpadas, permitindo a operação remota. O aplicativo foi projetado para uso fácil e intuitivo. Os testes de eficiência realizados com o radiômetro mostram que a diminuição da dose de radiação é exponencial à medida que objetos ou superfícies se afastam da torre. A torre inibiu o crescimento microbiano (bactérias e fungos) mesmo com baixas doses de radiação UVC (12 mJ/cm²) e reduziu a carga viral da amostra clínica positiva para SARS-CoV-2. **Conclusão:** Foi possível desenvolver uma tecnologia segura e de fácil operação, com baixo custo para que possa ser utilizada em ambientes de saúde, e com resultados satisfatórios na inativação de microrganismos.

Descritores: *Descontaminação. Desinfecção. Raios ultravioleta. Luz UV. Radiação não ionizante.*

RESUMEN

Justificativa y Objetivos: En los hospitales, donde circulan muchos microorganismos, las tecnologías complementarias son clave para mejorar la desinfección. Este estudio tuvo como objetivo desarrollar una tecnología adaptada a nuestra realidad, que sea segura y fácil de operar, con bajo costo de construcción para que pueda ser utilizada en entornos de salud como los hospitales con recursos limitados. **Métodos:** Después de la investigación, se eligieron lámparas de 55W, T8 - G13 - 909 mm con emisión de radiación ultravioleta a 254 nm como fuente UVC. La aplicación “Torre UVC” se creó con el IDE de Android Studio. Para verificar la eficiencia de la torre UVC y determinar las dosis a utilizar, se tomaron medidas de potencia utilizando un radiómetro. Se evaluó la eficiencia de la torre frente a algunos microorganismos clínicamente importantes. **Resultados:** La Torre UVC fue construida con un marco de aluminio y 8 lámparas, lo que permite la operación remota. La aplicación fue diseñada para un uso fácil e intuitivo. Las pruebas de eficiencia realizadas con el radiómetro demuestran que la disminución de la dosis de radiación es exponencial a medida que los objetos o superficies se alejan de la torre. La torre inhibió eficazmente el crecimiento microbiano incluso con dosis bajas de radiación UVC (12 mJ/cm²) y redujo la carga viral de la muestra clínica positiva para SARS-CoV-2. **Conclusión:** Se desarrolló una tecnología segura, fácil de usar y de bajo costo, con resultados satisfactorios en la desinfección de microorganismos, adecuada para ser implementada en ambientes sanitarios.

Layout Version

Palabras Clave: *Descontaminación. Desinfección. Rayos Ultravioleta. Luz UV. Radiación No Ionizante.*

INTRODUCTION

The coronavirus disease 2019 (Covid-19) pandemic brought the need for comprehensive methods of decontamination of environments, while exposing the lack of human and technological resources available on a large scale. Rigorous measures are necessary to optimize the quality of care provided to infected patients and reduce the risk of pathogen transmission to other patients or healthcare operators.[1] SARS-CoV-2 is highly contagious, many people are generally susceptible, and many healthcare workers have been infected during patient care.[2] This virus is mostly transmitted through infected respiratory droplets and contact with the infected person. Exposure to high concentrations of the virus in a confined space for a long period of time increases the risk of aerosol transmission.[3]

Hospital-acquired infections are a challenging health problem worldwide, as inanimate surfaces and equipment can be contaminated with microorganisms. This facilitates their sporadic transmission and even outbreaks, since healthcare workers not only contaminate their hands after direct contact with patients, but also after touching inanimate surfaces and equipment.[4]

Appropriate protocols have to be used in hospitals for the decontamination of their space to reduce infection and in-hospital transmission. The aerosol deposition of viruses on surfaces and their resuspension is a potential transmission pathway and effective sanitization is critical in minimizing aerosol transmission of pathogens. As some traditional protocols are insufficient to protect vulnerable patients from serious and life-threatening infections, new strategies for decontaminating hospital environments are crucial for reducing the spread of infections. The use of complementary technologies is indicated to supplement traditional methods and improve desired levels of surface decontamination. Regardless of the type of surface, the objective of a cleaning and sanitizing procedure is to reduce contamination to an acceptable level of safety by applying operating methods for removal of pathogens from surfaces.[5]

Several novel approaches have been developed for microorganisms' inactivation in recent years. Among these is the ultra-violet irradiation (UVC), which is able to destroy a broad range of microbes, including bacteria, fungi and viruses.[6] The ability of UVC rays to destroy microbes is largely attributed to their impact on DNA or RNA.[7] Given its advantages -

Layout Version

including broader virus inactivation, manageable costs, and practical applicability – UV radiation can be used to supplement existing techniques.[6]

In this context, the development of a UVC radiation system is of great help to professionals directly involved with hospital environments. Thus, hygiene professionals will have an easy-to-install equipment that allows a quick and efficient disinfection process, being a supplementary technique especially in situations such as the high-contagion Covid-19 pandemic. The main objective of this study was to design, develop and evaluate the effectiveness of a UVC disinfection tower, with a focus on ensuring its performance and cost-effectiveness, so that it can be used in healthcare environments such as hospitals with limited resources.

METHODS

Study design and setting

The methodology adopted in this study was the Design Science Research, which focuses on developing and testing innovative solutions. As the development of the equipment does not involve practices with human beings, approval from the Research Ethics Committee was not necessary, in accordance with current regulations. We formulate the following hypotheses: (1) The developed technology will provide an effective means of disinfection in hospital environments; (2) The technology will be feasible for implementation in resource-limited healthcare settings. Key variables include the cost of construction and the effectiveness of disinfection.

The study was developed between August 2020 and July 2022, at the Universidade de Santa Cruz do Sul (UNISC). The tower was built in the university's prototyping laboratory, as was the smartphone app. The irradiation test, antimicrobial test, disinfection evaluation of PFF-2 masks and antiviral test were carried out in the university's technical laboratory (TecnoUNISC). The first year of the study was dedicated to setting up the equipment and carrying out the irradiation tests. In the second year, practical disinfection tests were carried out.

Definitions of requirements and material selection

Firstly, it was to evaluate the different types of UVC radiation sources available in the Brazilian market. The main technical characteristics for the use of UVC radiation sources were listed based on the documentation provided by the suppliers and information available in the literature. Commercial and market availability issues were also considered, as economic

Layout Version

viability is one of the commitment conditions of the study, allowing production scalability of the final products developed through this research. The production of a technology that can be replicated will effectively contribute to the fight against Covid-19 and other infectious diseases. This step was time consuming, but essential for the elaboration of strategies for the development of this disinfection system and correct acquisition of the main components.

Therefore, after carrying out an intense market research in search of models of UVC radiation sources with the objective of identifying the best relationship between wavelength, useful life, geometry, manufacturing material, power, current and voltage, lamps of 55W, T8 - G13 – 909 mm with emission of ultraviolet radiation at 254 nm were selected. This wavelength is considered the most effective for the maximum germicidal activity [6]. Thus, the disinfection tower project was dimensioned for the use of this source of UVC radiation, and 8 lamps in total were designated for the construction of the tower.

According to UV lamps manufacturers (Osram®), the radiation intensity decreases exponentially with increasing distance from the source. Another important factor is the positioning of the disinfection tower in a way to avoid shadows, since these regions may be exposed to lower-than-expected UVC doses,[8] depending on the characteristics of the disinfection environment (surgery room, or exam room). When the occurrence of shadows is unavoidable, the disinfection process must be carried out in more than one step, alternating the positioning of the tower to cover as much surface as possible. As a result, the tower was made with 8 lamps to minimize the occurrence of shadows, allowing irradiation at an angle of 360°.

App development to turn on the UVC tower

The "Torre UVC" app was created for Android® smartphones using the Android Studio IDE. An external module has been seamlessly integrated into the app to enable Bluetooth® connectivity and operations. An Android® device, such as a cell phone or tablet, with a minimum operating system version of 4.4 is necessary to use this app.

Study protocol

Several experimental procedures have been conducted to evaluate the effectiveness of the UVC tower irradiation in decontaminating pathogens, including bacteria, fungi, viruses, and commonly used healthcare materials such as PFF-2 masks. The following sections summarize the tests performed to validate the effectiveness of the device.

Irradiation test

Layout Version

Power measurements (mW/cm²) were taken using the Portable Radiometer 7.1 (Gen UV) with a detachable LA9 sensor, detection range between 220~280nm, with a calibration peak at 254 nm for assessment of the efficiency of the UVC tower and definition of the dosages to be used. The measurements were taken at 12 different distances ranging from 10 cm to 200 cm, and the dosage (mJ/cm²) was subsequently calculated using the exposure time.

Antimicrobial test

Staphylococcus aureus (ATCC 29213) and *Escherichia coli* (ATCC 25922) were used to test the decontamination efficacy of the tower by UVC radiation. Bacteria species were inoculated in 3 mL of BHI medium (Brain Heart Infusion) at 37°C for 24 hours, then seeded in Mueller Hinton agar and placed at 37°C for 24 hours. Cultures were prepared from a 0.5-scale suspension of MacFarland diluted in a 0.9% NaCl solution, and seeded 100 µL with sterile swab on plates containing 25 mL of Mueller Hinton agar.

Candida glabrata (ATCC) was used to test the effectiveness of UVC decontamination of the tower. The fungus species was inoculated in 3 mL of BHI medium at 37°C for 24 hours. The *C. glabrata* was seeded in Sabouraud agar and placed at 37°C for 48 hours. Cultures were prepared from a 0.5-scale suspension of MacFarland diluted in a 0.9% NaCl solution, and 100 µL were seeded with sterile swab on plates containing 25 mL of Sabouraud agar. The strains labelled ATCC were obtained from the American Type Culture Collection (Manassas, VA, USA).

The plates positioned at different distances from the tower (20, 50, 70, 100 and 200 cm) were exposed to UVC radiation for 5 minutes. Then, the plates were exposed to 37°C for 24 hours for bacteria species and 48 hours for fungus for subsequent colony counting. All tests were done in duplicates and the control had no exposure.

Disinfection evaluation of PFF-2 masks

The disinfection efficiency of PFF-2 masks (Life Protect®), was evaluated using a mask previously used for 12 hours. Briefly, the PFF-2 mask was initially placed in contact with Replicate Organism Direct Agar Contact plates (RODAC) (Laborclin®) on both sides (inside and outside) for 5 seconds. Subsequently, the mask was exposed to UVC radiation on both sides for 5 minutes, positioned at a distance of 20 cm (dose 2096 mJ/cm²) from the UVC tower. After exposure, the mask was again placed in contact with RODAC plates on both sides for 5 seconds. The plates were exposed to 37°C for 24 hours for subsequent colony counting.

Layout Version

Antiviral test

Samples with a positive result in real-time polymerase chain reaction (RT-PCR) for SARS-CoV-2 were used to evaluate the effectiveness of UVC radiation in a clinical nasopharyngeal swab sample for SARS-CoV-2. The samples placed in Petri dishes and positioned at different distances from the tower (70 cm, 100 cm and 200 cm) were exposed to UVC radiation for 5 minutes. Subsequently, automated viral RNA extraction of the samples was performed in the Extracta 32 equipment using the MagMAX™ CORE Nucleic Acid Purification Kit, and reverse transcriptase followed by RT-PCR was performed using the AgPath-ID™ One-Step RT-PCR Reagents kit per manufacturer's instructions. The samples were amplified using the QuantStudio 3 to identify the human ribonuclease P gene (RNaseP) as an internal control and the SARS-CoV-2 virus envelope (E) gene for viral load detection. The number of Ct (Cycle Threshold) was evaluated in the analyzes, and when Ct was above 35, samples were considered positive. All tests were done in duplicates with a control without exposure.

RESULTS

UVC disinfection tower

The tower was built entirely with structural aluminum profile (40 x 40 mm), industrial standard. The bottom base plate is 8 mm thick carbon steel with epoxy powder coating, and the closing plates are 2 mm thick stainless-steel. The central tube, the handle, support, and assembly parts are also made of stainless-steel. The pieces were cut on a Computer Numerical Control (CNC) laser cutting machine and folded on a CNC bending machine. Some stainless-steel parts are welded, such as the central tube flanges and the upper disc (Figure 1B).

The UVC tower was designed for single-phase 220 Vac power supply, controlled by a knob type switch for manual activation. As a safety measure, a residual current circuit breaker has been included to protect against electric shocks. A 220 Vac LED indicates the tower is energized and ready for use (Figure 1C).

The activation of the lamps passes through the control system, which is carried out through a standard electronic board, from the ESP32 family. This board has Wi-Fi and Bluetooth® communication, in addition to digital inputs and outputs and analog inputs. The digital outputs were used to activate transistors, which activate relays, and then two sets of four reactors, responsible for activating the lamps. The 12 Vdc source is reduced to 5 Vdc to

Layout Version

power the ESP32 board. The interface relays are 12 Vdc. The control circuit was mounted on a standard commercial board.

Finally, identification stickers and safety signs for the Tower were produced, as well as a protective cover for the lamps and a user manual for the UVC tower (Figure 1A). The manual was developed in an accessible language with operating instructions for the equipment and the respective application, in addition to safety procedures.

Figure 1. UVC tower and smartphone app.

App "*Torre UVC*"

The app Torre UVC was developed to allow the remote activation of disinfection lamps. It presents a set of guidelines to users for the correct use and guarantee of maximum disinfection efficiency without offering risks.

The app's home screen presents a message for the user to enable Bluetooth® in the mobile device that is operating system settings. Once Bluetooth® is activated, the user must click on the Bluetooth® icon (Bluetooth® symbol in white color) to start locating the tower. Thus, a new screen will open, and all Bluetooth® devices located within a range of up to 10 meters (without obstacles) will be scanned. The user must select the UVC tower from the list of available devices. If no device appears, the button at the bottom of the screen restarts the search.

Once the UVC tower is located and a valid connection is established, the color of the Bluetooth® symbol changes to light blue. The application screen will show the guidance to

Layout version

position the Tower in the first disinfection region, leave the room, and turn on the lamps (Figure 1D).

By pressing the button on the previous screen, the user will turn on the tower lamps for 6-minute periods, and the timer can be monitored via the application (Figure 1E). At the end of the disinfection time, the lamps will turn off and the tower will be available for a new disinfection process by simply repositioning it in another region (second region) and clicking on the icon to turn on the lamps.

Efficiency tests

The measurements taken with the radiometer confirmed that the UVC tower was operating efficiently. The dosage calculations were performed under real operating conditions of the UVC tower. The decay of radiation dosage is exponential, as objects or surfaces move away from the tower. These results allowed us to identify that the radiation dosage at distances greater than 2 meters is less than 1% of the radiation determined at 20 cm (Figure 2).

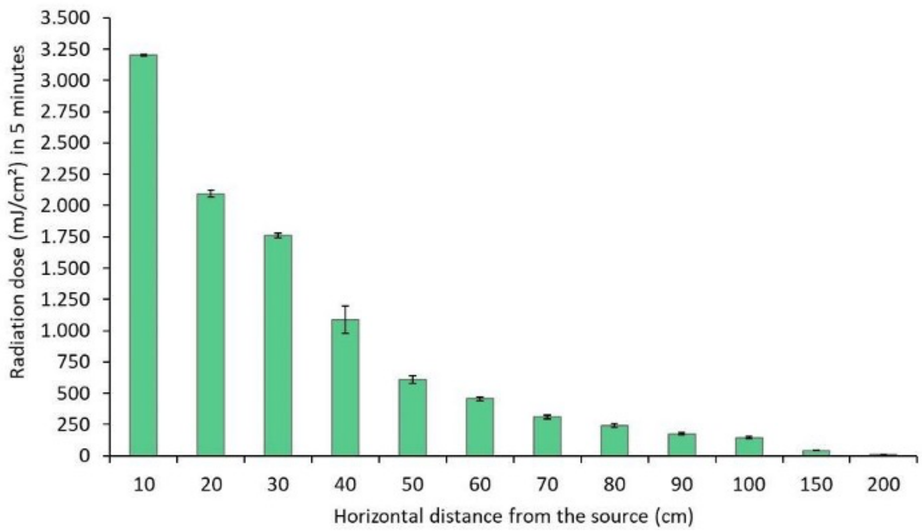

Figure 2. Exponential decay of UVC radiation with distance from the tower.

Disinfection against microorganisms

This work evaluated some of the main microorganisms of clinical importance, which are frequently associated with healthcare-associated infections and can be commonly found on contaminated surfaces and objects. In the three species tested, all control plates (not exposed to ultraviolet light) showed microbial growth > 100,000 CFU/mL (Table 1).

When comparing the two bacteria tested, we observed that *E. coli* (gram-negative) has a total inhibition with the dose of 146 mJ/cm² and only 2 CFU with the dose of 12 mJ/cm². *S. aureus* (gram-positive) has total growth inhibition with the dose of 312 mJ/cm² and only 2 CFU and 4 CFU with the dose of 146 mJ/cm² and 12 mJ/cm² respectively. Regarding *C. glabrata*, a species fungus responsible for invasive candidiasis, the total inhibition of growth is observed with the dose of 146 mJ/cm² and only 2 CFU with the dose of 12 mJ/cm² (Table 1).

Table 1. Results of microbial growth as a function of distance and dose of exposure to UV radiation.

Distance (cm) **Dose (mJ/cm²)**	**0** **0**	**20** **2096**	**50** **611**	**70** **312**	**100** **146**	**200** **12**
S. aureus, CFU/mL	> 100.000	-	-	-	2	4
E. coli, CFU/mL	> 100.000	-	-	-	-	2
C. glabrata, CFU/mL	> 100.000	-	-	-	-	2

In the disinfection of PFF-2 masks, after counting the colonies, the RODAC plate placed in contact with the inside of the mask before exposure to UVC radiation showed growth of 36 CFUs (Figure 3A). The plate RODAC placed in contact with outside of the mask showed growth of 9 CFUs (Figure 3B), in addition to the growth of a biofilm on the edge of the plate. After exposure to UVC radiation, the plate placed in contact with the inside of the mask (Figure 3C) did not have CFU growth, while the plate placed in contact with the outside of the mask showed growth of 1 CFU (Figure 3D).

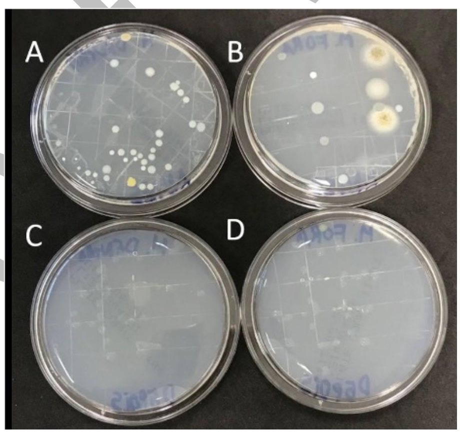

Figure 3. Effect of UVC radiation on the disinfection of PFF-2 masks.

The results show the Ct values of the E gene increase as the UV radiation dosage increases, indicating that UVC radiation is able to decrease the viral load of the tested samples (Figure 4).

Layout Version

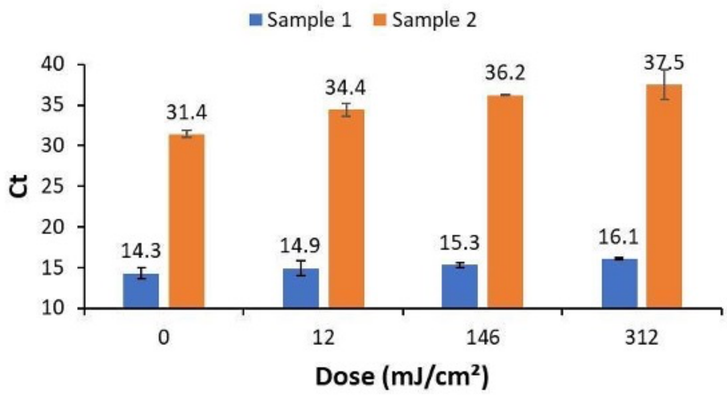

Figure 4. Effect of UVC radiation on the viral load of the samples.

Construction cost of the UVC disinfection tower

The construction costs of the UVC disinfection tower were low, considering expenses related to materials, labor, and administrative costs. All values were calculated based on prices practiced in Brazil and converted from BRL to USD (Table 2). The total equipment cost of approximately 3,300 USD is perfectly accessible to the reality of Brazilian hospitals, allowing for the widespread adoption of this indoor disinfection technology.

Furthermore, this cost is at least five times cheaper than other UVC radiation disinfection equipment available in the market.

Table 2. Construction cost values for the final version of the UVC disinfection tower.

Cost elements	Unitary value USD	Quantity	Total USD
UVC Radiation Lamp 55W, T8 - G13, 26mm	40	8	320.00
Electronic ballast 55W	30	8	240.00
Stainless steel sheets (8 mm and 2 mm), CNC laser cut	600	1	600.00
Structural aluminum profile (40 x 40mm), 150 mm	40	2	80.00
Android smartphone	160	1	160.00
Mechanical components	80	1	80.00
Electrical components	80	1	80.00
Labor			940.00
Administrative expenses			800.00
			3,300.00

DISCUSSION

Bacteria are classified into gram-positive and gram-negative according to the composition of the cell membrane structure. Gram-negative bacteria have an additional outer membrane that is not present in their gram-positive counterpart; the latter instead hold a thicker peptidoglycan layer.[9] This reinforces the findings of this study, which found greater inhibition of *E. coli*, which has a thin layer of peptidoglycan, compared to *S. aureus*, which

Layout Version

has a thicker wall of peptidoglycan, making it difficult for UVC light to reach the genetic material.

As far as action against fungi is concerned, the results found in this study are satisfactory for a species that has various virulence factors and resistance mechanisms to antifungals that has allowed this yeast to become one of the most frequent agents of candidiasis.[10]

Other works developed with UVC radiation disinfection devices have also obtained satisfactory results. A study showed that ultraviolet radiation applied for using the UVC equipment was effective in disinfecting slides inoculated with four microorganisms involved in healthcare-associated infections such as *Pseudomonas aeruginosa*, *E. coli*, *S. aureus* and *Candida. albicans*. UVC achieved a high reduction in the microbial burden when treating discs of several materials usually present in objects of medical practice, and/or daily use (borosilicate, polycarbonate, polyurethane, silicone, Teflon and titanium) in both conditions, achieving a reduction higher than 99.95%.[11] Furthermore, another study reported 100% microbial inactivation, encompassing *E. coli, P. aeruginosa, Salmonella enterica typhimurium, S. aureus*, and *Staphylococcus epidermidis*, with no observed bacterial growth following UVC irradiation. Additionally, a reduction of approximately 4 logs was noted for the yeast *Candida albicans*.[12]

The number of Ct (Cycle Threshold) was used to evaluate the effectiveness of the UVC tower against SARS-CoV-2 positive clinical samples. The Ct value corresponds the number of PCR cycles needed to produce a detectable signal, it is the point of intersection between the amplification curve and the threshold line, so the Ct can serve as a relative measure of target concentration, since its value is inversely proportional to the amount of genetic material. The lower the Ct value, the fewer PCR cycles needed to produce a positive result, the greater the quantity of viral nucleic acid in the sample tested, and the greater the quantity of viral nucleic acid (the viral load) in the sample; and on the contrary, high Ct values may mean low target concentrations or even absence.[13]

In research that related Ct values and SARS-CoV-2 viral load, the mean Ct values in nasal and throat swabs obtained from patients with severe cases were lower than the values in swabs obtained from patients with mild-to-moderate cases.[14,15] Ct values also were used to determine dynamics of SARS-CoV-2 viral load with the aim to guide the isolation period for Covid-19 patients.[16] Using the RT-PCR technique, it is not possible to affirm that the virus has been eliminated, but rather that there has been a decrease in the genetic material and consequently damage to the virus RNA.

Layout Version

However, the use of UVC irradiation is well described for the inactivation of various viruses. A study evaluated the efficiency of UVC irradiation with a wavelength between 207-222 nm on 2 strains of human coronavirus (alpha HCoV-229E and beta HCoV-OC43) and found that this method was effective in eliminating viral particles, inactivating 99.9% of the aerosolized coronavirus[17] Note that since all human coronaviruses have similar genomic sizes, UVC light is expected to show similar inactivation efficiency against other human coronaviruses, including SARS-CoV-2, the causative agent of Covid-19, present in the environment. Another study evaluated the effect of UVC irradiation on an experimental model of fomite disinfection. A lower dose of UVC (10.25-23.71 mJ/cm²) was sufficient to reduce the viral titer by >99.99%. In particular, plastic seems to be the most refractory material to UVC disinfection, followed by stainless steel and glass, with the latter showing the best adherence to treatment.[18]

UVC irradiation can be a fast and effective means of disinfecting indoor spaces. A paper describes an evidence-based approach to optimizing infection control and operating room management during the coronavirus pandemic. Improvement strategies to mitigate residual environmental contamination involve a combination of deep cleaning with surface disinfectants and UVC light in the routine cleaning of operating rooms.[19]

The high cost of equipment and the limited accessibility to available technologies are the main obstacles faced in the use of UVC light as a complementary alternative to the daily practice of health services.[20] The development of more accessible alternatives becomes a relevant contribution to the area, favoring the democratization of the use of this technology and making it viable for a wider range of users and institutions. The proposal for a low-cost UVC irradiation tower with a simplified and efficient design emerges as a solution to overcome financial barriers and facilitate the adoption of this technology.

Although the study on the UVC disinfection tower shows promising results, there are some limitations that can be better investigated in future studies. One of these limitations is the restriction of the spectrum of pathogens analyzed. For a more representative evaluation of the efficacy of UVC disinfection, we suggest further studies with an expansion of the variety of pathogens, including antibiotic-resistant strains and mycobacteria as the final step in the validation of the device to complement the disinfection routine in health services, enabling performance reports against these agents.

In addition, the study was conducted under controlled laboratory conditions, which may not accurately reflect the challenges encountered in real clinical settings. In hospital settings, variables such as temperature and humidity variations, as well as physical obstacles

Layout Version

(such as furniture and equipment), can significantly interfere with the effectiveness of UVC disinfection. Future studies should replicate real-world clinical conditions while taking these variables into account to evaluate the technology's practical applicability in scenarios of daily use.

The results presented in this work demonstrated satisfactory performance for the UVC tower in the disinfection of pathogenic microorganisms. In addition, the developed device has a low cost, using resistant and easy to clean materials. The UVC tower was designed with wheels and handles to facilitate movement and can be manipulated by just one operator. For safety reasons, lights indicating that the tower is energized and ready for use, as well as a sound signal when it is in operation, were included. The tower is operated through the "Torre UVC" application, developed in this project, which ensures the safety of the professional who can turn on the equipment from outside the room, without being exposed to UVC radiation. It is possible to make this product scalable, as the entire development was carried out by the team, and it is possible to further improve the cost benefit ratio and access to this equipment. Considering this, we can conclude that UVC irradiation could be a quick and effective means for the disinfection of indoor spaces, and could be helpful in the setting of irradiation-based sterilization.

Finally, it is important to highlight the social impact of this study, as a total of three units of the UVC tower were built, all of which were donated to the Hospital Santa Cruz, a philanthropic hospital in the municipality of Santa Cruz do Sul, Brazil.

ACKNOWLEDGMENTS

To FAPERGS (Fundação de Amparo à Pesquisa do Estado do Rio Grande do Sul), for supporting the study.

REFERENCES

1. Jerry J, O'Regan E, O'Sullivan L, et al. Do established infection prevention and control measures prevent spread of SARS-CoV-2 to the hospital environment beyond the patient room? J Hosp Infect. 2020;105(4):589-592. doi:10.1016/j.jhin.2020.06.026.

2. Wang D, Hu B, Hu C, et al. Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus-infected pneumonia in Wuhan, China. JAMA. 2020;323(11):1061-1069. doi:10.1001/jama.2020.1585.

3. Ling Y, Xu SB, Lin YX, et al. Persistence and clearance of viral RNA in 2019 novel coronavirus disease rehabilitation patients. Chin Med J (Engl). 2020;133(9):1039-1043. doi:10.1097/CM9.0000000000000774.

Layout Version

4. Odoyo E, Matano D, Tiria F, et al. Environmental contamination across multiple hospital departments with multidrug-resistant bacteria pose an elevated risk of healthcare-associated infections in Kenyan hospitals. Antimicrob Resist Infect Control. 2023 Mar 29;12(1):22. doi:10.1186/s13756-023-01227-x.

5. Moccia G, Motta O, Pironti C, et al. An alternative approach for the decontamination of hospital settings. J Infect Public Health. 2020;13(12):2038-2044. doi:10.1016/j.jiph.2020.09.020.

6. Bhardwaj SK, Singh H, Deep A, et al. UVC-based photoinactivation as an efficient tool to control the transmission of coronaviruses. Sci Total Environ. 2021;792:148548. doi:10.1016/j.scitotenv.2021.148548.

7. Enaki NA, Paslari T, Bazgan S, et al. UVC radiation intensity dependence of pathogen decontamination rate: semiclassical theory and experiment. Eur Phys J Plus. 2022;127(9):1047. doi:10.1140/epjp/s13360-022-03252-y.

8. Grist SM, Geldert A, Gopal A, et al. Current understanding of ultraviolet-C decontamination of N95 filtering facepiece respirators. Appl Biosaf. 2021;26(2):90-102. doi:10.1089/apb.20.0051.

9. Riu F, Ruda A, Ibba R, et al. Antibiotics and carbohydrate-containing drugs targeting bacterial cell envelopes: an overview. Pharmaceuticals (Basel). 2022;15(8):942. doi:10.3390/ph15080942.

10. Frías-De-León MG, Hernández-Castro R, Conde-Cuevas E, et al. Candida glabrata antifungal resistance and virulence factors, a perfect pathogenic combination. Pharmaceutics. 2021 Sep 22;13(10):1529. doi:10.3390/pharmaceutics13101529.

11. Guridi A, Sevillano E, de la Fuente I, et al. Disinfectant activity of a portable ultraviolet C equipment. Int J Environ Res Public Health. 2019;16(23):4747. doi:10.3390/ijerph16234747.

12. Santos T, de Castro LF. Evaluation of a portable Ultraviolet C (UV-C) device for hospital surface decontamination. Photodiagnosis Photodyn Ther. 2020;33:102161. doi: 10.1016/j.pdpdt.2020.102161.

13. Fox-Lewis A, Fox-Lewis S, Beaumont J, et al. SARS-CoV-2 viral load dynamics and real-time RT-PCR cycle threshold interpretation in symptomatic non-hospitalised individuals in New Zealand: a multicentre cross sectional observational study. Pathology. 2021;53(4):530-535. doi:10.1016/j.pathol.2021.01.007.

14. Zou L, Ruan F, Huang M, et al. SARS-CoV-2 viral load in upper respiratory specimens of infected patients. N Engl J Med. 2020;382(12):1177-1179. doi:10.1056/NEJMc2001737.

15. Veronesi L, Colucci ME, Pasquarella C, et al. Virological surveillance of SARS-CoV-2 in an Italian northern area: comparison of real time RT-PCR cycle threshold (Ct) values in three epidemic periods. Acta Biomed. 2020;91(9-S):19-21. doi:10.23750/abm.v91i9-S.10138.

Layout Version

16. Aranha C, Patel V, Bhor V, et al. Cycle threshold values in RT-PCR to determine dynamics of SARS-CoV-2 viral load: an approach to reduce the isolation period for COVID-19 patients. J Med Virol. 2021;93(12):6794-6797. doi:10.1002/jmv.27206.

17. Buonanno M, Welch D, Shuryak I, et al. Far-UVC light (222 nm) efficiently and safely inactivates airborne human coronaviruses. Sci Rep. 2020;10(1):10285. doi:10.1038/s41598-020-67211-2.

18. Gidari A, Sabbatini S, Bastianelli S, et al. SARS-CoV-2 survival on surfaces and the effect of UV-C light. Viruses. 2021;13(3):408. doi:10.3390/v13030408.

19. Dexter F, Parra MC, Brown JR, et al. Perioperative Covid-19 defense: an evidence-based approach for optimization of infection control and operating room management. Anesth Analg. 2020;131(1):37-42. doi:10.1213/ANE.0000000000004829.

20. Zaman A, Majib MS, Tanjim SA, et al. UVC-PURGE: A novel cost-effective disinfection robot for combating Covid-19 pandemic. IEEE Access. 2022;S/N(1):37613-37634. doi: 10.1109/ACCESS.2022.3163243.

Layout Version

AUTHORS' CONTRIBUTIONS

Aline Teichmann contributed to the bibliographic research, execution of the project, writing of the abstract, introduction, methodology, discussion, interpretation and description of the results, preparation of tables, conclusions, review and statistics. **Demis Pesatto Faqui** contributed to the literature search, project execution, abstract writing, introduction, methodology, discussion, interpretation and description of results, conclusions, review and statistics. **Eduardo Dullius** contributed to the bibliographic research, project execution, abstract writing, methodology, interpretation of results, conclusions, review and statistics. **Gilson Augusto Helfer** contributed to the execution of the project, development and testing of the application, analysis of results, writing of the abstract, review and statistics. **Nayanna Dias Bierhals** contributed to the execution of the project, analysis of results and review. **Maitê Souza Magdalena** contributed to the bibliographic research and review. **Andréia Rosane de Moura Valim** contributed to the execution of the project, analysis of results and review. **Jane Dagmar Pollo Renner** contributed to the execution of the project, analysis of results and review. **Janine Koepp** contributed to the literature research and review. **Mari Ângela Gaedke** contributed to the execution of the project, analysis of results and review. **Adilson Ben da Costa** contributed to the project administration, procurement of inputs, project execution, abstract writing, review and conclusions.

All authors have approved the final version to be published and are responsible for all aspects of the work, including ensuring its accuracy and completeness.