PUBLICAÇÃO OFICIAL DO NÚCLEO HOSPITALAR DE EPIDEMIOLOGIA DO HOSPITAL SANTA CRUZ E PROGRAMA DE PÓS GRADUAÇÃO EM PROMOÇÃO DA SAÚDE - DEPARTAMENTO DE BIOLOGIA E FARMÁCIA DA UNISC

Revista de Epidemiologia e Controle de Infecção

Hospital Santa Cruz

ORIGINAL ARTICLE

Efficacy and effectivity of UVC for disinfection of hospital materials of COVID-19 patients

Eficácia e efetividade do UVC para desinfecção de materiais hospitalares de pacientes com COVID-19

Eficacia y efectividad de UVC para desinfección de material hospitalario de pacientes con COVID-19

https://doi.org/10.17058/reci.v11i3.16233

Received: *16/02/2021*
Accepted: *14/01/2022*
Available online: *20/01/2022*

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ABSTRACT

Background and Objectives: After the beginning of the COVID-19 pandemic, more effective and efficient means were needed to disinfect hospital materials. The objective of our study is to evaluate the *in vitro* efficacy and the economic effectiveness of type C ultraviolet (UVC) irradiation for disinfection of materials used in the care of COVID-19 patients. **Methods**. Four bipartite Cled plates were inoculated with suspensions of 10,000 CFU/mL of *Escherichia coli* and *Staphylococcus aureus* strains, exposed to two 18W lamps, placed inside a laminar flow and incubated for quantitative growth assessments. The germicidal equipment was built: the "UVC box" was developed with two 18W lamps for use in materials returned to pharmacy and a "UVC closet" with two 60W lamps for surgical gowns exposure. The economic effectiveness was evaluated by comparing inventory costs with quarantine of materials versus UVC usage costs. **Results.** Microbiological inactivation in the plates started after 4 minutes with an efficiency close to 100% at 8 minutes. The "UVC box" reduced the time to release the material from 9 days to immediately, generating savings of approximately R$ 68,400, and the "UVC closet" changed the use of surgical gowns to 0.7/patient, compared to the usual of 1.5, generating savings of nearly 3,000 reais/month. The cost of installation and maintenance was R$ 1,500. **Conclusions.** The efficacy and effectiveness of the UVC system was proven, as well as the economy promoted by its installation.

Keywords: *Ultraviolet Rays. Coronavirus Infection. Administration of Healthcare Services.*

RESUMO

Justificativa e Objetivos: Após o início da pandemia de COVID-19, meios mais efetivos e eficazes foram necessários para desinfetar materiais hospitalares. Este trabalho visa avaliar a eficácia *in vitro* e a efetividade econômica

Please cite this article as: *Couto, H. R. D., Lima, W. S., Romaniello, J. A. Q., Giarola, L. G., Saldanha e Silva, D. C., Couto, B. R. G. M., & Rocha, D. B. (2022). Eficácia e efetividade do UVC para desinfecção de materiais hospitalares de pacientes com COVID-19. Revista De Epidemiologia E Controle De Infecção, 11(3). Recuperado de https://online.unisc.br/seer/index.php/epidemiologia/article/view/16233*

de luz ultravioleta tipo C (UVC) para desinfecção de materiais usados em pacientes com COVID-19. **Métodos:** Quatro placas bipartidas de Cled foram inoculadas com suspensões de 10.000 ufc/mL de cepas de *Escherichia coli e Staphylococcus aureus*, expostas a duas lâmpadas de 18W, colocadas dentro de um fluxo laminar e incubadas para avaliações quantitativas de crescimento. O equipamento germicida foi construído: uma "caixa UVC" com duas lâmpadas de 18W para materiais da farmácia e um "armário UVC" com duas lâmpadas 60W para exposição de capotes. A efetividade econômica foi avaliada comparando os custos de estoque, com quarentena de materiais versus custos de uso da UVC. **Resultados:** A inativação microbiológica nas placas se iniciou a partir de 4 minutos, com eficácia próxima a 100% aos 8 minutos. A "caixa de UVC" reduziu o tempo para liberação do material de 9 dias para imediato, gerando uma economia de aproximadamente R$ 68.400,00, e o "armário de UVC" alterou o uso de capotes para 0,7/paciente, comparado ao uso habitual de 1,5, gerando uma economia de 3.000 reais/mês. O custo de instalação e manutenção foi de R$ 1.500,00. **Conclusão:**Foi comprovada a eficácia e efetividade dos sistemas UVC, além da economia promovida por sua instalação.

Descritores: *Raios Ultravioleta. Infecções por Coronavírus. Administração de Serviços de Saúde.*

RESUMEN

Justificación y Objetivos. Despuésdelinicio de la pandemia de COVID-19, se necesitaronmedios más efectivos y eficientes para desinfectar losmaterialeshospitalarios. El artículo tiene como objetivo evaluarlaeficacia *in vitro*y la efectividad económica de la luz ultravioleta tipo C (UVC) para desinfección de materiales utilizados enlaatención al paciente con COVID-19. **Métodos**. Cuatro placas partidas Cledfueron inoculadas consuspensiones de 10,000 UFC/mL de cepas de *EscherichiacoliyStaphylococcusaureus*, expuestas a dos lámparas de 18W, colocadas dentro delflujo laminar e incubadas para evaluacionescuantitativas de crecimiento. Se construyóel equipo germicida: una "caja UVC" con dos lámparas de 18W para materiales de farmacia y un "armario UVC" con dos lámparas de 60W para exponerlas batas. La efectividad económica se evaluó comparando loscostos de inventario conlacuarentena de materiales, versus loscostos de uso de UVC. **Resultados**. La inactivación microbiológica enlas placas se inició a los 4 minutos con una eficienciacercana al 100% a los 8 minutos. La "caja UVC" redujoeltiempo de liberacióndel material de 9 días a una liberacióninmediata, economizando aproximadamente R$ 68.400 y el "armario UVC" cambióel uso de batas a 0,7/paciente, frente al uso habitual de 1,5, economizando aproximadamente 3.000 reales/mes. El costo de instalación y mantenimientofueR$1.500. **Conclusiones.** La efectividad y eficaciadel sistema UVC fuecomprobada, además de los resultados enlaeconomía por suinstalación.

Palabras clave: *Rayos ultravioleta. Infecciones por coronavirus. Administración de servicios de salud.*

INTRODUCTION

The emerging outbreak of COVID-19, declared a pandemic by the World Health Organization (WHO), has set up an extremely challenging scenario for health services globally. The Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2)pathogen, causing the Coronavirus Disease Discovered in 2019, emerged in Wuhan, China, and took global proportionsin 2020.

The virus has high pathogenicity and transmissibility, and can cause from asymptomatic conditions to mild systemic involvement, such as fever, cough, arthralgia, myalgia, rhinorrhea and diarrhea.[1] It is also responsible for the large increase in the number of hospitalizations for pneumonia with repercussions of the disease in multiple organs and may progress to severe disease marked by hypoxemic respiratory failure and the need for prolonged ventilatory support.[2,3]

The transmission of SARS-CoV-2 has also a challenging issue: an infected person without symptoms can also transmit COVID-19, which can occur through the air, by respiratory droplets that come out of the mouth or nose when an infected person speaks, sings, shouts or by person-to-person contact through touch, kiss, hug or handshake, followed by mouth, nose and eye contact. It also occurs by fomites contaminated with these droplets, when these surfaces or objects are touched and the contaminated body part comes into contact with the mouth, nose or eyes.[2]

As there is still no vaccine for SARS-CoV-2 available for the entire population, it is necessary to avoid exposure to the virus for infection prevention, which can be done through nonpharmacological interventions with proven effectiveness against the other six coronaviruses throughout history.[4] Some examples are measures such as frequent hand washing up to the wrists with soap and water or 70% alcohol-based hand rub, covering the nose and mouth with a tissue or the inside of the elbow during coughing or sneezing, and the minimum distance of one meter between people in public and social spaces, in addition to the use of masks in all environments.[5]

Another aspect involves environmental considerations to reduce transmission of the virus. As the pathogen can survive for days on solid surfaces and a few hours in suspension in the air, effective disinfection is essential to reduce viral transmission.[6] Even with adequate hand

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hygiene, this measure alone, especially in clinics and hospitals, may fail, as when touching contaminated surfaces close to a patient, the professional can invalidate the effect of hand washing by transferring pathogens from that patient to another, perpetuating the transmission of microorganisms.[7] In addition, studies evaluating the effectiveness of standardized cleaning interventions in healthcare facilities have reported that approximately 5–30% of surfaces remain potentially contaminated because the existing detergent and disinfectant formulations are ineffective to break biofilms.[8] However, not all objects can be treated with chemical biocidesgiven the possible risk of deterioration of the material, especially those with electronic parts.[9]

Many current studies have addressed the effectiveness of using ozone as a disinfection method, a substance that has proven effective during*in vitro* inactivation of a series of microorganisms, including important pathogenic bacteria and viruses in hospital infections.[10] Since its use as a preferred procedure in disinfection or sterilization of environments or hospital areas is not well establishedand due to its toxicity, it has fallen into disuse for disinfection of closed environments in many places.[11]

While the effect of daylight on viruses such as COVID-19 is still unexplored, spectrum-tuned electrical lighting is already implemented as an engineering control for indoor disinfection.[12-14] An important, growing strand of environmental considerations to reduce viral transmission for the control and prevention of COVID-19 involves more specifically the use of ultraviolet (UV) rays.[15] In this context, UV germicidal irradiation has received greater attention in the hospital environment after decades of underutilization. Used in several sectors as a germicide given its cost-effectiveness, its use in the hospital sector is on the rise for its proven high effectiveness in cleaning surfaces contaminated by hospital pathogens, being able to reduceby more than 99% the formation of bacterialcolonies on surfaces such as Intensive Care Unit (ICU) computers.[16] With renewed interest in this technology, new practical questions arise, especially with regard to efficacy and safety. Many investigations have concluded that if used correctly, UV radiation can indeed be safe and highly effective in air disinfection.[17] Some pathogens are persistent in healthcare environments and contaminate surfaces and materials in wards, operating rooms and intensive care centers, where the practice of disinfecting hospital utensils with germicidal irradiation has also been quite common.[9]

The effectiveness of UVC lamps against microorganisms on surfaces is known. At shorter wavelengths (UVC ≈ 254 nm), they are safe and have germicidal quality. For example, UVC can be effective to inactivate droplets with mycobacteria if it reaches an average irradiance of 30-50µW/cm2.[18] The effects of UVC irradiation result in cell damage by photohydration, photodissection, photodimerization and photo-induced crosslinking, thereby inhibiting the replication of microorganisms. We highlight the main advantages of using this technology: it does not require changes in the ventilation of the environment; leaves no residue after disinfection; has a broad spectrum of action at fast exposure times; and the possibility of designingportable devices of simple handling until large devices, which expands the disinfection capacity, covering procedural materials, surfaces and environments.[14]

After the beginning of the COVID-19 pandemic, an increase in hospital supplies and PPE expenses was observedin the hospital studied. When suppliesdispensed by the pharmacy are not used by patients with suspected or confirmed COVID-19, they are placed in a nine-day "quarantine", which generates an extra need/cost of stock. Regarding gowns, there was an increase in demand at the hospital as a whole and, especially, at the unit of care for COVID-19 patients. Therefore, the question on how to increase the shelf life and reuse of gowns and how to eliminate the "quarantine" of hospital suppliesarose, thus eliminating the consequent stock/extra cost safely. The use of UVC lamps is an alternative for greater economic effectiveness in hospital management in a pandemic context.

Given the variety of possibilities for using UVC, arises the question if there is a way to guarantee the germicidal efficacy of lamps available in the Brazilian market.

In this sense, the objective of the study is to evaluate the germicidal effectiveness of UVC lamps available in the Brazilian market. The aim of the study is also to evaluate the economic effectiveness of this model of disinfection of hospital supplies returned to the pharmacy and of gowns used in the care of patients with suspected or confirmed COVID-19.

METHODS

Microbiological tests were done in the microbiology laboratory of a high complexity hospital located in the city of Belo Horizonte, Minas Gerais. The aim was to demonstrate the bactericidal effect of ultraviolet light through the exposure of newly seeded plates with microorganisms used for quality control of culture media in order to infer the ability to deliver energy of UVC radiation specifically (two 18W lamps each). In this experiment, four bipartite Cled plates were inoculated with 10,000 cfu/mL suspensions of *Escherichia coli* (ATCC 25922) and *Staphylococcus aureus* (ATCC 29213) strains on each side and then placed inside a laminar flow of radiation and covered with aluminum foil in such a way that the upper half of each seeded area was protected from light exposure. The first plate was exposed to light for only 1 minute, the second for 2 minutes, the third for 4 minutes and the fourth plate for 8 minutes. Plates were incubated for quantitative growth assessments after 12, 24 and 48 hours.

In the pharmacy, a mobile box built with two UVC lamps of 18W each was positioned (Figure 1). The disinfection device had a total cost of R$ 500.00. Between March and July 2020, supplies from 128 patients were returned to the pharmacy, exposed to UVC lamps for 10 minutes and made available for immediate use by other patients (Table 1). On average, the box with UVC lamps can be used five times per hour, allowing the disinfection of approximately 1kg of material at a time.

Table 1. Quantity and percentages referring to materials returned to the pharmacy.

SUPPLIES	FREQUENCY	PERCENTAGE
40 x 20 needles	569	23%
10ml syringe	372	15%
Optiumpoc test tape	259	10%
Blood glucose lancet	255	10%
20ml syringe	149	6%
Gauze 7.5 x 7.5	126	5%
1ml syringe with device	95	4%
5ml syringe	66	3%
3ml syringe	59	2%
Surgical glove 7.5	50	2%
Jelco 20D safety	42	2%
Surgical glove 6.5	35	1%
Sterile gloves 8.0	29	1%
25 x 7 needles	26	1%
Number 11 scalpel blade	24	1%
Surgical glove 7.0	22	1%
Endo tube 8.0	22	1%
3 way faucet	21	1%
Disposable electrode	20	1%
Infusion pump LF 2001	19	1%
Closed suction system 14	17	1%
Othersupplies	242	10%
TOTAL	2,519	100%

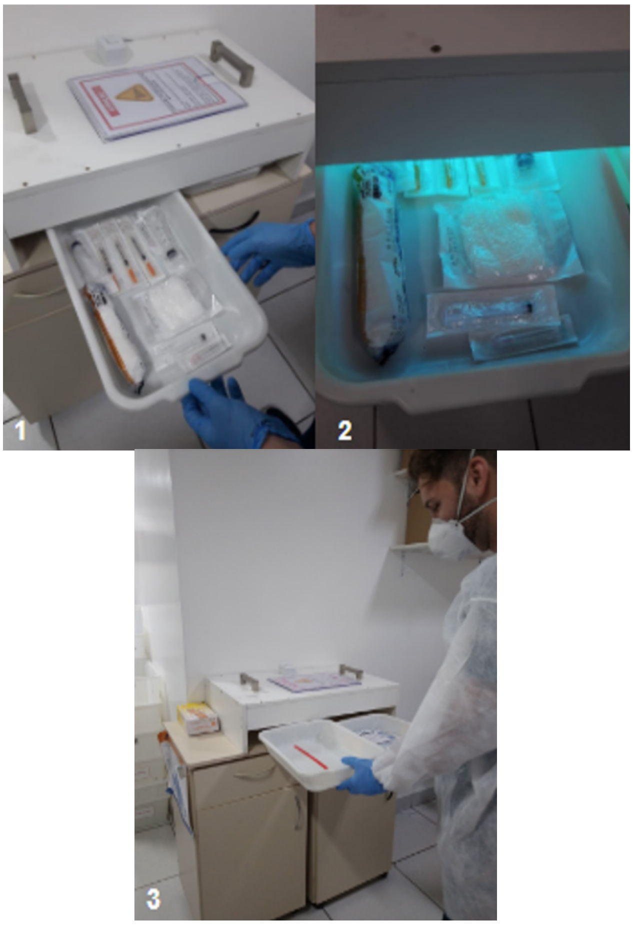

Figure 1. "UVC box" for disinfection of supplies returned to the pharmacy: portable device at different angles (1, 2 and 3) with two 18W lamps each.

In the sector of COVID-19 patients, a "UVC closet" was built with two 60W lamps each and a motion detector device to turn them off as soon as the curtain is opened, in addition to the option of turning them on with an external switch (Figure 2). This system was evaluated for two months: in July 2020, 622 patients were hospitalized in the COVID-19 area with consumption of 434 waterproof gowns; in August, 576 patients were hospitalized in the sector, with consumption of 403 gowns. In June, the UVC system had not yet been installed, and 284 patients were hospitalized that month and 420 gowns were used. The installation of the closet meant that each patient generated the use of 0.7 gowns, on average. Without the device, 1.5 gowns are used for each patient. The savings with waterproof gowns, unit cost of R$ 7.20 (seven reais and twenty cents), was approximately R$ 3,000.00 per month. The total cost of installation and maintenance was R$ 1,000.00.

Figure 2. ""UVC closet" with motion detector device at different agles (1, 2 and 3), for disinfection of gowns in the COVID-19 area: two UVC lamps of 60W each.

In addition to microbiological analysis, the use of a radiometer is essential to measure the real power and dose of radiation generated by UVC lamps available in Brazil (Figure 3). This was the item with the highest cost (R$ 5,000.00) in the project, but it can be used for other projects and for the provision of services in other hos-

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pitals. Radiometer measurements showed no leakage of radiation outside the pharmacy's "UVC box", nor outside the "UVC closet" of the COVID-19 area. In the pharmacy UVC box, the two lamps generate an average power of 1.11 mW/cm^2, well above the minimum limit required by the CDC to eliminate mycobacteria, which is 30-50 $\mu W/cm^2$.[13]

Figure 3. Different angles (1, 2 and 3) of the radiometer used to measure the power and radiation dose of the "UVC box": essential for full control of the use of lamps.

RESULTS

After incubation of the four bipartite Cled plates, the inactivation of bacteria in the area exposed to UVC radiation starts at 4 minutes and reaches efficiency close to 100% at 8 minutes of exposure for both strains of *E. coli* and *S. aureus*, commonly used in routine quality control of a microbiology laboratory through microbiological assays (Figure 4). In addition, it was possible to observe the elimination of colonies also in the shaded half of the plates, which shows the indirect action and may suggest irradiation of the energy delivered by UVC lamps between bacteria, or even some penetration by the aluminum foil. The presence of colonies was also observed in regions of the medial and inferior edges of the unshaded area of the plate at 8 minutes, which, at first, raised suspicions about the germicidal effectiveness of the lamps. However, when analyzing the experiment more closely, these colonies were actually found under the agar plate. A leakage of the suspension containing bacteria in these regions was observed, which can lead to conclusionson the low penetration capacity of UVC radiation in liquid or gelatinous media, evidenced by bacterialgrowth below the culture medium even after 8 minutes of exposure. Thus, given the good germicidal results and considering that SARS-CoV-2 is an enveloped virus hence, easier to be eliminated when structurally compared to inoculated *E. coli* and *S. aureus*, a device of UVC light emission of 36W power is 100% effective with at least 10 min of irradiation.

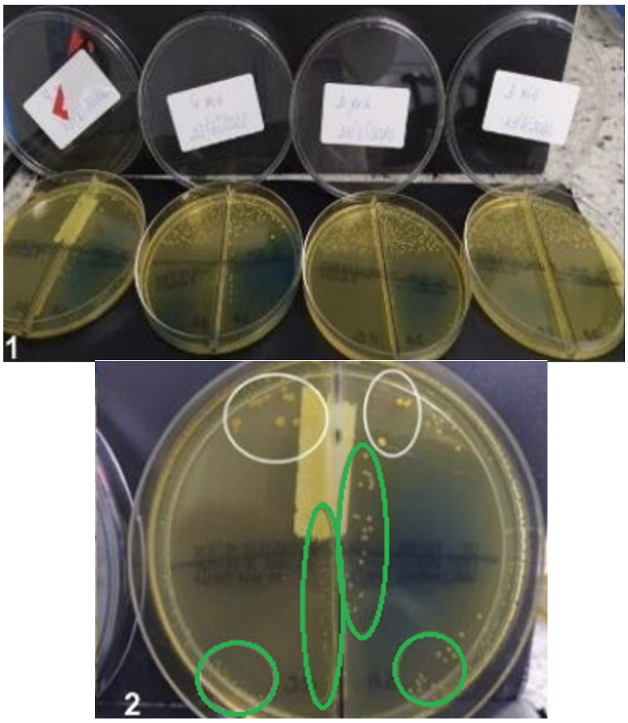

Figure 4. On the left, are the plates exposed to UVC radiation for 8, 4, 2 and 1 minute, respectively. On the right is the plate exposed for 8 minutes, indicating the colonies circled in white that grew on the surface of the shaded half and survived the indirect action of UVC. In green are microorganisms that have infiltrated under the agar at the edges of the plate and have resisted the exposure.

With use of the "UVC box" for disinfection of materials returned to the pharmacy, there was a reduction in the time to release the material from nine days to immediate, avoiding the stock increaseby approximately R$ 68,400.00. In five months, 2,519 supplies used by the 128 suspected or confirmed COVID-19 patients were returned. The use of UVC lamps to sterilize gowns meant that each patient generated the use of 0.7 gowns, on average. Without the "UVC closet", 1.5 gowns are used for each patient. Savings only with waterproof gowns, at a unit cost of R$ 7.20 (seven reais and twenty cents), were of approximately R$ 3,000.00 per month. The total cost of installation and maintenance was R$ 1,000.00. Economic effectiveness was evaluated by comparing material quarantine inventory costs versus UVC usage costs. Thus, in addition to being effective,the system proved to be totally economically effective both for the disinfection of hospital supplies returned to the pharmacy and for the disinfection of gowns.

DISCUSSION

The UVC lamps available in the Brazilian market are proven to be effective. The microbiological inactivation in the experiment with bipartite Cled plates starts after 4 minutes with efficiency close to 100% at 8 minutes of exposure for both strains used. Considering that SARS-CoV-2 is an enveloped virus,hence easier to eliminate, a 36W UVCdevice is 100% effective with at least 10 min of irradiation. Furthermore, through the experiment, the growth of microorganisms was noticed only on the surface of the plates with a low penetration capacity of UVC rays in liquid or gelatinous media, drawing attention to the care with this detail in the disinfection of gowns and materials that could possibly have been moistened prior to disinfection by UVC devices.

The construction of a low-cost and safe UVC equipment for disinfecting gowns and unused medical supplies that return to the pharmacy is possible. The two devices developed based on the UVC germicidal action were built at low cost and, as long as handled with appropriate PPE, they are completely safe for use. Measurements made by the radiometer showed no leakage of radiation out of the devices. Furthermore, the installation of an "inverted" motiondetector device, which turns off the lamps in the gown "closet" in the presence of a person proved to be a fundamental safety resource.

In five months, the total cost of installing and maintaining the devices, added to the acquisition of the radiometer, was R$ 6,500.00. The total return was R$ 83,400.00; considering the extra stock at the pharmacy and expenses with gowns, after subtracting the cost of assembling the devices, a return of practically R$ 77,000.00 was generated in five months.

Data in the literature on similar sizedequipment that allow disinfection of a similar volume are scarce. LUCIA is a prototype used for the disinfection of N95 masks with an initial cost of 360.00 U$D (equivalent to about R$ 1,980.00) for equipmentassembling. However, itsdimensions are significantly smaller and the costs of monthly maintenance of the equipment were not specified.[19]

The germicidal efficacy and economic effectiveness of systems that use UVC rays were demonstrated, adding even more value to studies of this resource and leaving as a legacy of continuity the improvement and the search for more devices, as well as different and innovative ways of using the antimicrobial action of UVC irradiation.

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AUTHOR'S CONTRIBUTION

Henrique Rietra Dias Couto, Danilo Cotta Saldanha and Silva e **Lucca G Giarola** contributed to the planning and writing of the article.

Bráulio Roberto Gonçalves Marinho Couto contributed to the analysis and interpretation of the data.

Jeruza AQ Romaniello contributed to the design and review of the article.

Davi B Rocha and **Wilson Souza Lima** contributed to the design and final approval of the article.

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