American Journal of Infection Control 45 (2017) 288-92

Contents lists available at ScienceDirect

American Journal of Infection Control

journal homepage: www.ajicjournal.org

Practice Forum

A model for choosing an automated ultraviolet-C disinfection system and building a case for the C-suite: Two case reports

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Key Words:
Infection prevention
Environmental interventions
UV-C technology
Environmental disinfection
Evaluating infection prevention technology
Building a business case for infection prevention

Environmental disinfection has become the new frontier in the ongoing battle to reduce the risk of health care–associated infections. Evidence demonstrating the persistent contamination of environmental surfaces despite traditional cleaning and disinfection methods has led to the widespread acceptance that there is both a need for reassessing traditional cleaning protocols and for using secondary disinfection technologies. Ultraviolet-C (UV-C) disinfection is one type of no-touch technology shown to be a successful adjunct to manual cleaning in reducing environmental bioburden. The dilemma for the infection preventionist, however, is how to choose the system best suited for their facility among the many UV-C surface disinfection delivery systems available and how to build a case for acquisition to present to the hospital administration/C-suite. This article proposes an approach to these dilemmas based in part on the experience of 2 health care networks.

Environmental disinfection has become the new frontier in the ongoing battle to reduce the risk of health care–associated infections (HAIs). Evidence demonstrating the persistent contamination of environmental surfaces despite traditional cleaning and disinfection methods has led to the widespread acceptance that there is both a need for reassessing traditional cleaning protocols and for using secondary disinfection technologies.[1-10] Research has shown that as many as 50% of surfaces remain contaminated with pathogens, including multidrug-resistant organisms such as methicillin-resistant *Staphylococcus aureus* (MRSA), despite regular manual cleaning efforts.[2] Additionally, it has become clear that there are multiple reservoirs for these pathogens within the health care setting, from portable blood pressure monitors to intravenous stopcocks, that are not adequately disinfected even with enhanced manual cleaning protocols.[3,4,11] Ultraviolet-C (UV-C) disinfection is one type of no-touch technology shown to be a successful adjunct to manual cleaning in reducing environmental bioburden.[12-18] The dilemma for the infection preventionist, however, is how to choose the system best suited for their facility among the many UV-C surface disinfection delivery systems available and how to build a case for acquisition to present to the hospital administration/C-suite.[19,20] This article proposes an approach to these dilemmas based in part on the experience of 2 health care networks.

BACKGROUND

The literature is replete with evidence documenting the persistence of pathogens on environmental surfaces, manual cleaning efforts notwithstanding.[1-10,21-23] The ability of many pathogens to survive for extended periods of time on inanimate surfaces contributes to this problem,[23] but the inadequacy of cleaning protocols and lack of consistency with protocol implementation are clearly important factors.[1,2] The challenge is that the environmental service (EVS) worker must cover all surfaces and allow sufficient contact time of the cleaner or disinfectant per the manufacturer's recommendations. Concerns about poor staff compliance with cleaning protocols and the recognition that pathogens can be spread by means other than direct contact, including through aerial dissemination, have further highlighted the need to supplement manual cleaning

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Conflicts of interest: None to report.

http://dx.doi.org/10.1016/j.ajic.2016.11.016

methods.[1,24-26] In Carling's multisite study, an average rate of just 32% for cleaning thoroughness was reported.[27] One study evaluating a secondary disinfection technology to be used after manual cleaning found that manual cleaning actually introduced MRSA and vancomycin-resistant *Enterococcus* (VRE) onto previously negative surfaces because of contaminated cleaning cloths and cleaning solutions. However, the continuing desire to prevent HAIs, particularly those caused by hard to kill pathogens such as *Clostridium difficile*, has led to a growing demand for adjunctive automated disinfection technologies, including UV-C disinfection.[1,14]

UV-C light's germicidal function is largely a result of the formation of thymine dimers, which inactivate the organism's DNA and RNA.[28] Ultraviolet germicidal irradiation for surface disinfection has been demonstrated to be highly effective at eliminating both vegetative pathogens, including MRSA, VRE, carbapenem-resistant *Enterobacteriaceae*, and multidrug-resistant *Acinetobacter baumannii*, and spores, such as *C difficile*.[1,12-17,29,30] Multiple studies have demonstrated a $>3 \log_{10}$ colony forming units per square centimeter reduction in clinically significant pathogens when UV-C systems were tested in a variety of configurations within a hospital room[14,31,32] and in vitro studies.[12] Napolitano et al actually demonstrated a 34% reduction in HAIs in a California hospital when UV-C systems were integrated into their environmental interventions protocol.[33] The Environmental Protection Agency, however, has yet to establish device testing or efficacy standards, which are critically needed to facilitate the interpretation of published UV-C disinfection results.[19,20]

Automated area UV-C–emitting systems: What are the options?

A detailed description of all commercially available UV-C systems is beyond the scope of this article; however, the options are multiple, each with a variety of both nuanced and more distinct differences. One means of categorizing commercially available UV-C–emitting systems is by lamp or bulb class: steady-state low-pressure mercury bulbs that emit light at 254 nm and xenon bulbs that emit a pulsed spectrum of light encompassing the UV (100-280 nm) and visible (380-700 nm) spectra.[15] There is currently only one commercially available xenon bulb system which provides short, high-intensity pulses (2 Hz) of the broad-spectrum light and runs, as suggested by the manufacturer, in two 5- to 7-minute cycles, each in a different location in a room, taking approximately 15-20 minutes for the disinfection process.[15] The low-pressure mercury bulb systems deliver radiation in a continuous stream with one system having 2 settings, vegetative (12,000 uWs/cm^2) and sporicidal (22,000 uWs/cm^2), and one system having a single vegetative or sporicidal setting (46,000 uWs/cm^2).[16] The pulsed xenon system manufacturer suggests using shorter disinfection times than most of the commercially available steady-state mercury systems; however, the one published study comparing the efficacy of the 2 different lamp classes determined that "PX-UV was less effective than continuous UV-C devices [e.g. steady state mercury systems] in reducing pathogen recovery on glass slides with a 10-minute exposure time in similar hospital rooms."[15] The in vitro study concluded that steady-state mercury vapor 254 nm resulted in reductions of *C difficile* and MRSA colony forming units roughly twice that of pulsed xenon and 6 times greater for VRE. All systems can be operated remotely with tablets or personal digital assistants, but they must be manually wheeled into the room for operation. Additionally, almost all the systems have software that allows them to capture utilization data, including treatment time, location usage, and operator statistics. For the system with the remote wireless UV-C measurement sensors, the software also tracks delivered dose and utilization data in real time. How the final dose is determined for each device varies. Some systems calculate the dose to be delivered (dose = UV-C intensity × time of exposure to the UV-C) based on the dimensions of the room and are set on a timed interval, but without active dose measurement. Other systems have sensors on the emitter that measure the light reflected back to the device from surfaces within the room; however, movement of the device interferes with reflective light measurement, and rooms that inhibit the reflection of light require longer treatment times.[14] One system uses remote wireless sensors placed in different targeted areas of the room to measure incident light (both reflective and direct) and therefore actual dose delivered.[16] The estimated treatment time for these systems can range from 5 to ≥50 minutes, and the physical footprint of each can vary significantly.[16]

Despite the lack of UV-C efficacy standards and the difficulties interpreting studies because of methodologic variation and a lack of consensus on acceptable pathogen reductions, there is agreement that protein load and shadowing diminish UV-C effectiveness. Studies have repeatedly demonstrated that the effectiveness of UV-C systems is diminished with increasing concentrations of organic or protein matter (eg, bodily fluids, dirt), thereby underscoring the importance of using UV-C technology as an adjunct to manual cleaning.[14-16,18,29,34] Many of these systems are challenged with increasing distance between the device and targeted areas, particularly for shadowed areas or areas not in the direct line of light.[15-18,29] This is a particular issue for rooms that have irregular shapes or nooks, or have permanent structures or furnishings that create shadows. One system has a patented pause and reposition system that allows for the unit to be repositioned to address the more difficult to reach parts of the room in a time-effective manner.[16] Other systems that cannot be paused until their timed interval is complete or who rely on reflected light for dose calculation must build in additional time in their algorithms to disinfect the challenging areas.[14,15] Given the relationship between distance from device and effective killing, many researchers have advised that high-touch objects be moved closer to the device prior to utilization to optimize exposure.[14,15]

Choosing a UV-C–emitting system for your facility: The Vancouver example

The infection prevention and infectious disease team at Vancouver General Hospital, a 728-bed tertiary care hospital, went through this evaluation and selection process beginning in 2013. Their experience provides a great example for those looking to navigate their way through it. Their process began with a pilot study evaluating the incremental benefit of UV-C decontamination in MRSA, VRE, and *C difficile* isolation rooms using 2 different commercially available automated UV-C systems.[16] They chose 2 systems they thought to be good candidates for their facility, disregarding any preexisting relationships between their external, outsourced EVSs provider and specific UV-C manufacturers. Their study, published in the April 2016 issue of the *American Journal of Infection Control*, produced several key results. Even though housekeeping staff was aware of being audited for the ongoing study, researchers noted no significant changes in pre- and postmanual cleaning cultures for any of the 3 organisms. Although notable, this finding cannot necessarily be extrapolated to other institutions. By contrast, UV-C disinfection reduced the percentage of MRSA from 34.4% to 3.3%, VRE from 29.5% to 4.9%, and *C difficile* from 31.8% to 0%.[16] Pathogen killing was diminished in the presence of a protein load. The investigators concluded that, "both [systems] were equally excellent in enhancing overall patient room cleanliness as an adjunct to manual cleaning in a real-world setting."[16]

Their selection of technology was therefore made based on "operational and usability differences between the machines" in their health care setting. A deciding factor in machine selection was the room turnaround time in their overcapacity hospital, thus, the machine that could be repositioned and had the shortest average use time was therefore chosen.[16]

The determination of how those specific operational and usability differences would impact their facility was decided after a heuristic evaluation that was performed by their on-site human factors engineer who engaged housekeeping staff, infection preventionists, and operations personnel. This comprehensive multifaceted approach helped them determine that the faster emitter better suited their facility's specific needs based on a number of different factors, including the following:

- Their near 100% occupancy rate and need for rapid room turnover (faster use times lead to more rapid room turnover, the opportunity to treat more rooms in a shorter period of time, and therefore, more rapid room turnover and increased patient throughput).
- The history of their peak turnover times (further underscoring the need for rapid room turnover).
- Usability (one setting left less room for user error in cycle selection, and one machine could treat more rooms in a shorter time frame).
- The device's robust software with a metrics-driven tracking system. These software systems generally require that the purchaser input room data either manually or electronically. However, once the room data are entered, key pieces of data could be correlated, such as actual dose delivered to individual rooms, average room treatment times, operator variability regarding room turnaround time, and device utilization over time.
- The pause and reposition capability (which allows the operator to pause the system when the first 2 remote sensors have reached their predetermined dose and reposition the device, unlike other systems that must complete their full cycle before the device can be repositioned, further adding to use time).
- Ergonomic issues (related to the device's ability to be moved through small entrances and to be maneuvered by personnel).

Having made their decision regarding device selection, the team then proceeded to build their case for the C-suite. The business case included the pilot study data and potential for reducing antibiotic resistance rates and HAIs, human factors engineer's comprehensive evaluation, projected capital costs, projected operating costs (which they determined could be offset by funds saved from the dramatic reduction in enhanced cleaning requests based on results from their pilot study), and implementation plan.

The implementation plan was a critical part of the business case because they knew they needed to demonstrate optimal utilization. There were a number of key components of their plan which were done in collaboration with their EVS team to ensure that their needs were considered. For example, it was decided that not all EVS workers would operate the systems but rather EVS would manually clean a room and enter the completed job into a computer, which would then generate a computer call out to the dedicated EVS UV-C device user or operator. This allowed the EVS to proceed with the next job. In addition, it would facilitate the prioritization of UV-C jobs by the operator who understood which areas and rooms were to be targeted based on regular analysis that identified the units with the most opportunity to improve their MRSA and *C difficile* rates. These clear guidelines on room prioritization minimized operator variation in room selection if multiple call outs were received in a short period of time. They further optimized utilization by using the systems to provide nighttime disinfection for operating rooms, endoscopy suites, equipment supply rooms, and other high-use rooms that were typically vacant during the night shift. They determined docking locations for the devices that would allow for the quickest access for high utilization areas, emphasizing the need for proper device staging when considering labor and other operational costs. Because of the unique data capturing and tracking capability of the system, they developed a schedule for regular software report reviews so that they could monitor for quality control and compliance issues and regularly reassess their utilization patterns, particularly as they related to infection clusters or outbreaks, and the need for operator retraining. For example, after the device was implemented, they noted an operator trend of significantly shorter UV-C cycles compared with the average. Subsequently, they were able to work with the operator and determine that the remote sensors were being positioned closer to the device than recommended by the manufacturer. Additionally, random audits using adenosine triphosphate monitoring were initiated to ensure that use of the technology did not precipitate a regression in compliance with housekeeping manual cleaning. Finally, and perhaps equally as importantly, the infection prevention team and the human factors engineer looked at potential errors that could arise with the use of the system and preemptively proposed solutions for each.

With this approach, the team was able to secure authorization for purchasing the UV-C systems and began successfully implementing the systems in 2014.

Building a case for a UV-C system purchase: The Rochester example

Between 2010 and 2011, Rochester General Hospital (RGH), a 528-bed tertiary care hospital, saw a 23% increase in their crude *C difficile* infection (CDI) rates, prompting their infection prevention team to explore the use of additional environmental disinfection methods, specifically UV-C technology. The team ultimately determined that based on their facility's needs and their infection prevention goals, there were several critical components they were looking for in a UV-C system, the most significant of which was the ability to monitor dose-based performance. Their high occupancy rates and need for rapid turnover additionally demanded a rapid treatment time. Knowing that many of their rooms had shadowed areas and were not standard squares, they wanted to have a system they could pause and reposition to more quickly and efficiently disinfect. Finally, as they were embarking on a robust campaign to combat their rising *C difficile* rates, they wanted a system that allowed for comprehensive data capturing and analysis to help optimize utilization. Having chosen a system that met these needs, they began to build a case for the C-suite. This was a process that involved a number of the following key steps:

- Engaging an executive champion whom they could educate on the technology and have as an inside sponsor when bringing their case to the entire executive team.
- Creating a multidisciplinary team by bringing on board key leaders from infection prevention, EVSs, pharmacy (particularly those leading antimicrobial stewardship efforts), nursing, microbiology, and respiratory and obtaining their buy-in and support for both UV-C technology and the implementation plan.
- Proposing how UV-C disinfection would deliver a measurable return to the organization (Table 1):

Table 1
Business case for one UV-C system using a 20% reduction model

Variable	Value
CDI costs	
CDI cases per year	194 (2011)
Cost per case	$35,000[35]
Annual cost for CDI	$6,790,000
UV-C cost	$60,000
CDI savings	
CDI case reduction	20%
CDI cases less	39
Annual CDI savings	$1,365,000

CDI, *Clostridium difficile* infection; *UV-C*, ultraviolet-C.

- Show their current care rates for high-risk pathogens (eg, *C difficile*, MRSA).
- Provide data on the average cost of care for each.
- Demonstrate how incremental reductions in those infection rates would translate into direct savings, including decreased length of stay leading to increased throughput.
- Explain how the chosen UV-C system's attributes (rapid disinfection time, delivered dose measurement, comprehensive data tracking capability) would serve to achieve this goal.

With this comprehensive approach, the RGH infection prevention team obtained the C-suite's support for acquiring 2 UV-C systems and implemented them beginning in 2012 as part of a bundle approach to tackle their rising *C difficile* rates. Working with their multidisciplinary team, they developed a 4-pronged bundle with infection prevention, microbiology-laboratory, and pharmacology components. They revamped their infection prevention protocols by establishing equipment grids outlining who was responsible for cleaning each piece of equipment. They created isolation timelines to establish when CDI isolation could be discontinued. The crux of their environmental component was their newly acquired UV-C technology, but additionally, they used bleach-based disinfectants, performed ATP testing, and developed detailed daily and terminal cleaning protocols for staff. Literature has shown that inappropriate testing for CDI may lead to false identified true clinical cases and lead to treatment of asymptomatic carriers.[36,37] They reeducated staff on the definition of diarrhea and developed guidelines for stool testing. They also engaged pharmacy to create a tiered algorithm for CDI treatment. Perhaps most significantly, recognizing the impact of community onset and community onset health care facility–associated CDI, they produced clean sweep protocols to implement after unit CDI burdens were evaluated during biweekly meetings of their multidisciplinary team. Using an empty swing bed to facilitate patient movement, units identified as having increased CDI rates were all terminally cleaned and disinfected with UV-C. All available portable equipment was put in rooms for UV-C disinfection, and unit common areas were terminally cleaned. The results of these efforts led to significant reductions in CDIs at RGH. RGH saw a 56% reduction between 2011 and 2015 and a 46% reduction between 2012 and 2015 in their New York State risk-adjusted rates, which are adjusted for testing type.[38] Nationally, RGH's efforts yielded statistically significantly better than the average Centers for Medicare and Medicaid Services standard infection ratios for 3 consecutive years, most recently showing in 2015 30% less CDI cases than predicted.

CONCLUSIONS

Acquisition of a UV-C disinfection system can be a substantial purchase for a health care facility, and as a result, it is imperative that a comprehensive evaluation of a facility's need for UV-C disinfection, the potential for improved patient outcomes, and a return on investment can be demonstrated to the C-suite.

Clearly, it falls on the infection preventionist to perform thorough due diligence in their evaluation and to develop a strong case for the hospital administration. This includes using data on the estimated costs of infection, such as Dubberke and Olsen's estimate of $4.8 billion for CDI in U.S. acute care facilities alone in 2008 or Levy et al's estimated Can$12,000-Can$15,000 per CDI case in 2012, to demonstrate theoretically how many avoided cases would allow a facility to recoup the costs of the equipment.[39,40]

Limitations to these models include the difficulty in demonstrating data for true HAI reduction because the vast majority of research on UV-C's efficacy in environmental disinfection has focused on bioburden reduction and not actual infection reduction. To date, all but one study have been before-after studies in which HAI rates after implementation of UV-C were compared with those prior to UV-C use.[41] There has only been 1 randomized controlled trial evaluating the impact UV-C has on reducing HAI among patients admitted to a room previously occupied by a patient with either MRSA, VRE, or CDI.[41] In their 2016 article, Weber et al acknowledge the challenges facing researchers interested in documenting actual infection reduction with no-touch disinfection technologies, "...logistic and cost reasons are likely to preclude randomized clinical trials. Rather, decisions on use of these devices will need to be based on consistent demonstration of effectiveness in killing pathogens as previously detailed and quasi-experimental studies."[41] Additionally, Vancouver General Hospital and RGH are both tertiary academic centers, and their experiences may not necessarily be extrapolated to smaller community hospitals. This makes it all the more critical that infection preventionists take a comprehensive approach to their evaluation to determine cost-effectiveness for their facility (cost of equipment and operation vs savings in avoided infections based on past rates). Key steps in this process include the following:

Table 2
Example of system specification comparison checklist

Attribute/ specification	System A	System B	System C
Capital cost	$x	$y	$z
Service and support agreement	$y annually	$x annually	Included in price
UV-C lamp cost	Included	$xyz for 4-pack	Included
UV-C dose measurement	Yes: reflective light measurement	No	Yes: delivered dose measurement
Data capturing capability	Yes	Yes: compatible with EPIC	Yes: compatible with Cerner and EPIC
UV-C dose-based repositioning capability	No	No	Yes
Estimated treatment time	X minutes	Y minutes	Z minutes
Physical footprint of system	X × Y units	Y × Z units	X × Z units

UV-C, ultraviolet-C.

- Educating oneself on the options and their attributes: Consider creating a checklist of attributes and specifications to facilitate comparison of systems (Table 2).
- Analyzing your particular facility's needs: If you have access to a human factors' engineer, use them to determine the system most compatible with your facility's workflow, design, and staffing practices. If you do not have a human factors' engineer, use publicly available templates for evaluating new technologies, such as the Canadian Standards Association EXP06-2015, and engage other departments for feedback on the usability of the systems you are considering.
- Building a comprehensive business case: This should be built on cost avoidances or return on investment, including reduced hospitalization costs (eg, antibiotics, excess length of stay, intensive care stay, test costs, isolation room time, staffing time, disposable equipment costs), reduced emergency room divert time, reduced operating room case cancellations, reduced CMS penalties, among others.[42] Revenue enhancement potential through increased patient throughput, increased surgical cases, and increased emergency room visits and admissions should be another component of the business case.
  - The plan ideally would be able to draw on the experience of other facilities to demonstrate the technology's efficacy.

  - Outline how the chosen system meets your facility's needs and demonstrate the support of a multidisciplinary team in the adoption of the technology.
  - Include proposals for mitigating operating costs, such as sharing the burden across departments if possible (eg, if enhanced cleaning requests are reduced, funds from EVS could be diverted to UV-C operation; if a percentage of nursing staff is on furlough, they could be trained to operate systems).
- Developing a strong implementation plan: If you have selected your technology, engage the manufacturer to help you create an implementation plan designed to optimize utilization for your specific facility. Ask them to hold training sessions not just for operators but also for directors and of multiple departments (EVS, nursing, infectious disease, and corporate) so that everyone involved is aware of the why, the when, and the how of the UV-C disinfection systems.

UV-C disinfection can be an excellent adjunct to the cleaning process, but it is imperative that the technology is not just purchased out of the box. Infection preventionists must think strategically about how they are going to maximize usage to achieve the most efficiency. They must choose a system that meshes with their facility's patient flow and operational needs and develop an implementation plan that enables them to optimize a return on the investment.

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