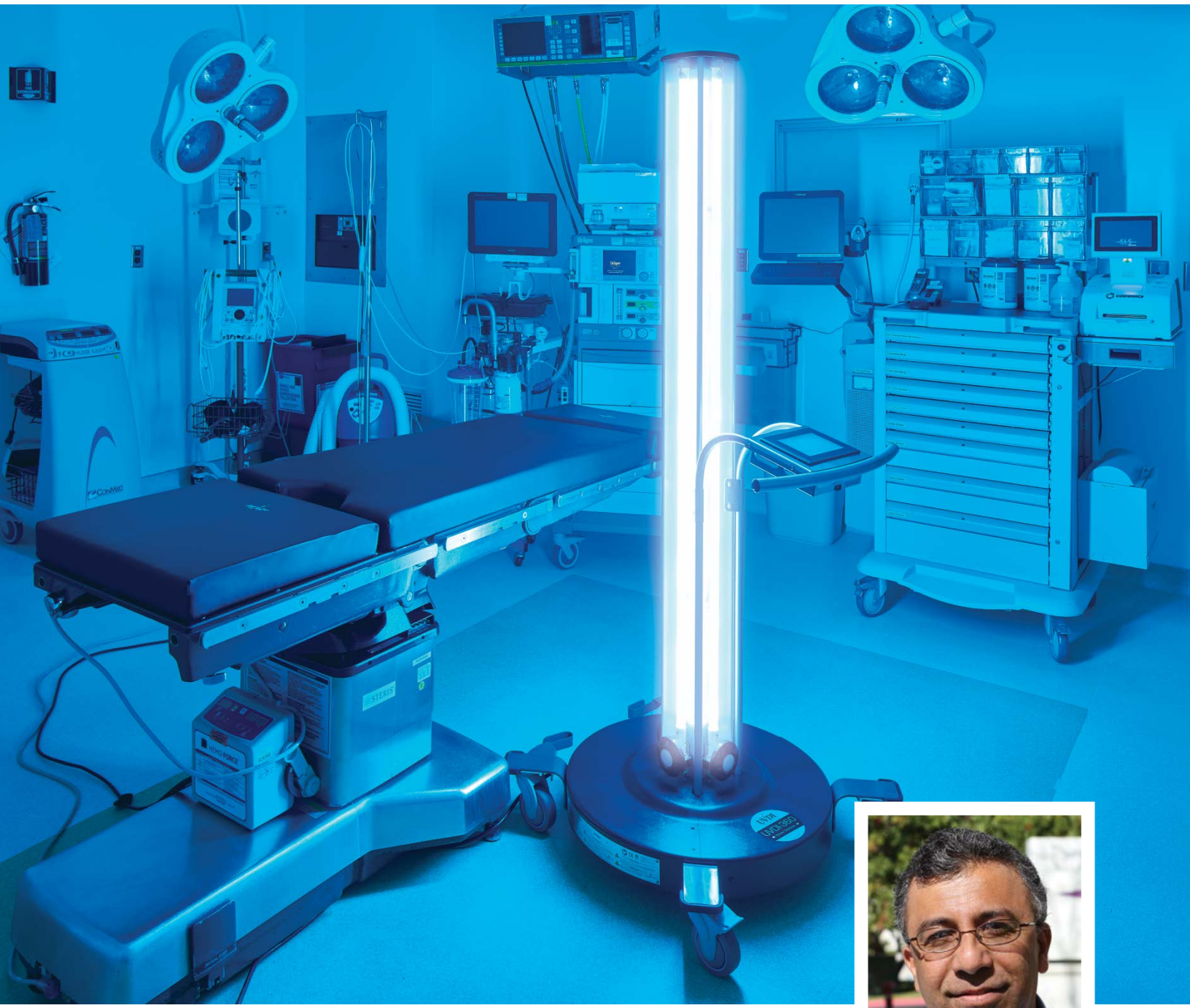
UV Disinfection in the Healthcare Environment:

Back to Basics



Ashish Mathur, Ph.D.

UV Disinfection in the Healthcare Environment: Back to Basics

Ashish Mathur, Ph.D.

Ultraviolet Devices Inc., Valencia, CA 91355, Email: ashish.mathur@uvdi.com

Introduction

The current outbreak of Coronavirus Disease 2019 (COVID-19) disease caused by the novel coronavirus SARS-CoV-2 has generated considerable global interest and adoption of UV technology. UV-based products are now offered in all shapes and sizes with sweeping claims of disinfecting surfaces and air in your home, business or healthcare facility.

The emphasis on environmental disinfection has never been greater, especially for healthcare facilities, who already face an ongoing battle to reduce the risk of health care–associated infections (HAIs). However, the marketing of a variety of UV devices with different designs, capabilities, and costs has made it challenging for healthcare institutions to select an effective device.

Adding to the confusion is the fact that there are currently no established industry standards for characterizing or certifying UV devices, which has resulted in false or misleading claims about the effectiveness and safety of UV devices offered in the market today.

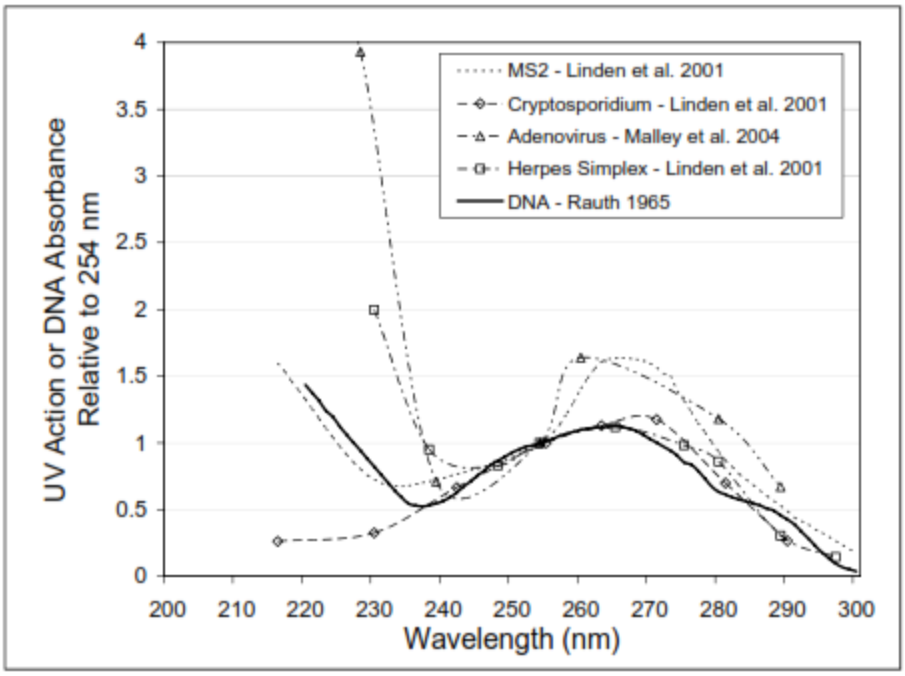
This article aims to provide (1) a basic understanding of the characteristics of UV technology (2) key criteria to evaluate device efficacy and (3) core factors to consider for safe implementation --- all towards assisting healthcare personnel when evaluating and purchasing UV disinfection devices for whole room surface disinfection.

1. Basics of UVC Disinfection

Mechanism of UV-C Inactivation

The ultraviolet spectrum is a band of electromagnetic radiation at higher energies than visible light, split into four major categories: UV-A (400 – 315 nm), UV-B (315 – 280 nm), UV-C (280 – 200 nm), and vacuum UV (VUV, 100 – 200 nm). UV-C light in the 240 – 280 nm range has been proven to be germicidal in nature and has been used for pathogen disinfection for over a century, with applications in water treatment, in air systems, and on surfaces.

Germicidal efficacy varies with UV-C wavelength and is unique to the pathogen being targeted (Beck 2015)—the germicidal action spectrum describes this response (Fig 1).



Source: Adapted from Rauth (1965), Linden et al. (2001), and Malley et al. (2004)

Figure 1. DNA Susceptibility as a function of Wavelength (EPA, 2016)

Microorganisms are particularly vulnerable to UV light at wavelengths close to 254 nm wavelength (produced by low pressure mercury lamps), since this represents the maximum absorption wavelength of their DNA or RNA molecules. At this wavelength, pyrimidine dimerization, the primary mechanism for microorganism inactivation by UV-C light, occurs. The formation of pyrimidine dimers leads to changes to the double helix structure, cell mutation and ultimately to the death of the cell.

UV Susceptibility of Microorganisms

Ultraviolet germicidal irradiation for surface disinfection has been demonstrated to be highly effective at eliminating both vegetative pathogens, including MRSA, VRE, carbapenem-resistant *Enterobacteriaceae*, *Acinetobacter baumannii*, spores, such as *C difficile* and *fungi* such as *Candida auris (Rutala, 2013, Rutala 2018, Maragakis, 2016, Donskey 2018)*. It is well known that different pathogens exhibit varying susceptibility to UV-C light, with vegetative bacteria and viruses typically easier to inactivate than spores or fungi (Kowalski, 2009). Therefore, coronaviruses are more readily killed by disinfectants than pathogens like MRSA which is harder to kill than *C. difficile* or Candida species, which is in the hardest group to kill and requires a much higher UV-C dose.

One of common misapplications of UV devices is the estimation of UV dose required to achieve a certain log reduction for a target pathogen. Due to limited data on the UV dose requirements for different microorganisms and lack of industry standards, any performance claims of the efficacy of UV systems based on dosage from manufacturers should be scrutinized carefully. Actual validation of efficacy (log reduction) against the target microorganism(s) in third party laboratory and clinical settings should be requested.

Factors Affecting UV Dose

The required UV dose to inactivate a pathogen forms the basis of design and application for all UV systems. It is the required dose which dictates the collective intensity output and configuration of the UV lamps for any UV device. The UV dose delivered at a target surface or object is the product of UV irradiance at that target and exposure time, meaning that a higher UV dose could be delivered by increasing the intensity of UV light and the exposure time. The intensity of UV irradiance is inversely proportional to the square of the distance between the lamp and the exposed surface, based on the "inverse square law". Therefore, the UV intensity received by a surface decreases exponentially the further the surface is from the lamp. As the distance between the lamp and the exposed surface increases, the log reduction of pathogens achieved decreases significantly. One practical implication of the marked effect of distance on UV irradiance is that short cycles of only a few minutes may be sufficient for devices that place bulbs in close proximity to the surface to be decontaminated, whereas longer cycles are required for surfaces further away from the UV device or for the whole room.

Important variables that affect the dose delivered to surfaces and the resulting log reductions of pathogens achieved include the amount of irradiance generated by the UV lamp(s), exposure (cycle) time, distance from the lamp to the exposed surface, the angle at which the UV strikes the surface, whether the surface is in direct line sight of the lamp or receives light that has been reflected off other objects (surfaces in shadowed areas).

2. Key Criteria in Evaluating UV Device Efficacy

As UV devices have proliferated in market, various factors – wide ranging UV device configurations and features such as user interface, safety, software, UV wavelengths employed and the lack of uniform efficacy standards - make it challenging for healthcare facilities to evaluate and select the appropriate device. Effectiveness is driven by the dose delivered by the device to a target surface; this is greatly affected by the total lamp power and configuration of lamps on the device. Whole room disinfection is achieved by single or multiple placements of the UV device to ensure a uniform germicidal dose is delivered to targeted surfaces throughout a room. Fully automated UV robots have also been introduced recently which treat the room utilizing a mapping and navigating software.

UV fixtures are also available which can be permanently mounted in the ceiling or on the side walls of the hospital room. However, these systems are challenged with increasing distance between the fixture and targeted areas, particularly for shadowed areas or areas not in the direct line of light.

Compounding the issue is the large discrepancy in the treatment times recommended by manufacturers to disinfect a typical patient room for terminal cleaning with times ranging from five minutes to almost an hour. Some devices calculate the disinfection cycle time based on room reading software, while others recommend disinfection cycle times based on actual dose validation on targeted surfaces in the room.

The following criteria is proposed for the evaluation and selection of a suitable UV device for a healthcare facility:

Light Source and Wavelength

The majority of the UV devices currently used in the industry employ low pressure mercury lamps that continuously emit UV-C primarily at 253.7 nm wavelength, which coincides with the maximum UV absorption wavelength of microorganisms as described in previous section. Some devices utilize pulsed

xenon lamps, which emit a broad spectrum light in the 200-315 nm or higher wavelength. Recently, other light sources such as UV-C LED with specific spectral output at 265-275 nm as well as krypton chloride (KrCl*) excimer lamps that emit specific wavelengths in the Far UV (207-222 nm) spectrum have been introduced. UV-A light and violet-blue light at 405 nm have also been introduced in ceiling fixtures and found to be effective, albeit at a slower pace, for bacterial pathogen reduction over prolonged exposure times.

It should be noted that germicidal low pressure mercury UV-C lamps emit greater than 90% of their spectral output at 253.7 nm. They are also the most efficient UV lamps available in the market today, with a wall plug efficiency around 33 % (e.g. a 100 Watt lamp will produce 33 Watts of UV-C power at 253.7 nm wavelength). In contrast, wall plug efficiencies of pulsed xenon lamps, UV-C LED sources as well as excimer sources are typically less than 10% of their potential germicidal effectiveness, resulting in wasted power compared to low pressure mercury lamps.

Time and Distance of Pathogen Inactivation Claims

In assessing pathogen inactivation claims made by UV devices, it is key to review the time and distance associated with said results. Faster inactivation times can aid integration with and efficiency of operational workflow and - correlated with the distance – support overall device effectiveness. Reporting the distance associated with such claims supports effectiveness in real-world settings. Healthcare professionals should be wary of fast room disinfection cycle times for an entire room supported by performance data showing device efficacy at short distances of only three feet or one meter. This is because, for a typical patient room size of 120-140 square feet, most of the target surfaces are expected to be greater than a 3 feet distance from the UV device.

Independent, Third Party Efficacy Validation

UV-C efficacy is dependent on a number of variables, such as lamp intensity (output), number of lamps, height of lamp, lamp configuration on device, device attributes (reflective features etc.), exposure time, distance and placement of lamps, reflectivity of surfaces in the room and the type of microorganisms present.

Due to the variabilities in devices and target dose values used by different manufacturers, it is extremely important to seek and review actual efficacy log reduction data, generated by independent third party laboratories of any UV device against prominent high-risk pathogens including MRSA, VRE , C.*difficile*, coronavirus and *Candida auris*. Given the relationship between distance from device and effective inactivation, the efficacy data should include the distance of the tested pathogen from the device and the exposure time.

Peer Reviewed Clinical and HAI studies

While it is well understood that UV-C is effective against microorganisms, it needs to be correctly applied to achieve the desired log reduction. Some device manufacturers utilize publicly available literature on UV-C efficacy as indirect proof of the effectiveness of their systems, which can be misleading about the actual effectiveness of their specific device. It is therefore extremely important for hospital decision-makers to check for and review the relevant peer reviewed clinical studies that prove the efficacy of the device they are evaluating. Further, the efficacy data should also have been validated in a clinical setting representing the actual device settings, configurations and placement protocols recommended by the manufacturer of the device. Such data would be useful in understanding the capability of the device for whole room disinfection that includes surfaces which are in both direct as well as indirect (shadowed) line of sight of the device.

While UV devices are being used in hospitals to improve the level of environmental disinfection beyond levels achieved from manual cleaning, the real value to the hospitals is a demonstrated reduction of the hospital acquired infections (HAI) rates. Most of the published studies have been before-after studies (Pegues 2016, Marra 2017) in which HAI rates after implementation of UV-C were compared with those prior to UV-C use, with one randomized, controlled study conducted (Anderson 2017). It is incumbent on the infection preventionists to perform their due diligence by reviewing the strength of HAI studies conducted for the devices they are evaluating.

Dose Validation on Target Surface

It is important to confirm the dose delivered to targeted surfaces in the hospital rooms and to confirm that devices are operating correctly. UV radiometers calibrated for the appropriate UV wavelengths can be used to measure the dose received at a point in the room. Use of radiometers requires additional training, frequent charging of the radiometer and the need for ongoing calibration to ensure accuracy. The use of inexpensive dose verification cards that utilize photochromic inks which change color have gained widespread adoption in providing good estimates of the UV-C doses delivered to surfaces. Only those cards should be used which have been validated for the accuracy of dose applied from the particular device by independent laboratory and in clinical settings.

3. Key Criteria to Assess Proper Implementation

Operational Effectiveness

After the efficacy of the UV device has been carefully vetted, the selection criteria should focus on the operational and usability differences between the UV devices in their health care setting. EVS personnel are constantly challenged with short room turnaround times, therefore devices which are simple to use and require minimal set-up, and those with the fastest validated disinfection cycle times should be preferred. Other important features include smart data reporting that provides valuable analytical and diagnostic data about device usage.

Safety

All UV-C devices should be certified to meet the appropriate UL and NIOSH electrical and human safety standards. UV-C light can be harmful to human skin and eyes depending on the extent of exposure. UV-C radiation in the wavelength range 200 – 225 nm (i.e., ‘far UV-C radiation’) has also received public attention for claims of disinfection capabilities and safety of human skin and eye exposure (Buananno, 2020). While initial findings are positive, further investigations are required on any secondary impacts of the technology when used in the presence of humans. Therefore, whole room disinfection UV-C devices can only be use when rooms are unoccupied. Devices should have appropriate built-in UV safety sensors for automatic shutoff when it detects human presence. Additional safety features such as remote operation, door warning signs, lamp protective sleeves should also be mandated.

Some devices use lamps (e.g., pulsed xenon and Far-UV), which emit wavelengths in the 200-220 nm range are known to produce ozone. If so, it should be verified that the device is compliant with NIOSH requirements for safe ozone levels and has mitigation measures to keep the ozone levels within safety limits.

Cost

Deployment of whole room UV disinfection devices across the hospital have a direct correlation to reducing infection risk for inpatients, costs for treating HAIs, and patients' length of stay. However, it is recognized that more than one device would be needed to positively impact infection rates across the

entire facility. The number of devices required for a hospital should be determined according to the number of hospital rooms, room turnover needs and the time required to disinfect a room.

Acquisition of a UV-C disinfection system can be a substantial purchase for a health care facility with device costs range from $40,000 to $150,000 and above. Infection preventionists can use the selection criteria laid out in this article to choose the appropriate device which provides the optimum performance, functionality and safety features at an affordable price.

References

Boyce, J M; Farrel, P A; Towle, D; Fekieta, R; Aniskiewicz, M. 2016, Impact of Room Location on UV-C Irradiance and UV-C Dosage and Antimicrobial Effect Delivered by a Mobile UV-C Light Device. Infect. Control Hosp. Epidemiol., 37: 667–672.

EPA. 2016, Ultraviolet Disinfection Guidance Manual For the Long Term 2 Enhanced Surface Water Treatment https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=600006T3.txt.

Kanamori, H; Rutala, W A; Gergen, M F; Weber, D J. 2016, Patient Room Decontamination against Carbapenem Resistant Enterobacteriaceae and Methicillin-Resistant Staphylococcus Aureus Using a Fixed Cycle-Time Ultraviolet-C Device and Two Different Radiation Designs. Infect. Control Hosp. Epidemiol., 37: 994-996.

Kowalski, W. 2009, Ultraviolet Germicidal Irradiation Handbook, Ch. 4: UV Rate Constants.

Linden, K.G; Shin, G.A; Sobsey M.D. 2001, Comparative effectiveness of UV wavelengths for the inactivation of Cryptosporidium parvum oocysts in water. Water Science & Technology, 43: 171–174.

Malley, J.P; N.A. Ballester, N.A; Margolin, A.B; Linden, K.G; Mofidi, A; Bolton, J.R; Crozes, G; Cushing, B; Mackey, E; Laine, J.M; Janex, M.L. 2004, Inactivation of Pathogens with Innovative UV Technologies. American Water Works Association Research Foundation.

Rauth, A.M. 1965. The physical state of viral nucleic acid and the sensitivity of viruses to ultraviolet light. Biophysical Journal, 5: 257–273.

Rutala, W A; Gergen, M F; Tande, B M; Weber, D J. 2016, Room Decontamination Using an Ultraviolet-C Device with Short Ultraviolet Exposure Time. Infect. Control Hosp. Epidemiol. Control Hosp. Epidemiol., 35: 1070-1072.

Kanamori, H.; Rutala, W.A.; Gergen, M.F.; Weber, D.J. Patient Room Decontamination against Carbapenem Resistant Enterobacteriaceae and Methicillin-Resistant Staphylococcus aureus Using a Fixed Cycle-Time Ultraviolet-C Device and Two Different Radiation Designs. Infect. Control Hosp. Epidemiol. 2016, 1–3.

Rock, C.; Curless, M.S.; Nowakowski, E.; Ross, T.; Carson, K.A.; Trexler, P.; Carroll, K.; Maragakis, L.L. UV-C Light Disinfection of Carbapenem-Resistant Enterobacteriaceae from High-Touch Surfaces in a Patient Room and Bathroom. Infect. Control Hosp. Epidemiol. 2016, 1–2.

Cadnum JL, Shaikh AA, Piedrahita CT, Jencson AL, Larkin EL, Ghannoum MA, Donskey CJ. Relative Resistance of the Emerging Fungal Pathogen Candida auris and Other Candida Species to Killing by Ultraviolet Light. Infect Control Hosp Epidemiol. 2018 Jan;39(1):94-96.

Pegues, D.A.; Han, J.; Gilmar, C.; Mcdonnell, B.; Gaynes, S. Impact of Ultraviolet Germicidal Irradiation for No-Touch Terminal Room Disinfection on Clostridium Difficile Infection Incidence Among Hematology/Oncology Patients. Infect.Control Hosp.Epidemiol.2016.

Marra AR, Schweizer ML, Edmond MB. No-touch disinfection methods to decrease multidrug- resistant organism infections: a systematic review and meta-analysis. Infect Control Hosp Epidemiol 2018;39:20–31.

Buonanno, M., Welch, D., Shuryak, I., Brenner, D.J., (2020) “Far-UVC light (222 nm) efficiently and safely inactivates airborne human coronaviruses.” Sci Rep 10, 10285.

Anderson DJ, Chen LF, Weber DJ, Moehring RW, Lewis SS, Triplett PF, Blocker M, Becherer P, Schwab JC, Knelson LP, Lokhnygina Y, Rutala WA, Kanamori H, Gergen MF, Sexton DJ, CDC Prevention Epicenters Program. Enhanced terminal room disinfection and acquisition and infection caused by multidrug resistant organisms and Clostridium difficile (the Benefits of Enhanced Terminal Room Disinfection study): a cluster-randomised, multicentre, crossover study. Lancet 2017; 389:805–814.