White Paper

Defeating the High Costs of Healthcare Acquired Infection (HAI): Protecting Patient Health with UVC Technology

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Healthcare-associated or hospital-acquired infections (commonly referred to as HAI) are a serious, growing threat to patient safety worldwide. At any given time, approximately one in every 25 patients has contracted an HAI after a routine healthcare procedure. These infections may range from mild to moderate, but are sometimes severe and can become life threatening, or life changing. HAIs stemming from the most serious antibiotic resistant bacteria can lead to sepsis and death. In the United States alone, HAIs affect 2 million patients per year, resulting in over 100,000 deaths, and account for medical costs estimated between $96B - $147B annually.[1]

Pathogens most often associated with HAI include *Clostridium difficile* (*C.diff*.), Methicillin resistant *Staphylococcus aureus* (MRSA), and Vancomycin-resistant *enterococci* (VRE). In addition, an alarming spike in the number of incidents of *Candida Auris* (*C.auris*), a multi-drug resistant yeast that spreads by person-to-person transmission or through contact with contaminated surfaces, is being closely tracked and reported throughout the world.[2,3]

One of the most powerful, effective and adaptable tools to aid in the control and mitigation of HAI is the use of UVC irradiation (also referred to as ultraviolet germicidal irradiation, or UVGI). In 2016, the U.S. Centers for Disease Control and Prevention (CDC) concluded that based on a study of the benefits of enhanced 'terminal room disinfection', the incidence of HAI-causing organisms could be reduced up to 35% by simply adding antimicrobial UVGI emitting devices to standard cleaning strategies.[Note]

The mechanism for pathogenic microbe and virus inactivation through UVC irradiation is relatively straightforward: UVC irradiation induces damage to the genomes of bacteria and viruses by breaking bonds and forming photodimeric lesions in nucleic acids, DNA and RNA. These lesions, in turn, prevent both transcription and replication, ultimately leading to inactivation which prevents microorganisms and viruses from infecting and reproducing.

Therefore, any *comprehensive* approach to improved infection prevention should include UVGI in conjunction with conventional physical and chemical cleaning. Versatile UVGI can be deployed throughout the healthcare facility in a wide range of modes. For disinfection of pathogens in ambient air, proven and well-established upper-air UVGI (e.g. LED-based) can be used to deactivate aerosolized virus. For enhanced surface disinfection, pulsed xenon ultraviolet (PX-UV) is highly effective in reducing MRSA and aerobic bacteria. In fact, in a recent study from a Japanese hospital, the *American Journal of Infection Control* reported a 72% reduction in the abundance of MRSA using PX-UV when compared with manual cleaning alone.[4] Although PX-UV does have a limitation in that it must be used 'after-hours' within unoccupied spaces (typically via UV-robots), more recently available 'eye-safe' 222 nm Excimer fixtures can be deployed safely in constant mode, even in occupied rooms.

It is precisely this remarkable versatility and adaptability that makes UVGI such an ideal addition to infection control programs. UVGI systems can be installed in a variety of modes within a broad array of applications to provide enhanced pathogen barriers *throughout the healthcare facility* to effectively help reduce HAI.

> **Note:** 'Terminal cleaning' or terminal room disinfection, simply refers to any cleaning procedure performed whenever a patient is discharged or transferred from a previously occupied patient room. During terminal cleaning, the facility's cleaning team (typically referred to as EVS or Environmental Services) will fully wipe down and disinfect all surfaces in a patient's room. Surfaces include 'high touch' areas or equipment, floors, and patient-care gear.

Overview of UVGI for HAI Prevention

The primary goal of any disinfection program is to limit the spread of disease, which could substantially alter an individual's life. But increasingly, HAIs exact a staggering financial toll upon global medical systems, patients and healthcare providers. Ignoring the enormous financial costs, the personal burden upon infected patients is often long-term and particularly grueling.

One story in particular highlights the arduous path for one patient after contracting an HAI. Mary Millard, M.Ed, is an advocate and public speaker dedicated to increasing public awareness about HAI, and the infection's long-term impacts, by sharing her journey.[5]

"Personally, since the fall of 2014, I have undergone 89 X-rays, 20 CT scans, and 4 more procedures. This is in addition to monthly blood draws and cultures, as well as 16 visits to the hospital. Thanks to a hospital-acquired infection, this is what life has turned into. In addition to costs to the healthcare system of preventable HAIs, there's a real cost – financial as well as quality of life – to the survivors."

Often, traditional cleaning/disinfection techniques may not eradicate all viruses and pathogens on surfaces. For example, alcohols (ethyl alcohol and isopropanol) are effective bactericides, fungicides, and virucidal agents, but they are not effective against bacterial spores and hydrophilic viruses. Quaternary Ammonium Compounds (QACs) are effective against gram-positive bacteria, fungi, lipophilic (enveloped) viruses, but they are less effective against gram-negative bacteria, tuberculosis bacteria, and again bacterial spores.

Some pathogens are extremely hardy, long-lasting and capable of evading chemical decontamination. For example, *C. diff* is notorious for its ability to resist a broad range of chemical disinfection treatments and is generally recognized as one of the most difficult of all healthcare pathogens to eradicate. *C. diff* produces spores capable of surviving harsh conditions for very prolonged periods. [6]

In the CDC's report, *Antibiotic Resistance Threats in the United States, 2019*,[7] *C. diff* is characterized as a major health threat. In 2017, there were an estimated 223,900 cases in hospitalized patients and 12,800 deaths in the United States. Moreover, the Yale School of Medicine recently estimated that two-thirds of *C. diff* infections originate in hospitals, long-term care facilities, or other healthcare settings.

Figure 1: *Clostridium difficile* (*C. diff*)

Similar findings have been reported with Vancomycin-resistant *enterococci* (VRE) and MRSA: in 2017, VRE alone accounted for over 54,000 infections with a 10% death rate. [ibid]

Standard manual cleaning remains an essential step for any infection control program, and improved training, new protocols, and specifically focused EVS teams have made recent strides in overcoming some of the deficiencies of typical, previous housekeeping cleaning. Even so, there are many variables that can lead to unsuccessful chemical disinfection (e.g. failure to follow the chemical manufacturer's instructions, using the incorrect dilution guidelines, not selecting the right cleaners with the most effective disinfectant to tackle the specific profile of pathogens encountered. Each disinfectant challenge is always *unique* based upon the characteristics of the infected patient that previously occupied the room.)

Numerous studies have shown that it is precisely this potential failure to adequately disinfect patient rooms at the time of terminal cleaning (hospital discharge, or moving a patient) that contributes to the increased risk of HAI when a patient is admitted to a room where the prior occupant had been 'colonized' or infected with a multidrug-resistant pathogen. [8]

However, UVGI disinfection eliminates much of this variability. UVGI systems can be deployed throughout the healthcare facility and can operate autonomously and, in many cases, can *proactively* disinfect the local environment (e.g. upper-air UVGI). Ultraviolet radiation with wavelengths typically in the 200 – 280 nm UVC range deactivate bacteria, viruses and other microbes by disrupting the structure of the DNA molecules, thereby rendering them unable to replicate (and thus lead to infection).

Versatile and adaptable UVGI helps enhance the terminal cleaning process, and aids in eliminating guesswork, inconsistency and variability within the germicidal protocols for any infection prevention program. UVGI systems have a force amplifier effect on terminal room disinfection. They enhance the strengths and the effectiveness of the EVS team and manual disinfection, and they reduce the overall burden of HAI pathogens. [9]

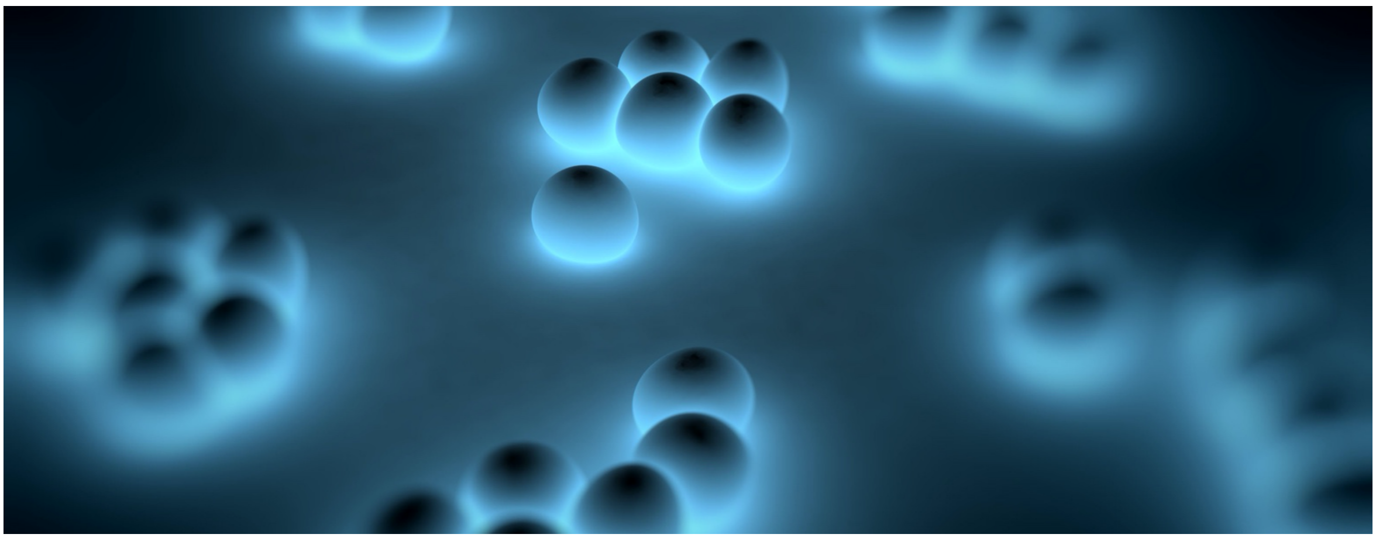


Figure 2: MRSA bacteria

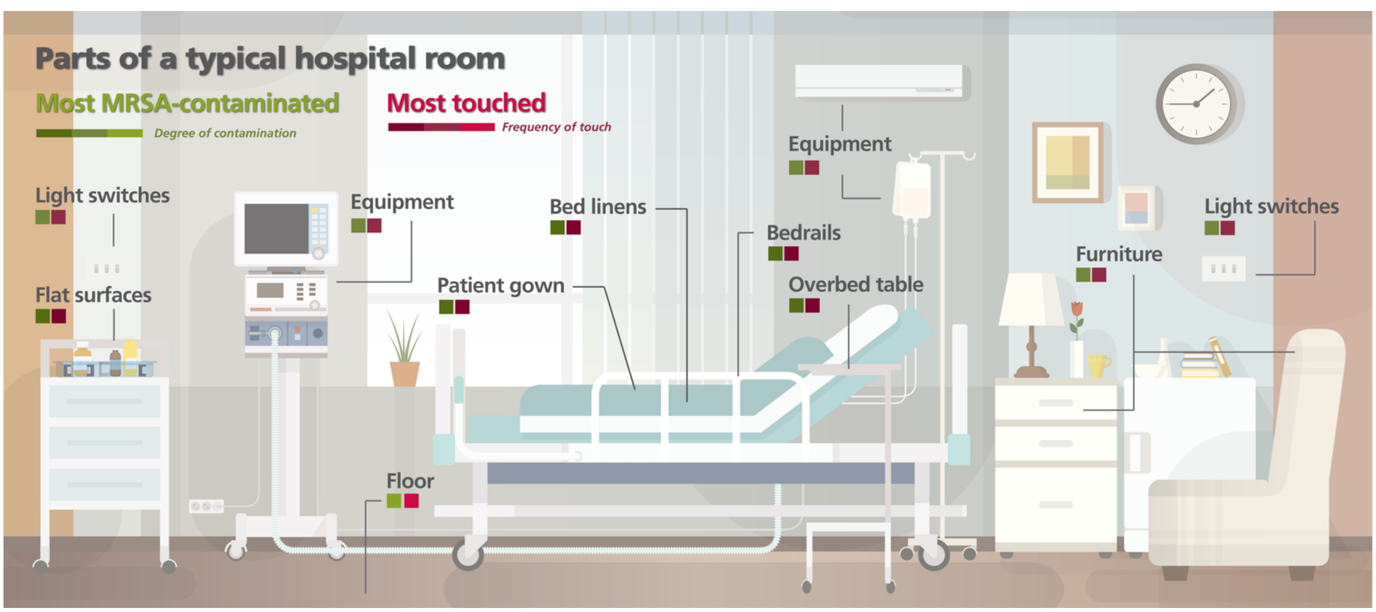


Figure 3: Environmental, 'high-touch' surfaces such as bed rails, door handles, bathroom faucets and doorknobs, keyboards and bed tables act as a **launching pad** for potential microbes and contribute to the transmission of pathogens to healthcare patients.

Available UVC Technologies

Low-Pressure Mercury Lamps

One of the older approaches in generating UVC radiation is through low-pressure mercury lamps (LP Hg). In terms of geometry, electrical connections and operating power, these lamps share much in common with standard fluorescent lamps without the coating.

To be most effective, low-pressure mercury lamp systems require long disinfection cycles, likely delaying moving a new patient into a clean room. LP Hg systems are also constrained by longer warmup times, they exhibit a monochromatic emission at 254 nm, and contain hazardous mercury. As mercury is toxic even in small amounts, caution is needed in cleaning up lamp fragments that may result from a broken device, and which then need to be disposed of responsibly.[10, 11] Low-pressure Hg lamps must also be deployed after-hours or when rooms are unoccupied and eye-safe operator safety gear must always be used.

Another drawback to these low-intensity, narrow-spectrum lamps (254 nm only) is that they provide only one deactivation mechanism: photodimerization of the microbe's DNA. This limitation, combined with the longer dwell time required for complete disinfection, increases the potential that treatment will yield sublethal irradiation which has been proven to allow the pathogens to repair and reactivate. [12]

Moreover, in 2013, the United Nations Environment Programme adopted the Minamata Convention on Mercury, which prohibits trade in mercury-containing products in order to protect the environment and human health. Effectuated in 2020, the use of low-pressure mercury lamps will eventually be discontinued, and new UVC sources will replace the older, outdated technology.[13]

Pulsed Xenon Ultraviolet (PUV)

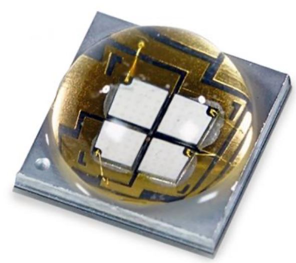
Often referred to as pulsed-xenon ultraviolet light (PX-UVL) or PX-UV, pulsed xenon is a mainstay in supplemental healthcare disinfection. Since 2010, PUV systems have increasingly been used within automated units for after-hours or non-occupied disinfection. PUV units produce a high-intensity, broad-spectrum emission (200-315 nm) which is ideal for germicidal applications. [14,15]

PUV has many advantages over low-pressure mercury because the broad spectrum produced results in equally **broad array** of pathogen deactivation mechanisms (photodimerization, protein damage, photosplitting and photohydration).

The wavelengths generated have shown to be 95 to 99% effective in eliminating healthcare pathogens from high-touch surfaces. PUV has been linked to effective, significant reductions in HAIs, and a recent 2019 study confirmed that surface and environmental contamination was reduced *further* by 75% after PUV compared to manual cleaning and disinfection alone. [16]

PUV's rapid disinfection cycles allow healthcare EVS staff to treat infected areas and surfaces in a matter of minutes and get the next patient into the room as quickly as possible. However, like low-pressure mercury sources, PUV must be used in unoccupied rooms, or during short periods of vacancy when EVS is cleaning.

Solid State Lightsource Solutions (LEDs)



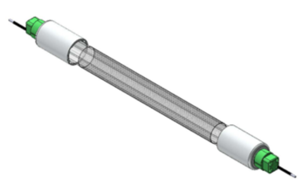
As one class of UVC emission sources, LEDs offer many compelling advantages over low-pressure mercury lamps and PUV for pathogen reduction in healthcare settings.

UVC LEDs are more robust, and much more compact in comparison to the larger low-pressure mercury lamps. This allows them to be easily integrated into smaller-footprint, more inconspicuous devices and fixtures. For healthcare settings (patient rooms, dental suites, ICUs, long-term care facilities), a sleeker more integrated design is preferable to a large, clunky industrialized, low-pressure fixture. In addition, UVC LED systems provide instant on/off, and some even offer dynamic switching capabilities, allowing for immediate adjustment to any change in disinfection demand or operating conditions. Finally, UVC LEDs are also environmentally advantageous, as they eliminate the use of mercury and are more energy efficient.

For most healthcare-specific pathogens, currently available UVC LEDs emit in wavelengths of 265 nm, 273 nm, 277nm, and 280 nm. This is an intriguing benefit since some pathogens exhibit a key sensitivity to particular wavelengths in combination. Further, some recent findings on a novel 233 nm LED reveal a 5 log reduction in microbial load at a dose of 40 mJ/cm^2.[17] Clearly, further studies on bactericidal efficacy and skin tolerability are needed, but this is an excellent example of wide-ranging versatility that LEDs display for HAI reduction.

LEDs can be deployed in upper-air disinfection devices and be operated continuously, even when rooms are occupied. They can also be deployed in surface treatment devices for use when rooms are unoccupied.

Excimer Sources – Lamps & Systems



Excimer sources have recently emerged as a valuable UVGI tool for HAI reduction and SSI (surgical site infection) control. The 222 nm-emitting KrCl lamps provide a dual-approach to pathogen deactivation (photodimerization of DNA / RNA, as well as protein damage), and they have shown a synergistic effect when coupled with other technologies. [19, 20, 21]

In recent studies, the biological effectiveness of 222-nm UVC has been explored using mouse models of a skin wound infected with methicillin-resistant Staphylococcus aureus (MRSA). The results demonstrated that irradiation with 222-nm UVC from an excimer source significantly reduced bacterial numbers on the skin surface compared with non-irradiated skin. Moreover, bacterial counts in wounds evaluated after irradiation showed that the bactericidal effect of 222-nm UVC was equal to or more effective than 254-nm UVC. [ibid]

Excimer sources are available in a wide array of form factors and can be easily incorporated into fixtures, ceiling mounts, door portals, and mobile sanitizers.

Conclusions

Healthcare associated infections (HAIs) are infections that patients contract while they are receiving health care, or undergoing a procedure to diagnose or treat another condition. HAIs are the result of contagious pathogens within any healthcare facility, including hospitals, acute care and long-term care facilities, ambulatory surgical centers, and end-stage disease facilities. Bacteria, fungi, viruses, spores, and other pathogens cause HAIs. [22, 23]

HAIs are a significant cause of illness and death globally — and they can have serious emotional, financial, and long-term medical consequences. At any given time, it's estimated that 1 of every 25 patients in the U.S. develop an infection resulting from an unrelated healthcare event. In mainland China, the rates are even higher: A recent systematic review suggests the prevalence of HAI there is 3.12%, with rates as high as 26.07% in adult ICUs. [24] These infections lead to hundreds of thousands of deaths and cost global healthcare systems billions of dollars each year. Many global health agencies, including the U.S. Department of Health and Human Services (HHS), have identified the reduction of HAIs as a top priority goal.

Standard manual cleaning remains the most critical step for any Infection Control program, and hospitals have created specially trained and focused Environmental Services Teams (EVS) to conduct enhanced cleaning. But room turnover is critical, and 'high-touch' surfaces in treatment areas may be missed or pathogens on surfaces may be resistant to chemical disinfection.

To overcome the limitations of manual disinfection, one of the most powerful tools in the fight against HAI is through the use of UVC irradiation (UVGI). UVGI can be deployed for constant air disinfection thru upper-air devices (to neutralize aerosolized virus and pathogens), and for surface disinfection in fixtures, ceiling mounted devices and via terminal room cleaning with automated robots.

UVGI overcomes the inconsistencies of manual cleaning, and provides needed support to healthcare EVS teams so that terminal room disinfection can be carried out swiftly and effectively, and patients can be moved without the worry of HAI. UVGI should be considered the foundation for any Infection Control program.

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