Testing for UV-C Antimicrobial Efficacy in the Healthcare Setting

Richard A. Martinello, MD, Yale School of Medicine
Contact: richard.martinello@yale.edu

Introduction
Healthcare-associated infections develop during a patient’s care and were neither present nor forming when the patient first initiated contact with the healthcare environment. These infections often are associated with the care being received by the patient or the environment that surrounds the patient during treatment. For example, patients who have undergone surgery are at risk for an infection of the surgical wound to develop during the immediate post-operative period. Also, invasive devices commonly used in healthcare – such as intravenous catheters, endotracheal tubes used for mechanical ventilation and bladder catheters used to drain the bladder of urine – increase a patient’s risk for a healthcare-associated infection. By their invasive nature, these devices violate the body’s defenses, which normally would help to prevent infections. Not only do surgeries and invasive devices increase the risk for infection, but patients also often have underlying illnesses and/or are receiving medications that may impair the function of their immune systems.

While many healthcare-associated infections arise from bacteria or fungi already colonizing the patient when they enter the healthcare environment, it is known that patients rapidly acquire microbes already present in the surrounding healthcare environment (Datta et al. 2011, Huang et al. 2006, Drees et al. 2006). Whether the microbes causing an infection are introduced by contaminated environments or invasive treatments, these pathogens have a greater likelihood of being resistant to frontline antibiotics, leading to potentially more
severe and more difficult to treat infections, and an increased chance for death.

As an adjunct to combatting environmentally-introduced infections through routine detergent and chemical cleaning and disinfection, the application of UV-C for surface disinfection in hospital patient rooms has been shown to decrease the rate of healthcare associated infections (Anderson et al. 2017). However, the ability for UV-C to effectively decrease the burden of pathogens on surfaces, and, therefore, decrease resulting healthcare associated infections, is dependent on how it is applied (Boyce et al. 2016a). Specifically, the surfaces must receive an effective dose of UV-C sufficient to eliminate potential pathogens’ ability to grow.

However, delivery of a sufficient UV-C dose is complicated by the significant variation in the shapes, sizes and surfaces of hospital rooms, the variation in medical equipment in the room, not to mention the addition of items, such as one or more patient beds, bedside tables and a chair or two. This variation and opportunities for shadowing affect not only the time which effective UV-C treatment will require to ensure a sufficient dose is received by the surfaces but also may require UV-C lamp systems to be placed and operated in more than a single location in any room being treated.

So how does a person operating the device know they are delivering a sufficient dose and achieving the desired microbiological impact? There are currently about 25 manufacturers of UV-C devices for surface disinfection supplying the US. Most devices are simply operated on a timed cycle, and manufacturers provide instructions for use outlining device placement, the number of cycles per room and cycle duration. A few manufacturers have incorporated features into their devices to ensure an effective UV-C dose is delivered to the surfaces. These features include such strategies as:

1. Incorporating multiple UV-C sensors in the device that measure UV-C light reflected back to the equipment; the data is then assessed using an algorithm to determine cycle length,
2. Multiple remote UV-C sensors placed around the room by the user, which measure the amount of UV-C delivered and adjust the machine’s cycle duration to ensure the desired minimum dose is received by each sensor, and
3. Pre-UV-C treatment room mapping to determine cycle duration based on room measurements and an onboard algorithm. Some manufacturers provide support to examine facility room configurations planned for UV-C treatment and provide specific instructions for UV-C device use by room.

However, UV-C devices with these additional features allowing machine-automated customization of treatment parameters come with significant added expense. Most devices currently available in North America lack these specialized features or support requiring the user to either follow generic instructions or add empiric adjustments. Even for systems with more sophisticated strategies to ensure an effective delivered dose, whether an effective dose is truly delivered to the surfaces of interest generally remains unknown to the user. Failure to deliver required UV-C dosage also may arise from mechanical issues such as variation in low-pressure mercury bulb efficiency over time, bulb temperature, burned-out bulbs, dust on bulbs in addition to shadowing, surface variation and distance issues previously mentioned.

An unresolved question continues to be, “How clean does the healthcare environment need to be?” In the US, while it is a standard of care for the healthcare environment to be visibly clean, there are no microbial standards of cleanliness. Some investigations have correlated environmental microbial cleanliness and risk for healthcare-associated infections, but the understanding of this risk remains incomplete (Donskey et al. 2013, Weber et al. 2013). It is clear though that:

1. Patients contaminate their own environment with potential pathogens, including antibiotic resistant pathogens;
2. New patients residing in beds and/or rooms previously occupied by patients with specific pathogens are significantly more likely to acquire those same pathogens; and
3. Healthcare providers, through their hands and other objects, can spread pathogens – further contaminating the healthcare environment.

Therefore, while there are no US guidelines or requirements for microbial cleanliness in the hospital environment, it is
while surveillance for the microbial quality of surface cleaning and disinfection is not routinely performed, or required, in US healthcare institutions, investigations have identified process problems impacting the concentration of chemical disinfectants.

A study performed by Dr. John Boyce and colleagues identified that quaternary ammonium agents, a chemical commonly used to disinfectant environmental surfaces in the healthcare environment, often was not present in the recommended concentrations while in use due to 1) improper dispensing from automated mixing stations and 2) binding of the quaternary ammonium chemical to cotton fibers in the materials used for cleaning (Boyce et al. 2016b). Insufficient disinfectant concentration could lead to a lack of effective disinfection and thus increase the degree of environmental contamination and risk for healthcare-associated infections. Boyce and colleagues concluded that healthcare facilities should consider periodically testing quaternary ammonium solutions to ensure the presence of proper disinfectant concentrations.

In an analogous manner, healthcare facilities implementing a program using UV-C for surface disinfection also should

Table 1. Potential quality assurance outcome metrics for the use of UV-C for surface disinfection in the healthcare setting

<table>
<thead>
<tr>
<th>Quality assurance approach-outcome metric options</th>
<th>Pros</th>
<th>Cons</th>
<th>Needs</th>
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<tbody>
<tr>
<td>Rate of healthcare-associated infections</td>
<td>• Reductions in healthcare-associated infections is the desired primary outcome • US CDC/NHSN* program has standardized case definitions and surveillance methods</td>
<td>• Large sample sizes are required to show significant change. May take years to accumulate a sufficient sample size. • Many confounding variables impact interpretation of the infection rate</td>
<td>• A more complete understanding of environmental microbial contamination as a risk for healthcare-associated infections</td>
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<tr>
<td>Standard test of UV-C impact on microbial pathogens</td>
<td>• Direct measurement of the expected impact of UV-C on biologicals</td>
<td>• Resource intensive-to-produce qualitative standard for testing • Resource intensive-to-quantify results</td>
<td>• More precise measurement of k values for human pathogens • Development of standardized test microbes and methods</td>
</tr>
<tr>
<td>UV-C dose measurement</td>
<td>• Expected to be an excellent surrogate for a microbiological test</td>
<td>• Required expensive equipment to directly measure UV-C dose • Equipment requires some expertise for accurate use</td>
<td>• Standardized test methods • Research and development of improved photochromic papers</td>
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* Centers for Disease Control and Prevention/National Healthcare Safety Network program
consider testing to ensure that the use of the equipment is achieving desired environmental sanitation. This impact could be measured by several approaches, such as:

1. Patient outcomes – the rate of healthcare-associated infections;
2. Measurement of the impact of UV-C on test surfaces contaminated with known amounts of specific microbial pathogens – a standard test of the UV-C impact on microbial pathogens; or
3. Measurement of the UV-C dose on specific surfaces. Each of these approaches has significant pros and cons (see Table 1).

But how should this be performed? While the desired outcome of reductions in the rate of healthcare associated infections appears to be an attractive metric to follow, the sample size necessary for sufficient power to show a difference is substantial, and infection rates can be impacted by a multitude of confounding variables. Microbiological metrics may possibly be used where known quantities of selected microbes are placed on sterile metal coupons, these coupons are then placed in a room to be treated and the microbes are quantified post-UV-C treatment. This work, however, is very labor-intensive, and most healthcare organizations do not have an in-house lab experienced in testing microbes from environmental specimens – creating additional expense if these tests are to be outsourced. The measurement of UV-C dose is an attractive alternative, though acquisition and proper use of UV-C meters remain a barrier.

There has been extensive work investigating the survival curves for specific bacterial, fungal and viral species important to human health, but in this body of literature, there remains significant variability in the results, indicating this is an area needing additional investigation. As noted, there is great variability in the spaces and surfaces where UV-C may be used for surface disinfection. Distances, angles and shadowing are inherent in the environment. In order to ensure the proper dose, operators of UV-C need to consider testing UV-C dosing. UV-C measurement using photochromic papers are potentially an option, though it appears that additional
work is needed to determine their accuracy and limitations of use.

Taking either a microbiologic or UV-C dose measurement approach, a problem that remains is deciding which area(s) to sample. Infection prevention teams in healthcare are primarily concerned about the cleanliness of so-called high-touch surfaces, which are simply the surfaces in the patient care areas that are more frequently contacted by the patient and caregivers, such as door knobs and nurse call buttons. Presumably, contamination of these high-touch surfaces is more impactful than other surfaces in the patient care environment.

In conclusion, while it does seem prudent for users of UV-C for surface disinfection in healthcare to perform periodic testing of the effect of their devices, there remains several gaps which need attention. Specifically:

- More precisely defined k values for significant microbial pathogens are needed to improve the understanding of the necessary UV-C dosing for effective surface disinfection and to guide quality assurance measurements.
- The identification of commercially available strains of these pathogens, which can serve as standards for future research and quality assurance testing.
- Easy to use, reproducible methods for the measurement of UV-C dose by users of this technology in the healthcare setting, including guidelines for the frequency of testing.

References