UVC light as a strategy for disinfection of hospital air and surfaces

Luz UVC como estratégia de desinfecção do ar e superfícies hospitalares

Luz UV-C como estrategia de desinfección del aire y superficies hospitalarias

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Abstract

Objective: To evaluate a fixed UV-C light emitting device for its antimicrobial effectiveness in the disinfection of distinct surfaces and its antifungal effectiveness on air quality in the hospital environment.

Methods: This quasi-experimental study was conducted in a hospital inpatient unit, in which a six-stage air Biosampler (Andersen®) was used for air analysis. In the evaluation of surfaces, three suspensions of microorganisms (*Acinetobacter* sp. multidrug-resistant, *Escherichia coli*, and KPC-producing *Klebsiella pneumoniae*) were used to contaminate the environment. In both evaluations, pre- (control) and post-activation of UV-C light (test) collections were made.

Results: In the air evaluation, an important reduction was observed in the colony count after irradiation with UV-C light, and pathogenic or toxigenic fungi were not found in either of the two moments. Regarding the disinfection of surfaces, no bacterial growth was observed after the application of UV-C light, showing 100% bacterial inactivation under the tested conditions.

Conclusion: The use of fixed UV-C light emission technology was effective and can be considered a promising intervention for hospital surface disinfection protocols.

Resumo

Objetivo: Avaliar a eficácia antimicrobiana de um dispositivo fixo emissor de luz UV-C na desinfecção de diferentes superfícies do ambiente hospitalar e sua eficácia antifúngica na qualidade do ar.

Métodos: Estudo quase-experimental realizado em uma unidade de internação hospitalar, que utilizou o Bioamostrador de ar Andersen® de seis estágios para análise do ar; e na avaliação das superfícies, utilizaram-se três suspensões de microrganismos (*Acinetobacter* sp. MDR, *Escherichia coli* e *Klebsiella pneumoniae* produtora de KPC) para contaminar o ambiente. Para ambos foram feitas coletas pré (controle) e pós-acionamento da luz UV-C (teste).

Resultados: Na avaliação do ar houve uma redução importante da contagem de colônias após a luz UV-C e não foram encontrados fungos patogênicos ou toxigênicos em nenhum dos dois momentos. Em relação à desinfecção das superfícies, nenhum crescimento bacteriano foi observado após a intervenção da luz, demonstrando 100% de inativação bacteriana nas condições testadas.

Conclusão: A utilização da tecnologia com emissão de luz UV-C fixa foi eficaz e pode ser considerada uma intervenção promissora para protocolos de desinfecção de superfícies hospitalares.

Resumen

Objetivo: Evaluar la eficacia antimicrobiana de un dispositivo fijo emisor de luz UV-C para la desinfección de diferentes superficies del ambiente hospitalario y su eficacia antifúngica en la calidad del aire.

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Conflicts of interest: The authors have no conflict to declare.

Métodos: Estudio cuasi experimental realizado en una unidad de internación hospitalaria, en que se utilizó el biomuestreador de aire Andersen® de seis etapas para el análisis del aire. En el análisis de las superficies, se utilizaron tres suspensiones de microorganismos (*Acinetobacter* sp. MDR, *Escherichia coli* y *Klebsiella pneumoniae* productora de KPC) para contaminar el ambiente. En ambos se tomó una muestra antes (control) y después de accionar la luz UV-C (prueba).

Resultados: En el análisis del aire hubo una reducción importante del recuento de colonias después de la luz UV-C y no se encontraron hongos patógenos ni toxigénicos en ninguno de los dos momentos. Con relación a la desinfección de las superficies, no se observó ningún crecimiento bacteriano después de la intervención de la luz, lo que demuestra un 100 % de inactivación bacteriana en las condiciones analizadas.

Conclusión: El uso de la tecnología con emisión de luz UV-C fija fue eficaz y puede ser considerada una intervención prometedora para protocolos de desinfección de superficies hospitalarias.

Introduction

Hospital surfaces and equipment can be considered vehicles of contamination and thus potential sources of infection.[1] Various microorganisms can be present in areas close to the patient and survive for long periods in these places, making them integral parts of the chain of transmission of healthcare-associated infections (IRAS/ HAIs).[2]

This reinforces the hypothesis that apparently clean sites become true reservoirs of multidrug-resistant (MR) pathogens when cleaning is negligent.[1] There is evidence of a 120% increase in the possibility that patients who later occupy the same unit will also be colonized and/or infected by these pathogens.[2]

Cross-transmission of diseases caused by MR pathogens can occur through direct or indirect contact. Air is part of the pathophysiology of respiratory diseases that are transmitted through droplets or aerosols. Systems of ventilation, climatization, flow, and filtration of the air and negative pressure interfere with the capacity and speed of microorganisms to spread in the environment reducing airborne contamination.[3]

Hospital hygiene, understood as cleaning and disinfection of hospital surfaces and the air, is a preponderant factor in the dynamics of health and illness of individuals in the healthcare environment.

This statement agrees with the main assumptions that Florence Nightingale considered essential: "pure air and water, efficient drainage, cleanliness, and light".[4]

As for air quality, clinically important filamentous fungi may be present in this environment causing invasive fungal diseases with high mortality rates.

Early detection of these pathogens, identification of patients at risk, as well as prevention measures, and transmission control, are essential measures that should be prioritized in healthcare areas.[5]

In this scenario, the use of technological innovations, with "touchless" techniques to sanitize the environment in these areas, appears to overcome obstacles related to traditional methods, which alone do not meet current demand. The use of ultraviolet radiation is highlighted.[6,7]

Ultraviolet light matches electromagnetic radiation with a wavelength in the range of 100-400 nm (or frequencies of $7.5x10^{14}$ - 3.0 $x10^{16}$ Hz), which can be divided into three categories: UV-A, UV-B, and UV-C.[8]

The wavelength of UV-C, which was first described in 1910, is the shortest of the highest energy portions of the UV spectrum and has been established as an antimicrobial range for nearly a century. It can damage the DNA and RNA of microorganisms through the formation of thymine and/or thymidine dimers, thus impairing the transcription and preventing the replication of microbial DNA, i.e., it inactivates viruses and bacteria.[9]

This germicidal light has several applications, including air and water purification, food and beverage protection, and sterilization of sensitive tools such as medical instruments.[8]

However, factors such as the structure of the surface interfere with its effectiveness and affect the quality of disinfection: the decontamination of smooth and hard surfaces is the one that presents the most satisfactory results. The accumulation of dirt and organic matter also alters the germicidal action, as they can absorb ultraviolet photons before they reach active bacteria and viruses.[10]

The distance between the fixed surface and the source of UV radiation is another relevant aspect, i.e., the greater the distance between the UV light source and the surface, the smaller the effect of decontamination.[11]

Therefore, the objective of the present study was to evaluate a fixed UV-C light emitting device in terms of antimicrobial effectiveness in the disinfection of surfaces and antifungal effectiveness in the air quality of the hospital environment.

Methods

This was a before-and-after quasi-experimental study, distributed in three phases (Figure 1) and developed in a federal university hospital located in the city of Rio de Janeiro, in the period August-December 2021.

The medical and surgical clinical unit, which is used as a cohort sector of patients with the microbiological diagnosis of enterobacteria resistant to carbapenem antimicrobials, ERC (and has the physical structure of individual rooms) was the scenario chosen for the intervention. Six different fixed surfaces were considered eligible for the intervention phase: feeding table, bedside table, mattress, bedside rail, closet door, and electronic bed control panel. Surfaces considered high-touch and made with materials of different porosities were inclusion criteria. Surfaces with loss of continuity were excluded. A UV-C emitter composed of 11, 15, and 36 W lamps (18, 4, and 2 lamps, respectively) that emit electromagnetic waves in the UV-C range (254 nm) was the system subjected to efficacy testing. The set of lamps and ballasts was manufactured according to the standard international norm (ISO 15,858, published in 2016) and imported by the company that owns the technology. The compact and fixed design makes the technology innovative as it proposes to minimize the areas where the light cannot reach the fixed hospital surfaces (shadow areas).

Procedures of data collection and intervention

Phase 1 began with the evaluation of the most suitable places to install the UV-C emitting lamp system, to reduce the occurrence of shadow areas as much as possible. For this purpose, a computer program (RTS - Rio AS) determined the lamp assembly positions through a mathematical model based on the architectural plan of the room. Before the system was installed, the engineers and programmers of the device manufacturer visited the site to assess the conditions of the electrical system, the type of

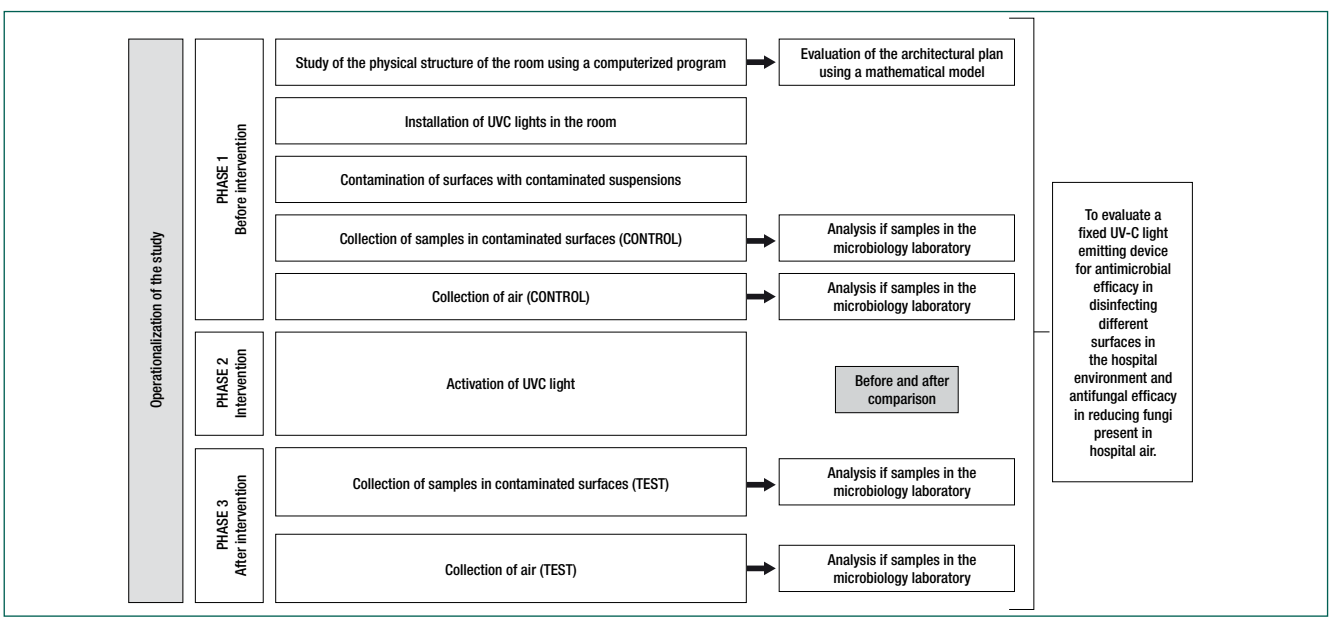

Figure 1. Operationalization of the study

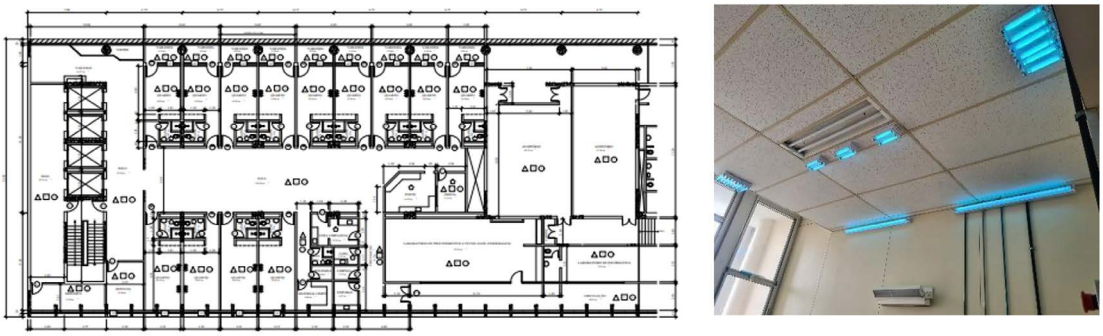

Figure 2. The physical floor plan of the unit eligible for the test and the installed UV-C light system

material used in civil construction, and the layout of the existing furniture in the room.

Based on this information, a new calculation was performed for the most suitable places to pose the lamp system, given the structural limitations of the unit and the layout of the furniture (Figure 2).

Phase 1 (2nd part) comprised the contamination of eligible hospital surfaces and the collection of air samples in a room previously sanitized by the outsourced cleaning team according to the institutional routine. To contaminate surfaces, gram-negative microorganisms (*Acinetobacter* sp. multidrug-resistant; *Escherichia coli*, and carbapenem-producing *Klebsiella pneumoniae*) obtained from clinical material cultures (stored in the bacteria "library" of the microbiology sector of the hospital) were used.[12] The referred pathogens were chosen because of their high association with infections related to health care in the institution and in the world. In addition, they are part of the scope of action of the Contingency Plan for Infections caused by Multiresistant Microorganisms in Health Services (PLACON-RM) as published by the National Health Surveillance Agency (2021).[13]

All microorganisms were prepared in suspensions (0.5 McFarland scale) and diluted again in physiological solution to reach a 1:10 ratio and obtain a dilution equivalent to 10^7 UGC/CFU/ml, recommended as a standard suspension by quality manuals for microbiology laboratories. Controlled contamination of predetermined surfaces (area: ~64 cm^2) was performed using gloves and sterile gauze. After the bacterial suspensions had dried, sampling from each contaminated surface (control sample) was performed using a moistened (0.9% saline solution) sterile swab.

The choice of the microorganism suspension applied to a given surface occurred randomly with blinding of the CCIH and microbiology teams.

As for air collection, samples were obtained using the 6-stage Andersen® Biosampler (Andersen; Thermo Fisher Scientific, Inc; Waltham, MA, USA; air collection capacity: 28.3 l/min). Each stage of the air sampler was filled with a glass Petri dish (90 x 15 mm) containing agar (2% Sabouraud-Dextrose).

Phase 2 comprised the activation of the UV-C light system. The system remained on at different times to disinfect the surfaces (15 min) and the air (50 min). We emphasize that the windows and doors remained closed before and after the collection to avoid contamination and compromise of the test. The choice of study time was determined by the device manufacturer.

The use of light technology was restricted to the non-occupation of the room, with manual control, handled only by the researchers to minimize any risk to patients and professionals. In addition, the tests were performed on different days so that any interference between tests could not occur.

In phase 3, the collection of test samples was carried out on surfaces and air. Pre-moistened saline swabs were used to collect samples from the surfaces. The control and test swabs were sent to the microbiology laboratory where they were processed in thioglycolate broth (72 h; oven: 35 ºC). At the end of the incubation, the turbid broths were plated on blood agar plates and incubated (24 h; 35 ºC) to obtain bacterial colonies.

In the qualitative analysis, the reduction of microorganisms can be visually observed in the culture medium. In addition, quantitative analysis was performed to count the colony-forming units in the turbid broths using the automated Vitek 2 identification system (Biomerieux®).

In the identification of fungi, the macro and micromorphological parameters were taken as a basis. We emphasize that subcultures were only performed when consistent characteristics of clinically relevant fungi (such as *Aspergillus*, *Fusarium,* mucormycosis agents, and other potentially pathogenic fungi) were observed.[14]

The count of bacterial colonies found on surfaces (before and after the application of UV-C irradiation) was analyzed in the Excel® program (Wilcoxon test) since the sample was small and unpaired. The percent and $\log_{10}$ CFU reductions of colonies were calculated as follows:[15]

$$\text{Percent Reduction} = \frac{(B - A) \times 100}{B}$$

$$\text{Log}_{10}\ \text{CFU reduction} = \text{Log}_{10}\ (B\text{-}A)\ \text{CFU}$$

Where:

A = Number of viable microorganisms

B = Number of viable microorganisms after irradiation with UVC light

As for the air test sample, the same collection technique used in phase 2 (duration: 30 min) was applied. After this time, the glass Petri plates containing agar (Sabouraud-Dextrose 2%) were sent to the mycology unit, where they remained sealed and incubated (30° C) in a Biochemical Oxygen Demand oven (BOD) for a period of up to 30 days.[16] Fungal growth was monitored daily, and colonies were counted weekly. For subcultures, potato-dextrose agar (DIFCO), Czapek agar (DIFCO), lactrimel agar, oat agar, and malt extract agar were used.

In the development of the study, the ethical principles recommended by the National Health Council (Resolution 466/12) and the SQUIRE 2.0 guidelines were respected. We emphasize that this study is part of a larger project on mapping the hygiene of beds approved by the Ethics Committee on Research with Human Beings (Federal University of Rio de Janeiro; CAAE: 48271421.3.0000.5238; opinion 4.931.444).

Results

In general, the effectiveness of bacterial killing by the UV-C device on surface samples was greater when compared to air samples, as the elimination of microorganisms on surfaces was complete and its reduction in the air was substantial. The average count of bacterial colonies tested was significantly reduced after UV-C irradiation (15 min; 107 CFU *vs.* 0 CFU; p=0.005). Turbidity was not observed in the test broth, showing a highly effective disinfectant effect for multiresistant Gram-negative enterobacteria (Figure 3).

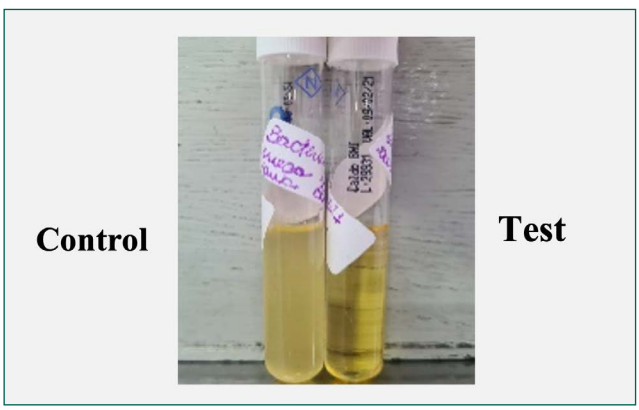

Figure 3. Flasks containing broth with turbidity (control) and without turbidity (test)

However, all control broths turned cloudy; after growth on a blood agar plate, they were submitted for identification to confirm the presence of the impregnated microorganism (control). The culture media of the test samples did not pass through the quantitative analysis step, as none of the cultures of the tested surfaces showed turbidity after irradiation with UV-C light (Table 1).

As for the air quality assessment, the results were presented in log (CFU/m³), in which an important reduction was observed in the tested conditions. A reduction from 38 to 4 CFU/m³ (90%) global mycological colonies occurred after irradiation with

Table 1. Analysis of contaminated surfaces and air after UV-C irradiation

Surfaces and air	Microorganisms	Phase I before UV-C (CFU)	Phase III After UV-C (CFU)	Reduction percentage (%)
Bed control	*Acinetobacter sp.* multidrug-resistant	10^7 CFU/mL	0 (zero)	100
Feeding table		10^7 CFU/mL	0 (zero)	100
Bed side rail	KPC-type carbapenemase-producing *E. coli*	10^7 CFU/mL	0 (zero)	100
Bedside table		10^7 CFU/mL	0 (zero)	100
Mattress	KPC-type carbapenemase-producing *K. pneumoniae*	10^7 CFU/mL	0 (zero)	100
Closet door		10^7 CFU/mL	0 (zero)	100
Air	Global mycological colonies	38 CFU/ m^3	4 CFU/ m^3	89.5
Air	Mycological agents of interest *	NI	NI	-

NI: not identified; * *Aspergillus*, *Fusarium*, mucormycosis agents, and other pathogenic fungi

UV-C light. We also emphasize that no mycological agent of interest, i.e., with pathogenic potential, was isolated before and after applying UV light, reflecting parameters of environmental normality. The minimum time required for effectiveness in reducing total pathogens in the air was not obtained in this study.

Discussion

This study evaluated the effectiveness of a UV-C light-emitting device on air quality and disinfection of different types of fixed surfaces. The results obtained suggest that its use is an important strategy to reduce and/or eliminate microorganisms present in the healthcare environment. Therefore, its application to improve the terminal hygiene of beds and operating rooms as a tool to reduce the transmission of pathogens, should be incorporated as one of the main measures to prevent healthcare-related infections. The findings agree with those of other studies that showed the effectiveness of UV light emitting devices when compared to the usual cleaning process, as their use provided a greater reduction in the bacterial log when compared to the traditional cleaning method.[9,17-23]

The study points out that the technology studied can reduce by 100% microorganisms such as *Pseudomonas*, multi-resistant *Acinetobacter*, MRSA, and VRE, including *mycobacterium abscesses* and *Aspergillus fumigatus*.[15]

However, even with findings similar to those shown in this present study, the use of UV light is considered an adjuvant method; its use dissociated from mechanical cleaning is not recommended. This statement is based on the justification of reduction in technology effectiveness in shaded areas (bed rails, closets, control panel).[9,11,23]

Reduction in the emission capacity of UV-C rays in bedrooms or living rooms with large architectural dimensions is another justification for limiting their use as the main method to disinfect hospital surfaces. In these places, moving the device to different strategic points for a given time is required to ensure that all surfaces are processed.[9,15]

However, the fixed UV-C light device used in the present study offers installation driven by a mathematical model as an advantage; it uses the physical layout of the environment and allows shadow areas to be almost eliminated thus increasing its effectiveness.

In addition to the ability to eliminate microorganisms from fixed surfaces in care units, improve air quality by reducing mycological colonies, and provide a reduction in shadow areas, the innovation of this device is also related to the fact that a professional to mobilize the equipment every period of use is not necessary.[15]

The failure to remove dirt or stains by UV-C light observed in this study is one of its limitations; this agrees with other studies and may be associated with a reduction in its efficacy potential; thus, further comparative investigations involving such conditions are suggested.[15,23]

In this study, the germicidal efficacy of UV-C light was proven by culturing samples collected from surfaces previously contaminated with strains of epidemiological importance and subjected to irradiation, as in other studies that used the same microbiological identification method to prove its effectiveness.[23,24]

In addition to the inactivation of nosocomial pathogens, such as multidrug-resistant bacteria, our study showed that UV-C light is an excellent fungicidal agent to reduce these microorganisms in the air, contributing to improve air quality and control emerging pathogens such as in the inactiva-

tion of strains of coronavirus.[24] Such effects of the UV-C light had already been demonstrated for the Influenza virus with positive intervention results in preventing aerial transmission of the person-to-person infection.[25]

The evidence that healthcare professionals often colonize the transient microbiota on their hands or gloves when touching contaminated surfaces is already known. This leads to the spread of pathogens by hands or equipment that comes into contact with such surfaces.[1,16]

According to this chain of cross-transmission that exists in the hospital environment, frequent and adequate cleaning and disinfection of highly touched surfaces have become fundamental parts of microbiological control in these places.[18] Such practice aims not only to remove dirt and organic matter from surfaces when carried out in critical environments but also to significantly reduce the microbial load when specific chemicals are used.[19,20]

However, the use of specific products validated by regulatory agencies is necessary, within the appropriate technique of movement, direction, and friction by a well-trained team so that these results are achieved.[16,21]

As this is a human intervention process, problems of dilution and toxicity of disinfectant solutions, inadequate action time on surfaces, unsatisfactory and superficial techniques are still observed, favoring the insertion of new technologies of environmental disinfection methods.[21,22]

The fixed technology for emitting UV-C light used to improve air quality and disinfect hospital surfaces has also shown to be more advantageous compared to traditional cleaning methods, as it is a method that leaves no residue, does not require ventilation after use, does not cause toxicity when manipulated by the professional, still being ecologically correct. [9,24] Therefore, it can be an excellent addition to existing hygiene protocols.

As mycological agents of interest were not found at any of the two moments before and after irradiation of UV-C light, a new collection at another moment is suggested. Testing different times of light use *versus* action on different types of surfaces, roughness, texture, and position in the environment will be interesting to evaluate disinfectant effectiveness on other surfaces.

Conclusion

The results suggest that the use of technologies with fixed UV-C light emission is effective in reducing the potential microbial load on different types of existing surfaces in hospitalization rooms. It can therefore be considered a promising intervention for disinfection as well as to improve air quality in hospital environments. It can reach long distances and shaded areas relative to mobile equipment or UV light towers commonly used for this purpose.

Collaborations

Freire JOP, Paes GO, Gonzalez CM, Barreiros MGC, and Ferreira ALP collaborated in the study design, data analysis and interpretation, manuscript writing, relevant critical review of the intellectual content, and approval of the final version to be published.

References

1. Furlan MC, Ferreira AM, Rigotti MA, Guerra OG, Frota OP, Sousa AF, et al. Correlation among monitoring methods of surface cleaning and disinfection in outpatient facilities. Acta Paul Enferm. 2019;32(3):282–9.

2. Chia PY, Sengupta S, Kukreja A, Ponnampalavanar S, Ng OT, Marimuthu K. The role of hospital environment in transmissions of multidrug-resistant gram-negative organisms. Antimicrob Resist Infect Control. 2020;9(1):29. Review.

3. Bortoluzzi TV, Ely VH, Cavalcanti PB. Quartos de isolamento em unidades de urgência e emergência: sinergia entre legislação e prática? Arquitetura Rev. 2020;16(1):119-36.

4. Silveira-Alves A, Sepp VJ, Loureiro LH, Moreira da Silva IC. Teoria ambiental no ensino e prática profissional em enfermagem: uma revisão integrativa. Práxis. 2021;13(25).

5. Ruiz-Camps I, Aguado JM, Almirante B, Bouza E, Ferrer-Barbera CF, Len O, Lopez-Cerero L, Rodríguez-Tudela JL, Ruiz M, Solé A, Vallejo C, Vazquez L, Zaragoza R, Cuenca-Estrella M; GEMICOMED (Medical Mycology Study Group of SEIMC). Guidelines for the prevention of invasive mould diseases caused by filamentous fungi by the Spanish Society of Infectious Diseases and Clinical Microbiology (SEIMC). Clin Microbiol Infect. 2011;17 Suppl 2:1-24.

6. Rock C, Small BA, Thom KA. Innovative methods of hospital disinfection in prevention of healthcare-associated infections. Curr Treat Options Infect Dis. 2018;10(1):65–77.

7. Couto JF, Silva MS, Machado WC, Tyrrel MA, Couto FF, Nunes MA, et al. Desinfecção baseada na radiação ultravioleta-c: um estudo bibliométrico no contexto internacional. Res Soc Dev. 2021;10(1):e46910111785.

8. Santos TD, Castro LF. Evaluation of a portable Ultraviolet C (UV-C) device for hospital surface decontamination. Photodiagnosis Photodyn Ther. 2021;33:102161.

9. Ramos CC, Roque JL, Sarmiento DB, Suarez LE, Sunio JT, Tabungar KI, et al. Use of ultraviolet-C in environmental sterilization in hospitals: a systematic review on efficacy and safety. Int J Health Sci (Qassim). 2020;14(6):52–65.

10. Bhardwaj SK, Singh H, Deep A, Khatri M, Bhaumik J, Kim KH, Bhardwaj N. UVC-based photoinactivation as an efficient tool to control the transmission of coronaviruses. Sci Total Environ. 2021;792:148548. Review.

11. Boyce JM, Donskey CJ. Understanding ultraviolet light surface decontamination in hospital rooms: A primer. Infect Control Hosp Epidemiol. 2019;40(9):1030-5. Review.

12. Universidade Federal do Rio de Janeiro UFRJ). Hospital Universitário Clementino Fraga Filho (HUCFF). Relatório anual da Coordenação de Controle de Infecção Hospitalar - 2021. Rio de Janeiro: UFRJ, HUCFF; 2022. p. 1–5.

13. Brasil. Ministério da Saúde. Agência Nacional de Vigilância Sanitária. Plano de Contingência Nacional para Infecções causadas por Microrganismos Multirresistentes em Serviços de Saúde PLACON – RM. Brasília (DF): Ministério da Saúde; 2021 [citado 2023 Ago 18]. Disponível em: https://www.gov.br/anvisa/pt-br/centraisdeconteudo/publicacoes/servicosdesaude/publicacoes/placon-nacional-mr-09-11-2021.pdf

14. De Hoog GS, Guarro J, Gené J, Figueras MJ. Atlas of clinical fungi. 2nd ed. Int Microbiol. 2001;4:51-2.

15. Yang JH, Wu UI, Tai HM, Sheng WH. Effectiveness of an ultraviolet-C disinfection system for reduction of healthcare-associated pathogens. J Microbiol Immunol Infect. 2019;52(3):487-93.

16. Meyer J, Nippak P, Cumming A. An evaluation of cleaning practices at a teaching hospital. Am J Infect Control. 2021;49(1):40-3. Erratum in: Am J Infect Control. 2022;50(1):122.

17. Dutra HS, Badaró CS, Farah BF, Coelho AC, Bahia MT, Gama BM. The use of technical visit in the nursing administration teaching. Rev Enferm Centro-Oeste Min. 2019;9:e2502.

18. Frota OP, Ferreira AM, Rigotti MA, Andrade D, Borges NM, Ferreira Júnior MA. Effectiveness of clinical surface cleaning and disinfection: evaluation methods. Rev Bras Enferm. 2020;73(1):e20180623.

19. São Paulo. Governo do Estado de São Paulo. Centro de Vigilância Epidemiológica. Divisão de Infecção Hospitalar. Melhores práticas para higiene e limpeza em ambiente hospitalar. São Pulo: Governo do Estado de São Paulo; 2019 [citado 2023 Ago 18]. Disponível em: https://proqualis.net/sites/proqualis.net/files/Melhores%20pr%C3%A1ticas%20para%20higiene%20e%20limpeza%20hospitalar.pdf

20. Center for Disease Control and Prevention (CDCP). Environmental Cleaning in Global Healthcare Settings. Best Practices for Global Healthcare Facilities with Limited Resources. USA: CDCP; 2020 [cited 2023 Aug 18]. Available from: https://www.cdc.gov/hai/prevent/resource-limited/index.html

21. Rutala WA, Weber DJ. Best practices for disinfection of noncritical environmental surfaces and equipment in health care facilities: abundle approach. Am J Infect Control. 2019;47S:A96-105. Review.

22. Boyce JM. Modern technologies for improving cleaning and disinfection of environmental surfaces in hospitals. Antimicrob Resist Infect Control. 2016;5:10. Review.

23. Casini B, Tuvo B, Cristina ML, Spagnolo AM, Totaro M, Baggiani A, et al. Evaluation of an Ultraviolet C (UVC) Light-Emitting Device for Disinfection of High Touch Surfaces in Hospital Critical Areas. Int J Environ Res Public Health. 2019;16(19):3572.

24. Lorca-Oró C, Vila J, Pleguezuelos P, Vergara-Alert J, Rodon J, Majó N, et al. Rapid SARS-CoV-2 inactivation in a simulated hospital room using a mobile and autonomous robot emitting ultraviolet-c light. J Infect Dis. 2022;225(4):587-92.

25. Schuit M, Gardner S, Wood S, Bower K, Williams G, Freeburger D, et al. The influence of simulated sunlight on the inactivation of influenza virus in aerosols. J Infect Dis. 2020;221(3):372-8.