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Evaluation of a portable Ultraviolet C (UV-C) device for hospital surface decontamination

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ABSTRACT

Background: Surface decontamination of hospital environments is essential to ensure the safety of health professionals and patients. This process is usually performed through active chemicals substances with high toxicity, and new decontamination technologies that do not leave residues have been currently used, such as UV-C light. Thus, the objective of the present study is to evaluate the effectiveness of a portable UV-C light device on the viability of standard pathogenic strains and other microorganisms isolated from different surfaces of a public health hospital.

Methods: *In vitro* decontamination was performed by applying Biosept Home© UV-C to *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella enterica* and *Candida albicans*. In real conditions, the application was made on different surfaces of a hospital. The device used in the experiment has a 254 nm UV-C light and a radiation intensity of 45.6 mW/cm² over a distance of 1 cm from the surfaces. The light dose was 0.912 J/cm² for 20 s of application in both conditions (*in vitro* and hospital).

Results: After *in vitro* decontamination with UV-C light no bacterial growth was observed, demonstrating 100 % of bacterial inactivation under the conditions tested. Additionally, there was a reduction of approximately 4 logs for the yeast *C. albicans*. In all hospital surfaces, the number of colonies of microorganisms was significantly reduced after the procedure.

Conclusion: The results suggest that Biosept Home© UV-C is efficient and constitutes a promising intervention for disinfection protocols in hospitals and clinics.

1. Introduction

Cleaning procedures of surfaces and instruments have been targets of interest that are not only restricted to prevention strategies on the COVID-19 Pandemic. Different pathogen inactivation techniques have been developed over the years to minimize the recurrence of a public health problem, the emergence of multidrug-resistant pathogens [1–4]. The hospital environment can be considered the main reservoir of multiresistant pathogens associated with untreatable infections and, consequently, related to increased morbidity and mortality among inpatients [5–8].

Surface decontamination of hospital environments is essential to ensure the safety of health professionals and patients and crucial to eliminate the dissemination of multidrug-resistant pathogens [4,9]. Usually, the decontamination process is performed through active chemicals substances. However, negative aspects such as unsatisfactory surface decontamination [9], the release of toxic products with a high

irritable capacity [4,10] and manual intervention resulting in inadequate dilutions and contact times [11] contribute to the strengthening of the insertion of new technologies.

The application of Ultraviolet (UV) irradiation for decontamination, first described in 1910 [12], has been increasingly used as an efficient alternative method for pathogen inactivation of hospital surfaces [4], ensuring health professionals' safety. The UV irradiation covers a wavelength ranging from 100 to 400 nm. The subdivisions of this electromagnetic spectrum can be classified into three distinct areas, including Ultraviolet-C (UV-C) (100–280 nm), UV-B (280–315 nm), and UV-A (315–400 nm). The UV-C has been applied to the development of germicide light since it is capable of damaging the DNA and RNA of microorganisms through the formation of thymine/thymine dimers and, consequently, impairing the transcription and replication process [13]. However, the efficacy of UV-C light on surface decontamination decreases as the distance between the light source and the contaminated surface increases. The structure of the surface is another factor that may

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affect the efficiency of the decontamination process, and hard, smooth surfaces are ideal for UV-C decontamination [14,15]. Several studies described the potential effects of UV-C on the reduction of the contamination of the transfusion of platelet concentrates [1–3], on the control of the dissemination of multidrug-resistant pathogens presented in the hospital environment [16,17], on the elimination of the foodborne pathogenic bacteria [18,19] and viruses on the water as well [20].

Recently, the COVID-19 pandemic has evidenced a neglected problem among health professionals. The generation of bioaerosols and the contamination of hospital surfaces and instruments have been attributed to a high proportion of COVID-19 infection in healthcare environments. The disinfectant potential of UV-C on hospital surfaces has several advantages, including the effective sterilization of bioaerosols [21], facility to use, reduction of exposure time and user manipulation. The inactivation of the virus and a wide range of microorganisms, including bacteria and fungi, is an effective alternative to be applied in routine decontamination protocols on hospital and clinical surfaces. Given the alarming need to prevent the uncontrolled spread of SARS-CoV-2 virus and the effective decontamination capability of UV-C, the objective of the present study was to evaluate the effectiveness of Biosept Home© UV-C on the viability of standard pathogenic strains and other microorganisms isolated from different hospital surfaces.

2. Materials and methods

2.1. Device setup and optical characteristics

The Biosept Home© device (Bioset, Rio Claro, Brazil) has an ultraviolet (UV-C) lamp for decontamination of surfaces acting on microbiological control (Fig. 1A). This UV light emits UV-C at 254 nm. The lamp

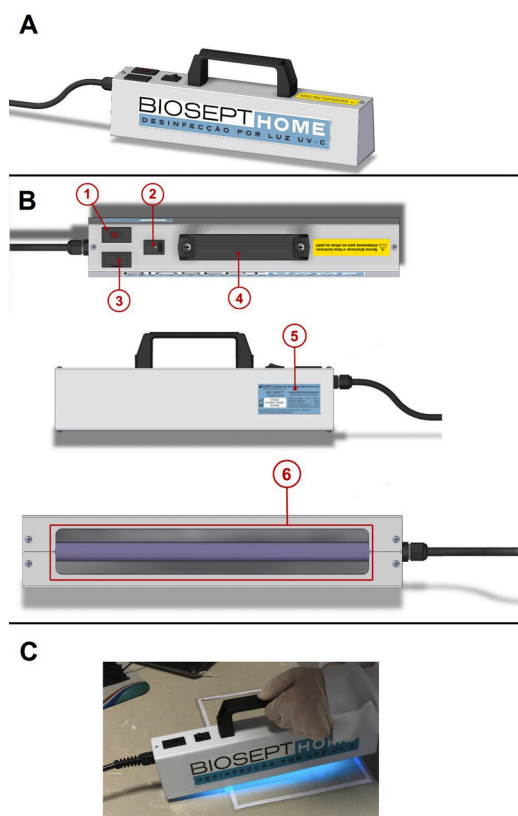


Fig. 1. (A) Biosept Home© UV-C device. (B) Biosept Home© UV-C device consisting of (1) voltage source, (2) on/off button, (3) protective fuse port, (4) handle, (5) technical characteristics, (6) emission output of UV-C. (C) Biosept Home© UV-C application at a surface of Public Health Hospital of Rio Claro, Brazil.

settings used to perform the experiments was 8 W of total luminous power, 46.08 cm² of usable area of 45.6 mW/cm² of radiation intensity (Fig. 2B). The compact and portable design has been developed for surface decontamination of healthcare environments.

2.2. *In vitro* decontamination using Biosept Home© UV-C (controlled conditions)

The microorganisms used for the *in vitro* decontamination tests were gram-positive bacteria *Staphylococcus aureus* (American Type Culture Collection - ATCC 6538), *Staphylococcus epidermidis* (Cefar Diagnostic Culture Collection – CCCD S010), gram-negative bacteria *Escherichia coli* (ATCC 25922), *Pseudomonas aeruginosa* (ATCC 27853), *Salmonella enterica* (*typhimurium*) (CCCD S004) and the yeast *Candida albicans* (ATCC 10231). These microorganisms were chosen because they are used to test the efficiency of antimicrobial agents, have different cell wall structures and are associated with health-associated infections. All microorganisms were grown in BHI broth (brain-heart infusion) in an oven at 37 °C for 24 h. After growth, the samples were centrifuged at 1000 rpm for 15 min and resuspended in PBS. The suspensions were quantified through the optical density, and the number of 10⁸ colony-forming units (CFU)/mL was estimated [16].

2.2.1. Experimental methodology

All tests consisted in irradiating microorganisms spread in Petri dishes with a culture medium and quantifying the viable population after irradiation. Before irradiation, the suspensions were homogenized, and aliquots of 100 µL were transferred to microtubes containing 900 µL of PBS to perform a serial dilution up to 10⁻⁵. Then, 50 µL aliquots of all dilutions of bacteria were mounted on Petri dishes containing Brain and Heart Infusion Agar (BHI) and aliquots of 50 µL of *C. albicans* were dispersed to Petri dishes with Sabouraud's dextrose agar [16]. The tests were performed in duplicate, for each microorganism; the first referring to control (before Biosept Home© UV-C application) and the second referring to the treatment in which Biosept Home© UV-C was applied, slowly, throughout the region of the plate for 20 s at a distance of 1 cm. Under these conditions, the light dose was 0.912 J/cm². The cultures were kept in oven at 37 °C for 24 h and the CFU/mL was estimated. The experiment was performed 3 times independently, and six quantifications were performed for each type of microorganism.

2.2.2. Data analysis

After decontamination, the CFU was quantified, and the results were compared with the control group, which did not receive the Biosept Home© UV-C application. Each experimental group was independently tested three times and measured in duplicate, resulting in six for a group. For analysis purposes, CFU/mL values were transformed into a base 10 logarithm (log₁₀), and for statistical analysis, *paired sample t*-test was performed between control groups (not irradiated) and their respective irradiated groups [16]. Differences were considered statistically significant at $p \leq 0.05$. Data were analyzed using GraphPad Prism 6.01 software.

2.3. Different hospital surfaces decontamination (real conditions)

2.3.1. Surfaces were chosen for Biosept Home© UV-C application

The experiments to verify the decontamination action of Biosept Home© UV-C were carried out on different surfaces of a public health hospital, located in Rio Claro, Brazil. A total of 8 surfaces were chosen to receive the treatment: a blood test chair (1), a doctor's office desk of adult clinic room (2), a doctor's office desk of a pediatric room (3), the hospital kitchen (4), an intensive care unit (ICU) bed curtain (5), an ICU medication room (6), an ICU workbench (7), and a urinalysis workbench (8). These places were chosen considering the large number of people using them on a daily basis, which represents a high contamination factor.

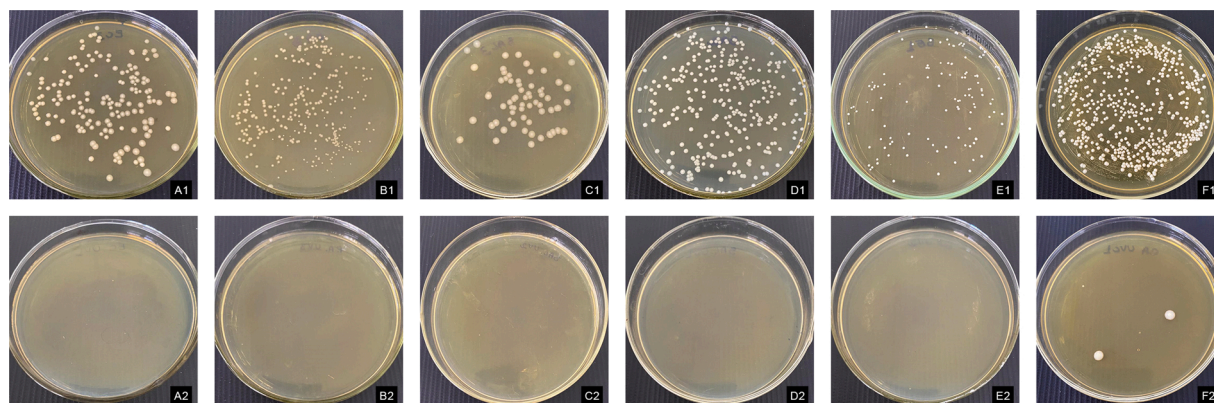


Fig. 2. Effect of the application of Biosept Home[®] UV-C on microbial growth. A. *Escherichia coli* (ATCC 25922). B. *Pseudomonas aeruginosa* (ATCC 27853). C. *Salmonella enterica typhimurium* (CCCD S004). D. *Staphylococcus aureus* (ATCC 6538). E. *Staphylococcus epidermidis* (CCCD S010). F. *Candida albicans* (ATCC 10231). 1. Before disinfection with Biosept Home[®] UV-C. 2. After disinfection with Biosept Home[®] UV-C.

2.3.2. Experimental methodology

The same application protocols were used for all surfaces. The samples were collected from a surface with an area of 260 cm² approximately divided into two sections using sterile swabs. The first section samples were mounted on a Petri dish containing BHI agar, without dilutions. Then, the UV-C light device Biosept Home[®] was applied, slowly, throughout the delimited region of the other section, for 20 s, at a distance of 1 cm from the surface (Fig. 1C), resulting in a dose of light 0.912 J/cm² and intensity of 45.6 mW/cm². A new collection was performed and the samples were mounted on another Petri dish containing BHI agar, without dilutions. This experiment was carried out in two different areas of each surface on three different days. The cultures were kept in an oven at 37 °C for 48 h and then the CFU growth was analyzed [16].

2.3.3. Data analysis

The colonies of irradiated and non-irradiated plaques were counted. Each irradiated session was compared to the corresponding control session, which had not been treated with Biosept Home[®] UV-C. All experiments were performed on three different days and quantified in duplicate, resulting in six quantifications per group. As the surface samples were passed directly on Petri dishes containing BHI agar, it was not possible to standardize the initial concentration of microorganisms. The mean, median, smallest and largest colonies for each group were identified [22] and paired sample *t*-test was performed between control groups (not irradiated) and their respective irradiated groups for statistical analysis, the. Differences were considered statistically significant at $p \leq 0.05$. Data were analyzed using GraphPad Prism 6.01 software.

3. Results

3.1. Effects of Biosept Home[®] UV-C on standard reference microorganisms

Before decontamination with UV-C light, *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Escherichia coli*, *Pseudomonas aeruginosa*, *Salmonella enterica (typhimurium)* and *Candida albicans* formed dozens or hundreds of colonies on the agar (Fig. 2). After decontamination with UV-C light, the colonies of all bacteria were reduced to 0, showing a disinfectant effect for these microorganisms, and *Candida albicans* reduced to 0–3, demonstrating high-efficiency decontamination by Biosept Home[®] UV-C.

In addition to the qualitative analysis, in which the reduction in the number of microorganisms in the culture medium is visually observed, a quantitative analysis was also carried out by counting colony-forming units. The results are shown in the log (CFU/mL) and the *in vitro* reduction of microorganisms after the application of Biosept Home[®]

UV-C is shown in Fig. 3. As shown in the graph (Fig. 3), no bacterial growth was observed, *i.e.*, 100 % of microbial inactivation after application of Biosept Home[®] UV-C, under the conditions tested. Additionally, a reduction of approximately 4 logs for the yeast *C. albicans* was observed.

3.2. Effect of Biosept Home[®] UV-C in hospital surfaces

As shown in Table 1, Biosept Home[®] UV-C significantly reduced the microbial colony count ($p \leq 0.05$) in all hospital surfaces. The most contaminated surfaces before applying Biosept-Home[®] UV-C were the hospital kitchen and the ICU workbench. Except for the doctor's office desk of the pediatric room, Biosept Home[®] UV-C was able to reduce microbial counts to zero.

4. Discussion

The results of the present study demonstrated that Biosept Home[®] UV-C is effective in reducing microorganisms both *in vitro* conditions and in healthcare environments. To reduce 99.99 % of the bacteria used in the experiment, a light dose between 8 and 13 mJ/cm² is required [23], or much lower than the one used (0.912 J/cm²). However, the dose used was not sufficient to completely reduce the yeast *Candida*

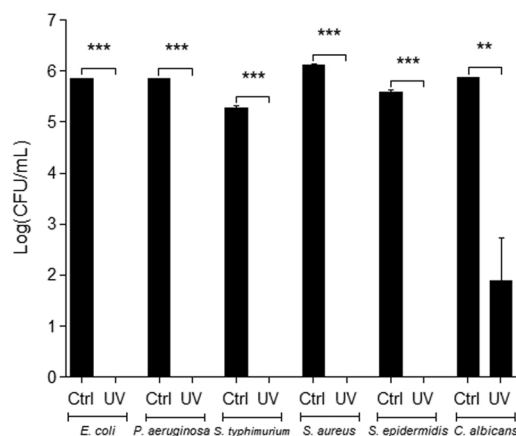


Fig. 3. Survival graph. *Escherichia coli* (ATCC 25922), *P. aeruginosa* (ATCC 27853), *Salmonella enterica typhimurium* (CCCD S004), *Staphylococcus aureus* (ATCC 6538), *Staphylococcus epidermidis* (CCCD S010) and *Candida albicans* in log₁₀ (UFC/mL) before and after the application of Biosept Home[®] UV-C with 0.912 J/cm² of light dose and 4.56×10^4 μ W/cm² of intensity. Data are shown as mean and SEM for log₁₀ CFU/mL. *** $p < 0.0001$ level, ** $p \leq 0.0050$. CFU, colony-forming units.

Table 1
Microbial reduction after UV-C application on surfaces of Public Health Hospital of Rio Claro.

Surface	Before Biosept Home UV-C Decontamination			After Biosept Home UV-C Decontamination			p
	mean	median	lowest-highest	mean	median	lowest-highest	
Blood sampling chair (1)	44,40	30	11–73	3,8	3	0–6	0,037
Doctor's office desk (adult) (2)	65,25	49	36–91	2,6	1	0–8	0,006
Doctor's office desk (child) (3)	16	18	11–19	3	3	2–4	0,022
Hospital kitchen (4)	192	168	81–300	16,67	8,5	0–50	0,002
ICU bed curtain (5)	36	33	12–66	0,25	0	0–1	0,049
ICU medication room (6)	53	50	6–99	0,4	0	0–2	0,046
ICU workbench (7)	177	168	34–275	1,75	2	0–3	0,042
Urinalysis workbench (8)	65,75	80	6–97	0,5	0	0–2	0,049

albicans.

Dai et al. [24] showed that a light dose of 2.92 J/cm² was necessary to reduce 99.2 % of the yeast *Candida albicans*. Therefore, to completely prevent the growth of this yeast, a greater exposure to Biosept Home© UV-C, of at least 65 s would be necessary.

Bacteria are generally more susceptible to UV-C light than fungi [25]. This is because fungi have eukaryotic cells and the presence of the nuclear membrane surrounding the genetic material requires a greater exposure to this radiation when compared to cell prokaryotes of bacteria [26–28]. On the scale of the highest to the lowest susceptibility to UV-C light, where fungi are the least susceptible, we have viruses as the most sensitive to this type of radiation; however, this is not always the case [25]. For example, *in vitro*, the SARS-COV-2 virus, at a distance of 3 cm from the light source, needed a light dose of 1048 mJ/cm² (corresponding to 9 min exposure to the light source) to show a complete inactivation [29]. On the other hand, *in vitro* exposure of the virus to Biosept Home© UV-C at a distance of 1 cm for 23 s would possibly be capable of showing total SARS-COV-2 inactivation [29].

There has been a progressive increase in hospital infections by microorganisms, with high rates of morbidity and mortality, and contamination cross-reactions (nosocomial) caused by these pathogens must be controlled with effective disinfection methods [30]. Transmission of agents pathogenic and/or opportunistic conditions can occur through contact with secretions or fluids, contaminated organic products, or through instruments, appliances and inanimate contact surfaces [31].

In the current world scenario of the COVID-19 pandemic, health professionals are at high risk of cross-infection by the SARS-COV-2 virus, especially dental office staff, due to their proximity to the mouth and the patients' airways during the procedures. The instruments used in the treatment procedures generate considerable amounts of potentially infectious bioaerosols and droplets can be deposited on any surface [32].

Manual cleaning is a widely used method for decontamination of hospital environments. Often, cleaning and disinfection procedures and the type of substances used in such processes are varied. However, the variety of environments, some with multiple surfaces, makes manual cleaning difficult and not efficient. Many patients use the same location between procedures, and this increases the risk of infection [16,22].

In this context, the decontamination of different surfaces of hospitals and dental offices by UV-C light may be an alternative. There are not many studies in the literature regarding the use of UV-C light for decontamination of surfaces in dentistry hospitals; however, as it has been widely used in other health areas, we can imply its use in the dental area [33].

It is worth mentioning that UV light has no penetrating power, acting only on the surface where the rays strike, and the germicidal action is affected by the accumulation of dirt, organic matter and the distance from the surface to be disinfected [34]. The material and design surfaces can also influence the germicidal action of the light. In addition, the composition of the material can also change the adhesion of microorganisms by forming biofilms that are resistant to disinfection processes [16].

The decontaminated surfaces in this experiment were composed of the following materials, respectively: (1) leatherette, (2) medium-

density fiberboard (MDF), (3) MDF, (4) stainless steel, (5) synthetic plastic polymers (PVC), (6) granite, (7) MDF, (8) MDF. On all surfaces, decontamination showed a reduction of microorganisms above 81 %. This is a promising result; however, new exposure time protocols must be developed for the total elimination of microorganisms on these hospital surfaces.

Considering all surfaces, we had an average of 63.2 colonies before the application of Biosept Home© UV-C and 3.6 afterward. Andersen et al. [34] observed 30.9 CFU and 2.1 CFU before and after exposure for 40 min in a patient's room, where the minimum light dose was 1.60 J/cm². Biosept Home© UV-C proved to be as effective as more robust UV-C equipment, in a much shorter period (20 s).

The decontamination of surfaces by Biosept Home© UV-C has the advantage of it is a portable device; the exposure time required for decontamination is short; UV-C light leaves no residue in the environment, a step forward compared to chemicals with high toxicity for human beings, and the environment.

It is important to note that exposure to UV-C radiation poses risks to human health, especially for the skin and eyes. Doses greater than 5 mJ/cm² can cause painful acute conjunctivitis, while doses greater than 10 mJ/cm² result in mild redness, flaking, and pigmentation of the skin [35]. Even if a dose emitted by Biosept Home© UV-C is higher than these values, it has an adequate design to minimize the risks of exposure, in addition to providing and recommending the use of protective goggles by the worker when using the device.

As already commented, the germicidal effect is reduced in the presence of dirt and organic materials. Therefore, visually dirty surfaces need to be cleaned before decontamination with Biosept Home© UV-C. This device does not replace the traditional manual cleaning of surfaces protocol, but as this cleaning generally fails, the use of Biosept Home© UV-C is a way to complement disinfection and minimize the risks of hospital infection.

5. Conclusion

The application of UV-C light for 20 s using Biosept Home© UV-C was effective in reducing the *in vitro* growth of microorganisms involved in health-associated infections. This device also achieved a high reduction in the microbial load on hospital surfaces. Overall, Biosept Home© UV-C is a promising alternative for implementing disinfection protocols in hospitals and also in clinics (medical, dental, esthetic), reducing the risk of infection transmission.

Declaration of Competing Interest

The authors have no conflicts of interest. The company Bioset had no role in the study design, data collection or analysis, decision to publish, or preparation of the manuscript.

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