Journal of Human Centered Technology Vol. 2: No. 1 (2023) 11 – 17

Journal of Human Centered Technology

E-ISSN: 2821-3467
https://humentech.utm.my

Surface Bacterium Disinfection Using Everlight 6565 UV-C SMD

Tan Tian Swee[1,*], Jahanzeb Sheikh[1], Syafiqah Saidin[1], Sameen Ahmed Malik[2], Lee Suan Chua[3], Matthias Tiong Foh Thye[1], Leong Kah Meng[4], Jia Hou Tan[4]

[1]Department of Biomedical Engineering & Health Sciences, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Malaysia.

[2]Department of Bio-medical Engineering, Faculty of Electrical Engineering, University of Engineering & Technology Lahore - Narowal campus, Narowal, 51600, Punjab, Pakistan

[3]Department of Bioprocess and Polymer Engineering, Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor Bahru, Johor, Malaysia.

[4]Faculty of Engineering & Information, Southern College, Johor Bahru, Malaysia.

*Corresponding Author tantswee@utm.my

Received 28 September 2022; Accepted 04 November 2022; Available online 06 February 2023
https://10.11113/humentech.v2n1.33

Abstract:
Ultraviolet-C (UVC) sourced has been widely used for the purpose of disinfection due to its germicidal spectrum. In this study, the effectiveness of Everlight's 275 nm Ultraviolet-C surface mounted device (UVC-SMD) to disinfect *Staphylococcus aureus (S. aureus)* was investigated at three exposure durations (10, 30 and 60 s) for a standard distance of 5 cm. The inhibition zones were greater with the increment of exposure duration. The highest records of 4.53 ± 0.03 cm were achieved when 102 mJ/cm² of dose was applied at a distance of 5 cm for 60 s. Whereas, on the other side, the lowest inhibition was seen when the exposure was set for 10 s. Thus, the Everlight 6565 UVC-SMD with 275 nm of wavelength is capable in providing bacterial disinfection which could possibly be used for the development of disinfection system based on SMDs at longer exposure duration.

Keywords: Bacterial disinfection; UV-C disinfection; Surface disinfection; Healthcare contamination

1. Introduction

The serious issue that is being looked by the practitioners, clinicians and doctors are microorganisms that occur within the healthcare facility ordinarily where disinfection is not given considerable attention. Severity of contaminated bacteria inside clinical/hospital rooms has always been a cause of infection which can lead to fatal infection. Strategies has still been discovered and research is still been done for cleaning and disinfecting things associated specially with healthcare to minimize the occurrence of healthcare associated infections (HAIs) [1 - 3]. The environment serves as a reservoir for microorganism which also allows the transmission of epidemiologically significant pathogens such as methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* (VRE), Acinetobacter spp., *Clostridium difficile* and norovirus [3 - 5]. The bacteria generally involved in infection are *Staphylococcus aureus* which have been isolated during the study and found to be around 93.5%, *Enterococcus faecalis* (71.1%), *Pseudomonas aeruginosa* (52.2%), anaerobic bacteria (39.1%) and coagulase-negative staphylococci including *Staphylococcus epidermidis* with around 45.7% as per studies [6]. The band of ultraviolet-C (UV-C), 200 - 300 nm has played a pivot role for effectively disrupting bacterial deoxyribonucleic acid (DNA) due to its germicidal effects and several procedures have been followed by the practitioners till today for treating the surface and water contamination. The very first thing recommended to avoid prolongation in healing of wound and to control the infection is cleaning. There are various disinfection techniques that have been proposed and are globally embraced, since pathogens are more likely to be transmitted by the hands that are often contaminated by human touch and the surface areas such as public toilets, door handles, bedside tables, phones, nurse call buttons and patient beds or seats [7].

Nosocomial Infection associated with hospital has been a major problem in today's world. Numerous epidemiological studies have been carried out to reveal the cause of such infection specially in western countries. The studies have shown promising improvement in decontaminating the environment and controlling infection by taking several control measures [8]. It is reported that ventilator-associated pneumonia (VAP) followed by central venous catheter-related bloodstream infections (CRBSIs) are the most common and important nosocomial infection generated in healthcare globally [9]. Lack of policies and control measures to overcome such issues has been a major problem to estimate the frequency of infection among the patients acquired from healthcare facilities in developing countries. Therefore, surveillance data are provided by International Nosocomial Infection Control Consortium (INICC) to acquire performance feedback to reduce the rate of infection majoring focus on education, hand hygiene and other control measures globally. The results concluded by INICC showed that infection control strategies significantly controlled and reduced infection rate in developed countries where reported baselines were 55.8 % for VAP, 54 % for CRBSI and 375 for catheter- associated urinary tract infection (CAUTI) [10, 11]. Information gathered from African countries about epidemiology and surveillance of hospital acquired infection is still lacking which shows the lack of resources and economic crisis. Some positive results were reported after WHO's implementation of hand hygiene strategies were followed stating that these guidelines were effective in controlling measures in low-income settings [12].

Several methods of disinfection have been demonstrated for disinfection purpose such as fluorescent dye and chemical germicides, that are used to disinfect and clean the environment which is still considered inadequate for proper disinfection [13, 14]. The procedures for disinfection followed conventionally are still not up to the mark as it is still not adequate for proper disinfection specially for medical equipment such as the usage of fluorescent dye which shows improved cleaning and have led to reduction in healthcare-associated pathogenic infection [15]. Chemical germicides and fluorescent are not adequate enough to counter contamination. "No-Touch" methods are introduced such as (UV-C light and hydrogen peroxide system) to improvise the quality of disinfection and environmental surfaces in patient rooms especially in intensive care units (ICUs) [16].

The ultraviolet-light emitting diode (UV-LED) technology has gained tremendous reputation in research and development industries. A subsequent increase in UV-LED manufacturers has been observed in market since the technology carries huge importance over the past few years. UV-LEDs have been manufactured not solely for electronic appliances which have changed the lightening industry completely but also have become available for the purpose of disinfection for various healthcare applications. The development of UV-LED at a rapid pace is replacing conventional disinfection application hence becoming a strong competitor specially for the applications used for disinfection. UV-LED that comes with a spectrum band of 200 – 300 nm is known to be called deep UV-LEDs while on the other hand the spectrum band from 300 to 400 nm of wavelength are considered near UV-LEDs. UVC-LEDs become commercially available ever after the technological advancements in nitride semiconductors. Due to the numerous advantages, a sweep in trend has been seen in whole of lightening industries which shifted from conventional lamp to light LEDs, yet it is considered a potential replacement for traditional UV sources in years to come. The most commonly seen UV-LED material such as III-nitride which includes gallium nitride (GaN), aluminum nitride (AIN) and aluminum gallium nitride (AGaN) where UV emission with 210 – 365 nm of wavelength can be obtained when such materials are used for development [17]. The wavelength ranging from 100 nm to 300 nm are considered to be the best for germicidal activity. The new era and recent studies are widely focused over the application for the purpose of disinfection majorly for water, food and healthcare [18, 19].

The existing UV lamps commercially available for disinfection purpose are available but at high cost. Availability of such conventional lamps utilize low pressure mercury and xenon technology which leaves many downsides of technology such as toxicity of mercury that is being used in the lamps and the power such lamps consumes to operate. Food & Drug Administration (FDA) disapproves low-pressure mercury lamp being non-ecofriendly thereby toxic to environment due to the presence of mercury contained in fragile glass [20]. UV-LED can draw its attention and take over low-pressure mercury lamp (LP-ML) technology if the projection could meet the required dosage. On the other hand, the conventional lamps that operates at approximately 130ºC for monochromatic and minimum temperature of 300ºC for polychromatic. For the germicidal UV lifecycle, Low Pressure (LP) have a short lifespan of 8000 – 10000 h whereas for Medium Pressure (MP) the lifespan restricts till 8000 h maximum before they need replacement [21]. The other conventional lamps utilize Xenon which is another source of UV-C. The main drawbacks of xenon lamps lie in term of its operating specification where the functioning requires high power to operate and produce enormous temperature approximately 500ºC which makes excessive maintenance. The lamp requires protocols such as warming up the room prior treatment. Also, the output light stability which is not very efficient with the lifespan which is short requiring frequent replacement of lamp that simultaneously add huge cost to the users [22].

Since the literatures do not show the disinfection system based of UVC-surface mounted device (UVC-SMD) for treating healthcare associated surface bacteria, the goal of this study was to evaluate the effectiveness of UVC-SMD. The investigation would help to develop low-cost UVC-SMD based disinfection system which would substitute the use of conventional disinfection robots in the healthcare facilities. The development of UVC-SMD based disinfection system would help to minimize the use of hazardous and high-power operating disinfection system such as mercury-based UV lamps and other room disinfection robots that are commercially available and will promisingly encourage better feasibility and environment of healthcare sector.

2. Methodology

The system was designed for the exposure of 275 nm Everlight's UVC-SMD where UV-C irradiation was directly exposed over *S. aureus* (ATCC 15442) spread on agar plates. The exposure duration was set for 10, 30 and 60 s at a distance of 5 cm illustrated in Figure 1. The exposure duration were chosen based on the disinfection effectiveness in our previous study. Since the maximum distance chosen to treat bacteria was 2 cm by utilizing Cree's UV-C LED in the recent investigation by Sheikh *et al.* [23], this study focused on the distance of 5 cm to investigate the efficiency of disinfection treated by 275 nm Everlight UVC-SMD. The duration of exposure was set for the lowest of 10 s and maximum of 60 s to examine the minimum and maximum doses, having applied on the sample with the minimal utilization irradiation.

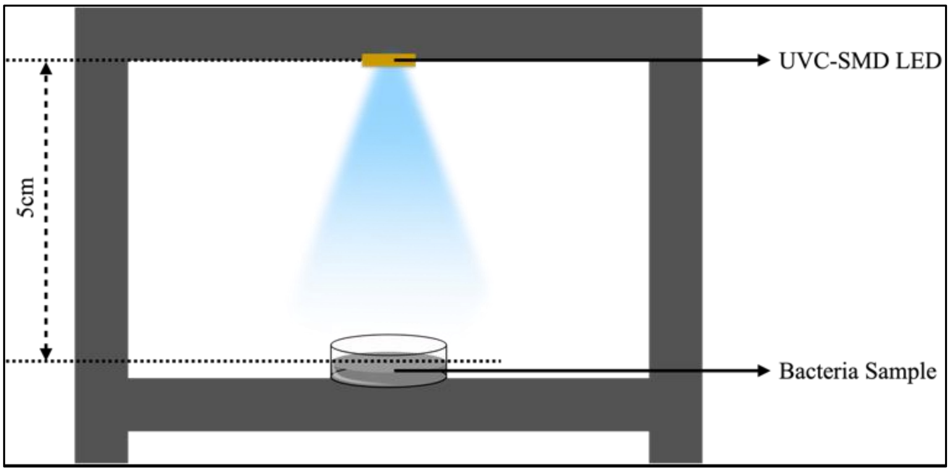

Figure 1. UVC SMD exposure over bacteria sample and analyzation of irradiance at 5 cm distance

All apparatus and equipments associated with the *in vitro* bacterial disinfection test were disinfected with an autoclave (HVE-50, Hirayama, Japan) at 120°C for 30 min. A circular wired loop attached to metal strip was utilized to plunge bacteria from bacterial stocks tenderly. The bacteria were streaked on Luria-Bertani (LB) agar plates by utilizing a back-forward technique. The agar plates were incubated in a lab incubator hatchery (SI-50D, Tech-Lab Protech, Malaysia) at 37°C for 48 h to develop the isolated bacterial colonies. According the recent studies by Sheikh *et al.* [23], five isolated colonies of confined *S. aureus* were extracted from the agar plates and suspended in 0.5 mL of saline solution. The turbidity of the bacterial suspensions was contrasted with 0.5 McFarland to get an assessment of 1×10^8 cells/mL. The bacterial suspensions were then spread on another LB agar plates by utilizing cotton buds. The bacterial suspensions were spread various times to affirm that no region on the agars was left empty.

The agar plates were then exposed directly under the UV-C source at a distance of 5 cm with various exposure times of 10, 30 and 60 s. One out of four bacteria spread agar plate was left untreated as the Control sample. The plates were then permitted to dry and again incubated at 37°C for 24 h. The post-test following the inhibition test was conducted using ImageJ™ software. The irradiance was calculated using UVC digital irradiance Meter (Graiger™) and the doses were calculated.

3. Results & Discussion

UV-C radiation is considered best for germicidal activity and is used to treat bacterial contamination [24]. In the previous study, the effectiveness of UV-C irradiation was demonstrated over *S. aureus* and *P. aeruginosa* when the light source was kept at a maximum distance of 2 cm, away facing directly over the samples at the center. The results showed the significant amount of bacterial inactivation when the samples were treated for 30 and 60 s [18]. Another study demonstrated the effectiveness of pulse UV-C irradiation cycle for 5 mins over different types of bacteria such as MRSA, VRE, *K. pneumoniae* and *E. coli* exposed at 1 m distance caused significant reduction of $5\log_{10}$ CFU/cm^2 [25]. Several studies [26 - 30] also showed the characteristics of commercially available UV-C disinfection systems in which the LEDs, Xenon and Mercury lamps sourced with UV-C were explored in terms of their characteristics such as lifecycle, heat generation, required warm-up time and environmental aspects. The studies put notes on the the lifecycle of all three sources and confirmed UVC-LED for having the longest lifecycle which was more than 20000 h unlike Xenon and LP Mercury lamps. The heat generations in LP Mercury Lamps (LPML) and Pulse Xenon lamps (PX) were high enough which required frequent maintenance of the tube and overall whereas for UV-C LEDs, there was no heat generation and the system did not necessitate any kind of maintenance. Also, the study mentioned on the warm-up time which is required by LPML and PX lamps prior treatments whereas for UV-C LEDs, no warmup time is needed. The mercury and xenon-based disinfection systems are also considered fragile due to the glass tubes which can break easily whereas for UV-C LED, the SMDs are light weight and can barely break. Also, the PX and LPML consume excessive power to operate compared to SMD LEDs.

In this study, the investigation was done on *S. aureus* being the most frequent occurring surface bacteria [31] and the irradiation was applied at the highest distance of 5 cm for 10, 30 and 60 s to evaluate the efficiency of the Everlight's 6565 UVC-SMD LED to prove the germicidal with respect to exposure time. Since in the recent study conducted by Sheikh *et al.* [18], it was proven that with the increase in distance and time duration, the inhibition region was increased simultaneously, and the highest record of 5.40 ± 0.10 cm was achieved. Subsequently for this investigation, the distance of 5 cm was chosen to see the difference in inactivation when the source with same wavelength was taken 3 cm further away from the samples and the samples were exposed at a maximum distance of 5 cm. The UV source was kept 5 cm away from the sample pointing the center of the sample in downward direction since the intensity remained maximum at the epicenter [32].

In this study, Figure 2 shows the region of bacterial inhibition post UVC-SMD exposure on *S. aureus*. It was noticed that despite of any increment in the distance between the source and the samples, the area of the zones kept increasing with the duration of exposure, hence proving the importance of time over distance for optimal inactivation. The disinfection of *S. aureus* at 10 s exposure, the mean inhibition zone of 2.56 ± 0.03 cm was observed when the distances were measured in horizontal, vertical and diagonal directions as illustrated in Figure 2. Followed by the continuous exposures for 30 s and 60 s, the inhibition zones of 3.93 ± 0.08 cm and 4.53 ± 0.03 cm were noticed respectively.

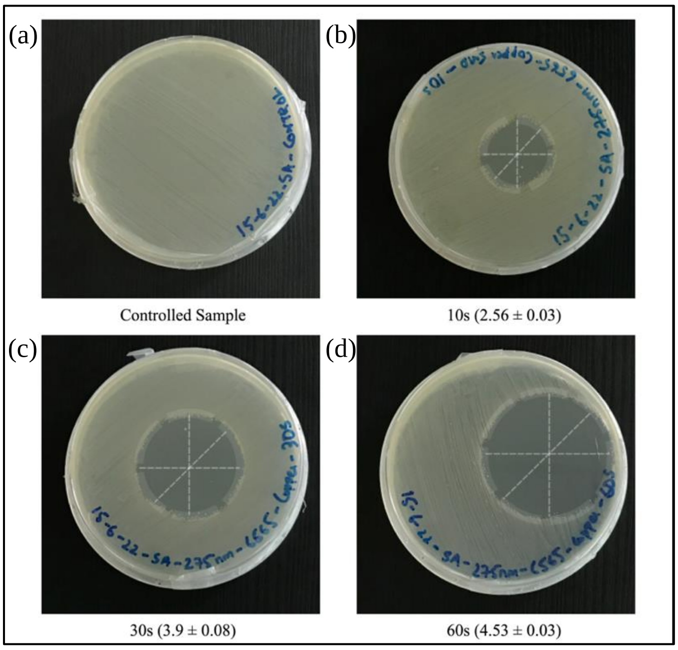

Figure 2. Inhibition zone measurements of *S. aureus* post UVC-SMD LED exposure: (a) Control, (b) exposure at 10 s, (c) exposure at 30 s and (d) exposure at 60 s

Table 1. Inhibition zone measurements of *S. aureus* post UVC-SMD exposure

Dosage and Inhibition Zone Analysis			
UV-C SMD (4 W, 275 nm, 300 mA, 15V)			
	10 s	**30 s**	**60 s**
Measurement Direction	*Distance (cm)*		
X-Axis	2.6	3.9	4.6
Y-Axis	2.5	4	4.5
Diagonal-Axis	2.6	3.8	4.5
Mean ± SD	2.56±0.03	3.93±0.08	4.53±0.03

The smallest region of inhibition of 2.56 cm ± 0.03 was attained when the minimum dose amount of 17 mJ/cm^2 was applied to the samples. At 30 s of UV-C exposure duration, the medium region of inhibition was achieved having mean restraint zone of 3.93 ± 0.08 cm when 51 mJ/cm^2 dose was applied. The maximum area of inhibition was seen when 102 mJ/cm^2 of dose was applied to the sample. Thereby, a direct relation was found between the amount of dose applied and the diameter of inhibition zones.

The inhibition zones shown in Figure 2 addressed the estimation of the treated areas determined with "horizontal", "Vertical and "Diagonal" distances after the bacteria samples were directly irradiated with the UVC-SMD LED at 15 V DC and 300 mA continuous exposure. Furthermore, for the 30 and 60 s, the higher records were attained as shown in Table 1 when contrasted with the 10 s which showed the immediate relation between the duration of exposure and diameter of inhibition zones. However, the distance between the source and the sample was kept constant for all experiments. The experiments were performed in triplets to ensure data validity. Therefore, the utilization of UV-C exposure for 60 s at 5 cm has shown to be optimal in disinfecting considerable amount of bacterial accumulation with a dosage of 102 mJ/cm^2. Also, the study proved that with no change in distance, the area of inhibition could increase with considerable extent.

4. Conclusion

The investigations demonstrate and conclude the germicidal activity of 275 nm Everlight's 6565 SMD to achieve bacterial disinfection at 5 cm when the samples were irradiated for 10, 30 and 60 s. The study also proved that at 102 mJ/cm^2 of dosage, considerable amount of surface inactivation could be attained. Consequently, the Everlight UVC-SMD with 275nm of wavelength is capable SMD to furnish considerable measure of bacterial disinfection with a single SMD when exposed for the shortest distance of 5 cm. The usage of multiple arrays of UVC-SMD in future investigation may possibly enhance the intensity and supplant the utilization of commercial disinfection robots used for the purpose room disinfection where it could help limiting the use of UV-C sources such as mercury or xenon-based lamps.

Acknowledgment

The authors are grateful to the funder by the Ministry of Higher Education under FRGS, Registration Proposal No: FRGS/1/2020/TK0/UTM/02/105 (5F282) and Universiti Teknologi Malaysia.

References

[1] Y.-S. Huang, Y.-C. Chen, M.-L. Chen ML, A. Cheng, I.-C Hung, J.-T. Wang, W.-H. Sheng and S.-C. Chang, Comparing visual inspection, aerobic colony counts, and adenosine triphosphate bioluminescence assay for evaluating surface cleanliness at a medical center, American Journal of Infection Control, 2015, 43(8): 882–886. https://doi.org/10.1016/j.ajic.2015.03.027

[2] S.G. Gibbs, H. Sayles, O. Chaika, A. Hewlett, E.M. Colbert and P.W. Smith, Evaluation of the relationship between ATP bioluminescence assay and the presence of organisms associated with healthcare-associated infections. Healthcare Infection, 2014, 19(3): 101–107. https://doi.org/10.1071/HI14010

[3] A.M. Ferreira, D. de Andrade, M.A. Rigotti, M.T.G. de Almeida, O.G. Guerra and A.G. dos Santos Junior, Assessment of disinfection of hospital surfaces using different monitoring methods, Revista Latino-Americana de Enfermagem, 2015, 23(3): 466–474. http://doi.org/10.1590/0104-1169.0094.2577

[4] K. Vickery, A. Deva, A. Jacombs, J. Allan, P. Valente and I.B. Gosbell, Presence of biofilm containing viable multiresistant organisms despite terminal cleaning on clinical surfaces in an intensive care unit, Journal of Hospital Infection, 2012, 80(1): 52–55. http://doi.org/10.1016/j.jhin.2011.07.007

[5] D.J. Weber, D. Anderson and W.A. Rutala, The role of the surface environment in healthcare-associated infections, Current Opinion in Infectious Diseases, 2013, 26(4): 338–344. https://doi.org/10.1097/qco.0b013e3283630f04

[6] P.G. Bowler and B.J. Davies, The microbiology of infected and noninfected leg ulcers. International Journal of Dermatology, 1999, 38(8): 573–578. https://doi.org/10.1046/j.1365-4362.1999.00738.x

[7] D.J. Weber, H. Kanamori and W.A. Rutala, 'No touch' technologies for environmental decontamination: Focus on ultraviolet devices and hydrogen peroxide systems. Current Opinion in Infectious Diseases, 2016, 29(4):424–431. https://doi.org/10.1097/qco.0000000000000284

[8] Y. Sakr, C.L. Moreira, A. Rhodes, N.D. Ferguson, R. Kleinpell, P. Pickkers, M.A. Kuiper, J. Lipman and J.L. Vincent, The impact of hospital and ICU organizational factors on outcome in critically ill patients: Results from the extended prevalence of infection in intensive care study. Critical Care Medicine, 2015, 43(3): 519–526. https://doi.org/10.1097/ccm.0000000000000754

[9] V.D. Rosenthal, D.G. Maki, A. Mehta, C. Alvarez-Moreno, H. Leblebicioglu, F. Higuera, L.E. Cuellar, N. Madani, Z. Mitrev, L. Dueñas, J.A. Navoa-Ng, H.G. Garcell, L. Raka, R.F. Hidalgo, E.A. Medeiros, S.S. Kanj, S. Abubakar, P. Nercelles and R.D. Pratesi, Nosocomial infection control consortium report, data summary for 2002-2007, American Journal of Infection Control, 2008, 36(9):627–637. https://doi.org/10.1016/j.ajic.2008.03.003

[10] V.D. Rosenthal, C. Álvarez-Moreno, W. Villamil-Gómez, S. Singh, B. Ramachandran, J.A. Navoa-Ng, L. Dueñas, A.N. Yalcin, G. Ersoz, A. Menco, P. Arrieta, A.C. Bran-de Casares, L. de Jesus Machuca, K. Radhakrishnan, V.D. Villanueva, M.C. Tolentino, O. Turhan, S. Keskin, E. Gumus, O. Dursun, A. Kaya and N. Kuyucu, Effectiveness of a multidimensional approach to reduce ventilator-associated pneumonia in pediatric intensive care units of 5 developing countries: International Nosocomial Infection Control Consortium findings, American Journal of Infection Control, 2012, 40(6):497–501. https://doi.org/10.1016/j.ajic.2011.08.005

[11] V.D. Rosenthal, S.K. Todi, C. Álvarez-Moreno, M. Pawar, A. Karlekar, A.A. Zeggwagh, Z. Mitrev, F.E. Udwadia, J.A. Navoa-Ng, M. Chakravarthy, R. Salomao, S. Sahu, A. Dilek, S.S. Kanj, H. Guanche-Garcell, L.E. Cuéllar, G. Ersoz, A. Nevzat-Yalcin, N. Jaggi, E.A. Medeiros, G. Ye, Ö.A. Akan, T. Mapp, A. Castañeda-Sabogal, L. Matta-Cortés, F. Sirmatel, N. Olarte, H. Torres-Hernández, N. Barahona-Guzmán, R. Fernández-Hidalgo, W. Villamil-Gómez, D. Sztokhamer, S. Forciniti, R. Berba, H. Turgut, C. Bin, Y. Yang, I. Pérez-Serrato, C.E. Lastra, S. Singh, D. Ozdemir and S. Ulusoy, Impact of a multidimensional infection control strategy on catheter-associated urinary tract infection rates in the adult intensive care units of 15 developing countries: Findings of the International Nosocomial Infection Control Consortium (INICC), Journal of Infectious Diseases, 2012, 41(10):885–891. https://doi.org/10.1007/s15010-012-0278-x

[12] S. Bagheri Nejad, B. Allegranzi, S.B. Syed, B. Ellis and D. Pittet, Health-care-associated infection in Africa: A systematic review, Bulletin of the World Health Organization, 2011, 89(10):757–765. https://doi.org/10.2471%2FBLT.11.088179

[13] E. Goodman, R. Piatt, R. Bass, A. Onderdonk, D. Yokoe and S. Huang, Impact of an environmental cleaning intervention on the presence of methicillin-resistant Staphylococcus aureus and vancomycin-resistant Enterococci on surfaces in intensive care unit rooms. Infection Control & Hospital Epidemiology, 2008, 29(7):593–599. http://doi.org/10.1086/588566

[14] C.J. Donskey. Does improving surface cleaning and disinfection reduce health care-associated infections? American Journal of Infection Control, 2013, 41(5):12–19. http://doi.org/10.1016/j.ajic.2012.12.010

[15] D. Fertelli, J.L. Cadnum, M.M. Nerandzic, B. Sitzlar, S. Kundrapu and C.J. Donskey. Effectiveness of an electrochemically activated saline solution for disinfection of hospital equipment. Infection Control & Hospital Epidemiology, 2013, 34(5):543-4. http://doi.org/10.1086/670226

[16] W.A. Rutala and D.J. Weber. Are room decontamination units needed to prevent transmission of environmental pathogens?, Infection Control & Hospital Epidemiology, 2011, 32:743–747. https://doi.org/10.1086/670226

[17] M.A. Khan, M. Shatalov, H.P. Maruska, H.M. Wang and E. Kuokstis, III–nitride UV devices. Japanese Journal of Applied Physics, 2005, 44(10), 7191–7206. https://doi.org/10.1143/JJAP.44.7191

[18] M.H. Crawford, M.A. Banas, M.P. Ross, D.S. Ruby, J.S. Nelson, R. Boucher and A.A. Allerman, Final LDRD report: Ultraviolet water purification systems for rural environments and mobile applications, Sandia Report, 2005, 1–37. https://doi.org/10.2172/876370

[19] C. Bowker, A. Sain, M. Shatalov and J. Ducoste, Microbial UV fluence-response assessment using a novel UV-LED collimated beam system. Water Research, 2011, 45(5):2011–2019. http://doi.org/10.1016/j.watres.2010.12.005

[20] FDA, Mercury vapor lamps (Mercury Vapor Light Bulbs), 2021. from https://www.fda.gov/radiation-emitting-products/home-business-and-entertainment-products/mercury-vapor-lamps-mercury-vapor-light bulb (accessed Dec. 31. 2021)

[21] U.S E.P.A, Ultraviolet disinfection guidance manual, DIANE Publishing: Washington, 2003. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=901T0000.TXT (accessed Nov. 4. 2022)

[22] S.H. Jang and M.W. Shin, Fabrication and thermal optimization of LED solar cell simulator, Current Applied Physics, 2010, 10(3):537–539. https://doi.org/10.1016/j.cap.2010.02.035

[23] J. Sheikh, T.T. Swee, S. Saidin, A. Yahya, S. Ahmed Malik, J.S.S. Yin and M.T.F. Thye, Bacterial disinfection and cell assessment post ultraviolet-C LED exposure for wound treatment, Medical and Biological Engineering and Computing, 2021, 59(1):1055–1063. https://doi.org/10.1007/s11517-021-02360-8

[24] M. Bentancor and S. Vidal, Programmable and low-cost ultraviolet room disinfection device, HardwareX, 2018, 4:e00046. https://doi. org/10.1016/j.ohx.2018.e00046

[25] H. Kitagawa, K. Tadera, T. Hara, S. Kashiyama, M. Mori and H. Ohge, Efficacy of pulsed xenon ultraviolet disinfection of multidrug-resistant bacteria and Clostridioides difficile spores. Infection, Disease & Health, 2020, 25(3):181–185. http://doi.org/10.1016/j.idh.2020.03.001

[26] M.M. Nerandzic, P. Thota, C.T. Sankar, A. Jencson, J.L. Cadnum, A.J. Ray, R.A. Salata, R.R Watkins and C.J. Donskey, Evaluation of a pulsed xenon ultraviolet disinfection system for reduction of healthcare-associated pathogens in hospital rooms, Infection Control & Hospital Epidemiology, 2015, 36(2):192–197. https://doi.org/10.1017/ice.2014.36

[27] M.I. Lomaev, V.S. Skakun, V.F. Tarasenko and D.V. Shitts, A high-power Xenon dimer Excilamp. Technical Physics Letters, 2006, 32(1):495–497. http://doi.org/10.1134/S1063785006060137.

[28] S.H. Jang and M.W. Shin, Fabrication and thermal optimization of LED solar cell simulator, Current Applied Physics, 2010, 10(3):537–539. https://doi.org/10.1016/j.cap.2010.02.035

[29] S. Rajkhowa, Heat, solar pasteurization, and ultraviolet radiation treatment for removal of waterborne pathogens, in: M.N.V. Prasad and A. Grobelak, Waterborne Pathogens, Butterworth-Heinemann: United Kingdom, 2020, 169–187. https://doi.org/10.1016/B978-0-12-818783-8.00009-8

[30] M. Allers, T. Reinecke and S. Zimmermann, Detection of mercury vapor in air by differential heat dissipation measurements. Proceedings, 2017, 1(4):440. https://doi.org/10.3390/proceedings1040440

[31] L.E. Lindley, O. Stojadinovic, I. Pastar and M. Tomic-Canic, Biology and biomarkers for wound healing, Plastic and Reconstructive Surgery, 2016, 138(3):18–28. https://doi.org/10.1097%2FPRS.0000000000002682

[32] S.A. Malik, T.T. Swee, N.A.N. Nik Malek, M.R. Abdul Kadir, T. Emoto, M. Akutagawa, L.K. Meng, T.J. Hou and T.A.I. Tengku Alang, Comparison of standard light-emitting diode (LED) and 385 nm ultraviolet A LED (UVA-LED) for disinfection of Escherichia coli. Malaysian Journal of Fundamentals and Applied Sciences, 2017, 13(42):430–437. https://doi.org/10.11113/mjfas.v13n4-2.758