Required Doses: Variability and Refining Measurements

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In recent years, multiple UV devices designed to improve disinfection of hard surfaces in healthcare facilities have been introduced to the marketplace, and there is a trend of increasing adoption of such devices among acute care hospitals in the United States. However, selection of the most appropriate device is difficult due to the lack of information regarding the doses (fluence) of UV that is required to achieve desired $\log_{10}$ reductions of healthcare pathogens, and data on the ability of devices to deliver adequate doses to various hard surfaces in patient rooms. Although substantial data are available on UV-C doses needed to reduce various microorganisms by 2-3 $\log_{10}$, most studies were conducted in liquid media and did not address healthcare-associated pathogens [1].

Only a few studies have evaluated UV-C doses necessary to reduce pathogens such as methicillin-resistant S. aureus (MRSA), vancomycin-resistant enterococci (VRE) and *Clostridioides difficile* by 3 $\log_{10}$, and the doses reported to be necessary to achieve such reductions have varied widely. For example, investigators have reported that doses that reduced *C. difficile* by 3 $\log_{10}$ ranged from 16,000 uJ/cm^2 to >300,000 uJ/cm^2 [2-5]. A recent study that used UV-C doses ranging from 10,000 to 100,000 uJ/cm^2 found that a dose of 46,000 uJ/cm^2 yielded a 3 $\log_{10}$ reduction of *C. difficile* [6]. The same study found that 10,000 uJ/cm^2 yielded a 3 $\log_{10}$ reduction of MRSA, while other studies found similar $\log_{10}$ reductions required 8,800 to 11,727 uJ/cm^2 of UV-C [4, 7]. UV-C doses required to reduce VRE by 3 $\log_{10}$ have been reported to range from 11,228 to 29,000 uJ/cm^2 [4, 7] Very few studies have evaluated the $\log_{10}$ reductions of Gram-negative bacilli such as *Acinetobacter* or *Klebsiella* achieved with measured doses of UV-C [2]. Several studies have evaluated $\log_{10}$ reductions of MRSA, VRE and *C. difficile* that resulted following use of an automated pulsed xenon mobile device, but reporting of UV doses in such studies is problematic due to the wide spectrum light emitted by such devices [8, 9].

The wide disparity in UV-C doses needed to achieve 3 $\log_{10}$ reductions of healthcare-associated pathogens is due in large part to variations in the methods utilized (Table). For example, testing different strains of *C. difficile* which can vary in their degree of susceptibility to UV-C may be responsible in part for the reported differences in doses needed to yield 3 $\log_{10}$ reductions [5, 10]. Of note, the emerging fungal pathogen *Candida auris* is less susceptible to UV-C than other *Candida* species [11]. Larger doses of UV-C may be required to achieve similar reductions if investigators use large inocula, or small-sized (e.g., 10-mm) carriers, or simply drop inocula onto carriers instead of spreading it over the entire surface of the carrier [12]. The presence of an organic load has in some studies increased slightly the doses necessary to achieve a given $\log_{10}$ reduction [6, 12]. However, additional research is needed to develop a standard organic load that more closely mimics that found on hospital surfaces [13]. Higher humidity and lower

temperatures may yield decreased sensitivity to UV-C. The potential impact varying radiometer design and accuracy on UV doses that yield 3 $\log_{10}$ reductions has not been determined.

In order for end-users to understand if a UV device will adequately reduce pathogens in patient care areas, it should be helpful to know the doses of UV light that are required to yield desired reductions, and to have practical methods of measuring doses delivered to surfaces located at different distances and orientations relative to the device. Standardization of variables used in determining UV doses necessary to achieve desired $\log_{10}$ reductions of healthcare-associated pathogens is needed [14-16].

Table. Variability in test methods used to evaluate UV-C efficacy against healthcare pathogens

Pathogen strain studied	Various strains of *C. difficile*; methicillin-resistant *S. aureus* (MRSA); vancomycin-resistant enterococci (VRE); *E. coli*
Spore-forming pathogen	*C. difficile; Bacillus subtilis*
Inoculum preparation	Variable, especially for *C. difficile* spores
Inoculum size (# colonies)	$10^4 – 10^5$; 10^5; 10^6; 10^5 - 10^7
Carrier material & size	Laminate; stainless steel; glass; plastic; aluminum Size (diameter in mm): 10; 20; 40 Area (cm^2): 25, 35
Presence/type of organic load	None; 5% or 10% fetal calf serum; 0.03%, 0.3% or 10% bovine serum albumin; ASTM E2197 multi-component load
Placing inoculum on carrier	Inoculum dropped onto carrier; spread to cover carrier surface
UV exposure conditions	Inoculum on agar surface; on dried hard surface
Exposure (cycle) time	Highly variable, from 4 min to ~50 min
Relative temperature & humidity	Various ambient temperatures and humidity levels
Method of recovering pathogen from carriers	Carriers submerged in liquid; RODAC plate: swab
Type of radiometer	ILT-254; ILT-1700; ILT-2000; General Tools-UV254SC

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