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Green Technology to Fight Hospital-Linked Infections:

A new study finds that although significant barriers exist to wider usage, the science of ultraviolet germicidal irradiation (UVGI) remains promising—a weapon in the war against pathogens that kill patients.

by Joann Rodgers, M.S.

Ultraviolet germicidal irradiation (UVGI), a technology commercially available in the United States for more than a century, destroys a lengthy list of disease-causing viruses, bacteria, and mold-making fungi by disabling their DNA and preventing reproduction—and it's affordable and done without harsh chemical disinfectants. The ultraviolet component of sunlight is one reason that microbes die faster outside than inside, and when placed properly in and around the ducts and coils of air-handling systems, or in portable room units, UV light delivery systems are a proven means of preventing disease transmission and microbial contamination in biological laboratories, TB clinics, and "sick buildings."

Ultraviolet radiation is an electromagnetic wave discovered in 1801 by German physicist Johann Wilhelm Ritter, but was mislabeled as "chemical rays" for more than a century because Ritter identified them with an experiment in which silver salts turned black when exposed to sunlight.

UVGI was first shown to disinfect water in 1877, and in 1903, Danish physician Niels Finsen won a Nobel Prize for the use of UV radiation to treat smallpox and lupus. Experiments in TB sanatoria around the same time demonstrated that UV decreased both influenza and TB transmission. Such promise led to the installation in 1909 of the first UVGI system for mass disinfection of the city's water system in Marseilles, France. Its use in disinfecting surgical and medical equipment has been popular ever since.

Such uses of UVGI are "common and reliable," according to Wally Kowalski, Ph.D., a consulting mechanical engineer, expert on UVGI, founder of the field of aerobiological engineering while a member of Pennsylvania State University's architectural engineering department, and a researcher who has conducted dozens of studies examining ways to stop or kill resistant germs; and a colleague, William Bahnfleth, Ph.D., a current Penn State professor and director of its Indoor Environment Center. In separate interviews, both Kowalski and Bahnfleth emphasized that UVGI air disinfection showed so much potential in the 1920s that experts were predicting the eradication of airborne pathogens and disease in hospitals and elsewhere. By 1936, UVGI was being used in operating rooms, and studies showed that UVGI could stop the transmission of TB in hospitals' exhaust air and reduce the transmission of measles in schools.

In relatively simple terms, UVGI is an air, water, and surface sterilization method generally produced by mercury vapor light emissions. These emissions operate in one tiny wavelength that is part of the germ-killing ultraviolet C (UVC) electromagnetic spectrum. (The wavelength measures around 253 nanometers, with a nanometer being one-billionth of a meter.) UVGI emits about 85 percent of its light in the wavelength easily absorbed by DNA. UV light's wavelength is much shorter than the light we can see, but it's longer than x-rays. (The light spectrum consists of electromagnetic waves with frequencies greater than what people see as the color violet, thus the name "ultraviolet.")

Found naturally in sunlight, UV light is visible to insects and birds, but not to humans, and it produces chemical reactions that cause fluorescence in some materials such as black lights, and the increasingly popular "UV drying lamps" used in nail salons to cure color gels and lacquers. In addition to mercury, other UV sources

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that continuously emit invisible light are xenon, deuterium, metal halide, and tungsten-halogen.

Under normal environmental conditions, the short wavelengths found in UVC rarely reach Earth from the sun because the ozone blocks them, thus protecting the DNA of this planet's inhabitants. But with UVGI technology devices in circulating air or water systems, the UV light energy is encased and harnessed. When placed properly in HVAC&Rs (heating, ventilation, air conditioning, and refrigeration), UVGI is able to kill pathogens in ways that limit human exposure to the radiation. In fact, several years ago, the U.S. General Services Administration required that UVC be included in air-handling cooling units for all new government facilities to improve cleanliness and air quality.

So it would seem UVGI is an obvious "must have" or "go to" technology for what are arguably this nation's most persistently germ-ridden places: hospitals. Healthcare-acquired infections (HAIs) pose lethal risks to millions of patients, visitors, and medical care providers. Overall, they strike at least 5 percent of all those hospitalized in the U.S., including Maryland, with that rate doubling in some intensive care units. In 2010, the Maryland Health Services Cost Review Commission put the number of "avoidable" HAIs in the state at 14,206, at a cost to insurers, taxpayers, and patients of $175 million.

Considering the increasing tendency of hospital marketers to view improved patient safety and green solutions as both life-saving upgrades as well as competitive edges, this only adds to the potential appeal of UVGI. Dozens of companies make UVGI units for air, water, room, and all-surface decontamination. And what hospital administrator isn't eager for cost-effective ways to safely reduce the use of liquid disinfectants, germicidal sprays, and mechanical filters that create their own environmental problems and require platoons of housekeepers? "The availability of smart, green technologies for HAI reduction certainly sparks *our* interest," says Theressa Lee, chief of the Hospital Quality Initiative at the Maryland Health Care Commission, a part of the Maryland Department of Health and Mental Hygiene.

However, to date, UVGI has largely failed in its bid to become a safety measure of choice for hospitals, or to gain significant traction as an environmentally sensitive approach to reducing HAIs. Widespread agreement about UVGI's effectiveness is elusive, while concerns about its safe use and applicable standards remain abundant. Although there are no reliable national figures documenting its use, those familiar with the industry say at most only a few hundred hospitals out of the 5,754 nationwide use UVGI in significant ways. According to the engineering firm of Leach Wallace, it has 60 hospital clients in Baltimore and around the country that use UVGI technology, with units in some areas of Mercy, Maryland General, Sinai, St. Joseph's, and a handful of other state health-care institutions. But no UVGI systems have been installed housewide in any major hospital, including Johns Hopkins' new $1.1 billion clinical building in East Baltimore, which opened in 2012.

Indeed, the history of UVGI since its first health application in the 18th century is one of seemingly endless promise, accompanied by disappointment and disuse. The current consensus among hospital epidemiologists, facilities managers, mechanical engineers, medical and public health professional societies, government and academic organizations, state regulators, and patient-safety researchers is that UVGI, like the bridesmaid who never weds, has perpetual prospects and eager beaus, but is unable to get to the "I do's."

Reasons for UVGI's small footprint, like poet Stephen Leacock's fabled horse, ride off in all directions—and there is no shortage of finger pointing. Depending on the source, the causes are regulatory roadblocks, the absence of standard UVGI industry specifications and components, hospital construction industry complacency, poor marketing, lack of rigorous effectiveness research, and misguided fear about UVGI's safety.

While all of these factors have credence, experts say, UVGI still has champions—both scientific and commercial—who predict a resurgence of interest and applications. They agree it is unlikely UVGI will ever be a stand-alone solution to HAIs, but

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they insist the technology deserves far more respect than it gets, and that its time is coming. But when?

In the fall of 2011, following a report of successful efforts to reduce some troubling infections in Maryland hospitals [March 2011, *The Abell Report*, Volume 24, Number 2], The Abell Foundation commissioned a detailed look at the status of the UVGI story, one highlighting the claims, counterclaims, prospects, and limitations proffered by champions and critics.

This is that report. It focuses on the scope of the HAI problem, the evidence for and against the use of UVGI as either a stand-alone or "adjunct" infection-prevention strategy, along with factors that keep Baltimore's major medical centers—and most of the state's network of teaching and community hospitals—from adopting UVGI and other greener protective technologies. This report concludes with recommendations for moving UVGI into the mainstream of infection-control plans and policies, gathered from reviews of the engineering and infectious disease literature, and interviews with more than a dozen people in the UVGI industry, academic engineering, hospital epidemiology, health-care facilities management, and patient safety in Maryland and around the U.S.

SO MANY INFECTIONS, TOO LITTLE HEADWAY: A ROLE FOR UVGI?

It's been more than a dozen years since the landmark Institute of Medicine book-length 1999 report, *To Err is Human*, declared unsafe medical care a significant national problem in need of a "systems" approach to remediation, rather than a focus on individual providers. In the interim, despite a long-time war on pathogens, fueled by bleach, ammonia, alcohol gels, HEPA filters, relentless handwashing campaigns, regulatory threats, and elbow grease, federal public health officials estimate 1.7 million new HAIs each year in the nation's temples of healing, killing 100,000 annually, and adding an estimated $45 billion a year to rising health-care costs and woe for already sick patients, employer health plans, taxpayers, and hospital risk managers.

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Despite vaccines, antibiotics, expensive isolation units, regulatory and financial penalties, "cover your sneeze please" signs, and countless infection-control projects attuned to the latest behavioral science, epidemiologists who track the emergence, transmission, and spread patterns of infections know that a trip to the hospital still means exposure to viruses, bacteria, and mold-building fungal spores that are easily airborne, and capable of riding on the products of sneezes, coughs, and moving air to sicken the vulnerable.

Abetted by antibiotic resistance, air-, water-, and surface-borne infections caused by streptococcus, methicillin resistant *Staphylococcus aureus* (MRSA), *Clostridium difficile*, influenza virus, pseudomonas, aspergillus, *Legionella*, vancomycin resistant enterococcus (VRE), and other nasties on the "most wanted" lists of hospital infection trackers, remain frustratingly resistant to eradication.

Studies show some germs survive on surfaces for days, weeks, or months, waiting for the hapless patient, visitor, physician, nurse, or housekeeper to pick them up from a room phone, an ice machine, a water faucet, or a bed rail and spread them around, and numerous studies have linked room contamination to patient infections.

Even discounting SARS, H1N1, and other emergent infections with new or no names, Maryland hospitals are under especially persistent daily threat not only from the bugs named above, but also from noroviruses, rotaviruses, Norwalk viruses, the viruses that cause hepatitis, and mycobacteria like the one that causes TB.

The March 2011 *Abell Report*, which compiled rates for one type of HAI in Maryland, noted that, compared to 16 other states whose data were made public by the U.S. Centers for Disease Control (CDC) in 2010, the Free State's rates were "troubling," ranking worst among the group. That same year, the Maryland Health Care Commission (MHCC) also published comparative rates for this HAI, known as CLABSI, or a central line associated bloodstream infection,

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measuring each institution against "national benchmarks." Of 45 hospitals cited in that report, eight, including University of Maryland Medical Center, Sinai Hospital, and Johns Hopkins Bayview Medical Center, had pediatric and adult infection rates substantially worse than similar institutions nationally.

CLABSIs are generally caused by germ-contaminated plastic tubes that are placed in patients to deliver drugs, and to sample blood and other fluids. All told, they account for 15 percent of HAIs and 30 percent of the CDC-estimated 100,000 deaths a year from these infections.

To be fair, not all hospitals nationwide report their HAIs, and those states that also audit and verify cases (just five including Maryland) predictably show higher infection rates because these states go looking for cases and for evidence of under-reporting. The shortcomings of data collection notwithstanding, however, public-health policy makers, patient-safety gurus, and infection-control specialists say it's clear that efforts to prevent or control transmission of infectious agents, particularly among the immune-compromised, the frail elderly, the very young, and the very sick, are not working to anyone's satisfaction.

"It's unacceptable that infections still kill more people in hospitals than die of breast cancer in the U.S.," says Peter Pronovost, M.D., a Johns Hopkins University critical care specialist, internationally recognized patient-safety researcher, and director of the Armstrong Institute for Patient Safety at Johns Hopkins. "*Every* hospital kills patients with infections," whether they acknowledge it or not, he says, via pathogens transmitted through the air, water, and contamination of medical equipment and devices. Pronovost's widely publicized operating room "checklists" have significantly reduced central line and surgical site infections (SSIs) at hospitals in the U.S. and abroad, and rates of CLABSI in Maryland hospitals have declined significantly, according to the Maryland Health Care Commission. Yet Pronovost's colleague, Johns Hopkins surgeon Martin Makary, M.D., has conducted a study showing that SSIs alone still kill about 8,000 patients a year and cost the health-care system roughly $10 billion.

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"Cleaning water, surfaces, and equipment in hospital rooms, ICUs, and ORs is imperative, and we are doing a better job, but all of our data suggest that the kind of cleaning we do is not enough despite Herculean efforts," says Trish Perl, M.D., MSc, former president of the Society for Health Care Epidemiology of America (SHEA), professor of medicine at Johns Hopkins University, and chief epidemiologist for The Johns Hopkins Hospital and Health System. Because of human behavior and clinical engineering factors, she says, studies show that adequate cleaning occurs in hospitals only 49 percent of the time, and the risk of infection in a room previously occupied by people with certain infections is close to 4 percent. "Even with improved disinfection and systematic cleaning, transmission of infectious organisms still occurs," she says, and even such basic preventive measures as consistent and frequent hand washing by medical personnel fall substantially short of the 100 percent goal.

Reporting in the journal *Infection Control and Hospital Epidemiology* in 2011, a team of researchers at the Center for Evidence-Based Practice at the University of Pennsylvania published results of a 2011 study lending support to Perl's glum assessment. Estimating the proportion of HAIs in U.S. hospitals that are "reasonably preventable," the Penn team found that only 65 to 70 percent of CLABSIs similarly caused urinary tract infections, and ventilator-associated pneumonias are likely preventable "with current, evidence-based strate-

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gies." The researchers concluded that "100 percent prevention of HAIs may not be attainable…" without different or additional preventive measures.

At the root of the HAI problem are germs that already are colonized or growing in the many nurturing environments and bodies in a hospital, compounded by those walked, wheeled, or carried in by the sick, the well, ambulance personnel, and equipment, and the air and water pumped through spaces, ducts, vents, and pipes. Cross contamination is virtually a continuous threat and although physicians, nurses, and other hospital personnel can always do more to practice optimal hygiene to protect patients and themselves, it's a Sisyphean task to keep up with what may come inside every time a door opens or a cough erupts.

The scientific literature teems with studies demonstrating that transmittable pathogens lurk and grow on bedrails, blood pressure cuffs, tables, TV remote controls, toilet seats, caregivers' hands, surgical tools, ventilators, diagnostic equipment, door handles, floors, walls, vents, ducts, refrigeration coils, drain pans, fountains, and IV pumps. *Legionella* and other organisms often find welcome niches to grow in ice makers, water fountains, and spigots, and hospitals don't have full control of urban water systems that can be periodically contaminated by plumbing failures and misconnections, or the backflow of waste water that gets through preventive systems before it comes into the hospital. Whirlpools and showerheads also have all been found to nurture *Legionella* and other pathogens, and such devices often are resistant to bleach flushes.

One recent study showed that MRSA could be cultured from 42 percent of *gloved* hands that never touched a patient but did touch contaminated surfaces; and that 46 percent of cultures taken from bare hands grew VRE after just five seconds of contact with a bed rail or table in a room with VRE infection. One touch, or one sneeze, or one cough is enough to send droplets of infection aloft to settle abroad on surfaces in a room or on others' bodies and clothing.

Further adding to the problem is the capacity for bacteria and viruses to alter their DNA (mutate), adapt, and become resistant to drugs and some disinfectants. Recent studies of bacteria discovered in a U.S. cave in New Mexico show that even bugs that never came in contact with people, their infections, or their antibiotics are resistant to such drugs—evidence that supports the argument that microbial resistance is "natural and ancient" and that even greater caution in use of antibiotics won't overcome the capacity for germs to win the day. Regardless of when and how bacteria, fungi, and other bugs learned to persist by altering their DNA or developing armor, their lethal efficiency awes even those sworn to destroy them, and suggests that current infection-control efforts are still too much like bringing a knife to a gunfight.

"The super bugs that you are hearing about are mostly these gram-negatives that are pretty much acquiring resistance to all known antibiotics, and we have nothing to treat them with," says Luis Ostrosky, M.D., an infectious disease expert at the University of Texas Health Sciences Center in Houston Medical School. Among these are *Klebsiella pneumoniae* and actinobacter. Also particularly menacing, Ostrosky says, is the hard-shelled bacterium *Clostridium difficile or "C. diff"* in the shorthand parlance of his field. *C. diff* infections are gram-positive (so named because they react positively to the so-called Gram stain test), and caused by bacteria that produce endospores whose toxins attack the intestinal lining. *C. diff* is extremely hard to get off of bare hands with soap and water, detergents with ammonia, or alcohol-based hand sanitizers. Some 30,000 are believed to die of *C. diff* infections each year in the U.S., and public health officials report that illness caused by *C. diff*—first discovered in 1978—is fast outpacing rates of MRSA infections in community and large hospitals alike.

Although a small number of people come into the hospital carrying *C. diff* spores in their GI tracts, many more acquire them through "oral fecal" contamination during their inpatient stay. Patients touch a service, utensil, doorknob, or other surface and pick up *C. diff* spores, then take a sandwich from their food tray and without washing their hands, eat it.

Noroviruses, the bugs that have ripped through cruise ships in recent years, can similarly live on dry surfaces for up to three weeks and have become the second leading cause of death from GI causes and a virulent threat to the elderly and the very young. Bacteria such as acinetobacter and staphylococcus have been known to survive on surfaces for as long as five months.

"Hospitals may be good at cleaning surfaces and equipment for certain bacteria and viruses, but *C. diff* spores survive on floors, can be kicked around by mops, walking, and air handling," says Wally Kowalski, the

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consulting engineer. "Aspergillus, a fungus, can blow in doors and windows, find receptive environments in carpets and in ORs, and are very hearty and resistant to cleaning," Kowalski adds. "Doctors and nurses walking from a hallway into an operating room bring spores in with their booties. And the sad fact is that hospitals can't even keep up with testing and sampling of biofilms and other stuff already on their floors, in their air vents, on tables, and on instrument surfaces, so there are few accurate baseline data to even measure results of actions they are already taking."

So complex are the ways and means of microbes and efforts to control them that infectious disease specialists long ago developed the so-called Spalding classification of disinfection resistance to sort them out by creating lists that describe hospital-linked germs in terms of their submission to *standard* cleaning.

Bacterial endospores such as *C.diff*, a gram-positive anaerobic bacillus spore-forming organism (meaning it thrives best in no- or low-oxygen settings), are, along with norovirus, the pathogens most resistant to standard disinfection with chemicals and to heat. Active only when no oxygen is present, *C.diff* becomes dormant when exposed to air but survives in endospore form, ready to grow again when it gets to the gut or stomach. Both norovirus and *C.diff* are considered the ultimate health-related pathogen because both contaminate the environment, are resistant to disinfectants, and are spread by diarrhea, making them hard to clean.

The next category of resistance is comprised of mycobacteria, rod-shaped aerobic bacteria that include tuberculosis germs. Their waxy outer layer makes them tough to kill, too, and they have been especially troubling in devices such as bronchoscopes and other invasive tubes and devices.

Continuing in descending order of resistance to standard disinfection, there are small, so-called non-enveloped viruses (viruses without a viral coating that infect cells more easily) that include noroviruses, followed by fungi, which include molds and yeasts. Then come gram-negative bacteria such as *Acinetobacter baumanii* and *Klebsiella pneumoniae*; large, non-enveloped viruses such as rotaviruses (a frequent difficulty for children in day-care centers); gram positive vegetative bacteria including MRSA and VRE; and—the most susceptible to disinfection—enveloped viruses, including blood-borne pathogens such as HIV, hepatitis B and C, and influenza A.

Compared to *C. diff* and other bacteria and fungi, the viruses are relatively easy to kill, including those that cause HIV, hepatitis B and C, and the flu. Disinfectants (i.e., liquid chemicals such as alcohols, bleach, phenols, aldehydes, and ammonia), when used properly, can take most of them out.

Federal agencies and infectious disease academies have, over the years, developed protocols for scrubbing surfaces, air, and water of bugs at each level of the Spalding classification. At the "most resistant" level of germs, conventional cleaning and disinfection may include sterilization with hot steam, peroxide gas, and alcohols. Moving down the spectrum, effective cleaning can be had with heat, various peroxides such as peracetic acid, chlorine bleach, air-drying enzymatic detergents, soap, and even sterile saline and clean water. "Dilution is the solution to pollution," goes one medical rubric.

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What the statistics and studies consistently demonstrate, however, is that even with the best use of available, standard cleaning and disinfection, HAIs continue to do enormous damage. Hopkins's Perl says additional ammunition is almost certainly needed to supplement or replace current weapons of mass germ destruction such as various concentrations of liquid bleach; disinfectant-soaked cloths and sponges; HEPA filters; special negative pressure air flow rooms;

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and protective masks, gowns, gloves, and booties.

"The outbreaks we see here in Maryland and across the nation," Perl says, "suggest that additional measures are sometimes required, especially with organisms that have a predilection for the environment. The real question is where we go from here and can UVGI help."

THE HEALTH-CARE INDUSTRY RESPONDS

Unsurprisingly in an entrepreneurial nation, entire "patient safety" industries have emerged to document and abate the HAI problem, marshaling all manner of prevention and cleaning strategies and producing an avalanche of publications, workshops, and guidelines designed to sell products that ostensibly help hospitals and other health-care facilities select, test, install, implement, refine, or develop infection-preventing methods of air handling, water treatment, and surface cleaning.

The response is due in no small part to market and regulatory pressures forcing hospitals to compete on the basis of quality improvement, treatment "outcomes," and overall patient safety. "Hospitals have a bigger interest these days in promoting safety and defending against risk," including the risk posed by HAIs, says Chris McCarthy, a mechanical engineer and senior vice president at Leach Wallace, whose firm has installed UVGI lamps in the new children's center at Baltimore's Sinai Hospital, at the Baltimore Washington Medical Center's new patient tower, and in parts of the central air-handling systems at Baltimore's St. Joseph's Hospital and Maryland General Hospital. "Hospitals like saying 'we have done all there is to do' to prevent or stop the spread of infection," McCarthy adds.

There is no dearth, either, of state agencies, nonprofits, professional societies, and voluntary organizations mobilized to address HAI rates. In Maryland, the MHCC, the HSCRC, the Maryland Hospital Association, and individual hospitals are upping the ante, setting progressively tougher standards for safety and quality. The Maryland Patient Safety Center, the designated state patient-safety organization and one of 25 organizations in the nation listed as a Patient Safety Organization by the federal Agency for Healthcare Research and Quality, is especially focused on reducing central line infections and MRSA.

Organizations like the Leapfrog Group, along with state governments and professional academies have begun serious efforts to develop and publicize infection-control "best practices," and publish successes and failures. Among other entities ramping up infection control, quality improvement, and patient safety are SHEA; LEED (Leadership in Energy and Environmental Design); and ASHRAE, the American Society for Heating, Refrigeration, and Air Condition Engineers.

The Leapfrog Group is a voluntary program formed in 1998 to mobilize and reward hospitals for "big leaps in health-care safety, quality, and customer value," as the organization's website describes its mission. Driven by the Institute of Medicine's *To Err is Human* report, and the desire of large employers to reduce health-care costs with evidence-based standards, Leapfrog has made infection control one of its major initiatives. Its strategy, similar to that of the Joint Commission, which asks hospitals to submit to "voluntary" inspections and "corrective actions" to improve performance, prods institutions to measure problems, solve them, audit corrective activities, and share what works with other institutions. It's a program that is big on measuring things, and a 2008 survey from Leapfrog found that 87 percent of hospitals fail to consistently practice infection-prevention measures.

SHEA was established in 1980 and has thousands of members nationwide. It sponsors research into HAI control, and produces guidebooks and resource manuals for hospitals and patients. Its popular "Compendium of Strategies to Prevent HAI in Acute Care Hospitals," issued in 2008, focuses especially on central line bloodstream infections, catheter-associated urinary tract infections, ventilator-associated pneumonia, and *C. diff*. The organization also coordinates research and outreach efforts with the Infectious Diseases Society of America; the American Hospital Association; the Joint Commission; and the Association for Professionals in Infection Control and Epidemiology (APIC), which is a 14,000 member association of "infection preventionists," physicians, nurses, epidemiologists, and lab technicians.

LEED, established in 1998 by the U.S. Green Building Council, promotes and implements a standardized rating system for the design, construction, and operation of green buildings, including hospitals. Companies and institutions that adopt green technologies can earn "LEED Credits" and certifications, a kind of third-party "validation" that adds value in

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the marketplace. In central Maryland, Baltimore Medical System, a federally qualified health center, has earned a platinum LEED rating, for example, for its commercial interiors at one of its facilities. Maryland's Health Care for the Homeless (HCH) has achieved gold LEED status for green technologies, including the installation of UVGI in its building's air-handling system in a bid to reduce airborne transmission of acute respiratory infections, prevalent in the population that HCH serves.

ASHRAE, a 50,000-member international technical society with headquarters in Atlanta, is widely considered the leading organization for establishing gold standards in heating, ventilation, air conditioning, and refrigeration (HVAC&R) building and engineering standards, including air handling and safety in hospitals and other health-care facilities. Its "seal of approval" on novel technologies is critical to the success of those technologies in the marketplace.

ASHRAE's impact on professional awareness of HVAC-R-linked HAIs is growing. In January 2012, for example, an outbreak of Legionnaires' disease—caused by the gram-negative aerobic bacterium *Legionella pneumophilia* and spread through inhalation contact with the germ in contaminated water—was traced to a Milwaukee hospital's decorative "water wall" lobby fountain. Eight people were sickened; three required intensive care and mechanical ventilators. Water walls produce sprays that can spew bacteria-filled water droplets into the air, where they are inhaled. Water collecting in the base of fountains beneath rocks and Styrofoam foundations are also a problem to clean, and some fountains are heated, adding to a nurturing bacterial growth environment. An official at the Wisconsin hospital, Aurora St. Luke's South Shore, said one piece of foam was found to house a million bacteria.

In a study of the outbreak reported in *Infection Control and Hospital Epidemiology*, a SHEA publication, a team of epidemiologists said it was the second documented outbreak of Legionnaire's in a health-care facility with a water wall. It noted that such fountains may be desired amenities, but they also are a rich environment for pathogens; and that even after rigorous cleaning with bleach and other disinfectants, people with underlying medical conditions get sick. In a widely hailed follow up, the CDC said its experts would work with ASHRAE to develop standard practices for building managers to prevent disease by either removing the fountains or adding novel technologies like UVGI to make them safer. (The Wisconsin hospital turned the fountain into a planter.)

Other organizations and professional societies with a hand in the patient-safety, infection-prevention industry include the American National Standards Institute and the American Institute of Architects, which publishes an industry bible, *Guidelines for Design and Construction of Hospitals and Healthcare Facilities*.

Arrays of devices and novel infection-control strategies have emerged from all of these groups and individual academic engineers. These include experimental and FDA-approved vaccines for hepatitis, various influenzas, and rotavirus; silver-coated and hydrogel-coated catheters designed to reduce contamination; sterile lubricant jellies to reduce transmission of catheter-related infections; and automated alerts and reminders to systematize cleaning and hand-washing behavior.

Hospitals are testing pre-operative bathing by patients themselves with chlorhexidine-soaked pre-packaged towelettes; routine screening for MRSA upon admission; intranasal and throat disinfectant sprays of patients undergoing intubation; antiseptic-impregnated endotracheal tubes; and antibiotics "locks" to fill the openings of catheters at the point where they are inserted into a blood vessel or body cavity.

It's worth noting that while many novel and green technologies are promising, some have unintended consequences. A case in point tested recently: "no touch" electronic-eye water faucets. Reducing contact between germy hands and equipment would seem to reduce germ counts. But when researchers at Hopkins actually checked, they found that electronic faucets were more likely, not less, to become contaminated with high levels of bacteria, including *Legionella*, when compared with traditional, manually operated faucets.

The faucets are increasingly popular because they use less water. But Emily Sydnor, M.D., an infectious disease graduate fellow who conducted the Hopkins study, said when she compared 20 manual faucets with 20 new electronic ones, each getting water from the same source, bacterial cultures showed that 50 percent of water samples from electronic faucets grew Legionella compared to 15 percent from manual faucets. The lopsided results persisted even after using chlorine dioxide to flush the water system. Sydnor speculates that the problem in electronic faucets may be due to contamination of the many

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parts and valves that make up their innards compared to the simpler makeup of manual spigots.

Clearly, health-care industries are paying attention to HAI. But equally as clear is that consistent use of standard disinfection; efforts to accurately measure rates of infection; and useful comparisons of cleaning strategies, technologies, and protocols are a "sometimes" thing. Consequently, there is more than enough room for additional technologies that show promise in reducing HAIs. And UVGI is certainly among the nominees.

ULTRAVIOLET GERMICIDAL IRRADIATION: THE PROMISE, THE PROBLEMS — AND A FEW PERILS

Along with other technological solutions, UVGI in the U.S. and abroad is the subject of renewed interest arising from a growing understanding that while HAIs are spread around in a variety of ways, many of the worst are of the airborne variety of infectious pathogens, all too easily transported through air-handling systems, known to mechanical engineers as HVAC (for heating, ventilation, and air conditioning) and sometimes as HVAC&R (the "R" added to include refrigeration) systems. These systems are comprised of ducts, coils, drains, pans, fans, and vents that stream and refresh heated and refrigerated air.

To stop the circulation of these bugs at the source is understandably the holy grail of any optimal infection-control strategy, so much so that the CDC and other groups now consider it standard practice for hospitals to use High-Efficiency Particulate-Arresting (HEPA) filters, usually made of randomly arrayed fiberglass fibers that, like a sieve, trap bacteria, viruses, and molds greater than 0.3 microns. If installed, cleaned, and changed properly and regularly, they can—under ideal circumstances—remove 99.7 percent of the most common pathogens that plague hospital patients, visitors, and staff.

The problem is, however, that such filters—even at that rate of effectiveness—give tens of thousands of microbes access to hospital air and surfaces. Filters also break down, and become contaminated even when regularly cleaned with disinfectants. Mechanical engineers and microbiologists have long established that disease microbes can grow in HVAC&Rs, forming biofilms on the coils that also increase the pressure drop; decrease heat transfer; increase energy consumption; and spew pathogens into room air in hospital patient rooms, operating rooms, laboratories, intensive care units, and public spaces. Once colonized with bacteria, fungi, viruses, and molds, air-handling systems become a "reservoir" of ongoing disease transmission.

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Hospitals can't even keep up with testing and sampling of biofilms . . . already on their floors, in their air vents, on tables, and on instrument surfaces, so there are few accurate baseline data to even measure results of actions they are already taking.

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As computer models provide more accurate ways to track and predict how pathogens spread through the air in enclosed spaces and ventilation systems, it is no surprise that many architects, infection-control specialists, and hospital safety engineers have embraced the potential of ultraviolet light technologies that—at least in controlled conditions in the laboratory—have achieved a 99.995 percent kill rate in HVAC&R systems when added to HEPA filters.

Today, dozens of companies offer commercial—off the shelf or customized—UVGI HVAC&R units and systems, marketing them under such trade names as Steril-Aire, Klean, Germ-O-Ray, Lumalier, Solarair, Vigilair, Biozone, Airguard Industries, Ultraviolet Devices, Medical Air Solutions, and American Ultraviolet.

In Maryland, Mt. Washington Pediatric Hospital, Sinai Hospital, Health Care for the Homeless, and Baltimore Washington Medical Center are among the organizations that have already installed UVGI lamp systems in the air-handling systems of some buildings, operating rooms, or other hospital and clinical areas. Portable units have been used in laboratories, operating rooms, and isolation wards and rooms, and to clean empty ambulances and waiting rooms in other area

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hospitals and emergency rooms.

Companies in the UVGI industry promote their technology as "green" or at least "greener" than other disinfection methods, arguing that UVGI units lower energy costs and operating costs. They say that UVGI is especially good at eliminating biofilms, the yucky coatings that collect on coils and in air ducts and vents comprised of a woven matrix of bacteria, viruses, mold, dust, and dirt.

Steril-Aire, a company based in Burbank, CA, is in many ways typical of the UVGI industry's players in that it includes infectious disease experts and engineers in the ranks and executive suite, relies heavily on testimonials for marketing, and struggles to differentiate itself in a fragmented marketplace. The company manufactures and installs UVGI emitters directly into HVAC&R systems. Although the U.S. Food and Drug Administration will not allow companies to say publicly that their lamps kill particular micro-organisms until each company publishes proof of the claims in clinical conditions—precious little data are available to that end—Steril-Aire officials say privately that its products kill all micro-organisms, "including *Legionella* and probably anthrax."

Steril-Aire also claims that UVGI is the best means hospitals have of continuously cleaning coils, drain pans, and ducts of germs, and making it safer to reclaim water from refrigeration coils and other sources that can be reused for flushing and irrigation. Its UVGI units, say company officials, also contribute to LEED certification and pay for themselves in maintenance and operation cost savings in an average of two years. In addition, the company's website contains customer testimonials and claims that UVGI reduces HAIs, cross contamination, hospital lengths of stay, and liability.

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Robert Scheir, Ph.D., a medical microbiologist who worked as a space biologist in the aerospace industry and for pharmaceutical companies, is a sales executive with Steril-Aire, and one of UVGI's most vigorous champions.

"UV technologies have been around more than 100 years," he says, "but it's only with the emergence of air conditioning systems in recent decades that an awful lot of bacteria, viruses, and molds found a nice home in their coils and drain pans."

Underscoring the various nuances, complexities, and distinctions among the myriad UVGI systems on the market, Scheir notes that old-style, traditional UV systems placed into cold moving air lose their effectiveness over time and work for only a few months before needing replacement.

THE RISKS OF UVGI

In addition to the shortcomings of UVGI mentioned previously, there are safety concerns as well. If not properly shielded, UVGI can cause ill effects because it is not blocked by ozone. Portable UVGI units in some hospital settings have been removed at the request of physicians, nurses, and housekeepers because of concerns over burns and other side effects, or are turned on only when humans are not in the line of fire.

Overexposure to all UV light, but especially the relatively high-energy UVC rays, can cause melanoma. In 2011, the World Health Organization's International Agency for Research on Cancer classified all UV radiation as a Group 1 carcinogen, meaning there is evidence to show it can cause human cancer. In addition to the cancer threat, UVC light along with other forms of UV light (UVA and UVB) have been found in various studies to damage connective tissue, accelerate skin aging, redden the skin, aggravate lupus and rosacea, and lead to cataracts. A 2009 article by scientists at the M.D. Anderson Cancer Center in Houston and the University of Texas Medical School, published in the journal *Archives of Dermatology*, reported two women who developed skin cancer on the backs of their hands from repeated exposure to UV nail lamps. Even fluorescent lamps produce damaging UV radiation by ionizing low-pressure mercury vapor. A coating on the inside of the tubes, however, absorbs the UV and converts it to visible light. (In UVGI systems, there are protective mechanical coverings, but to prevent harmful exposure, people need to be

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out of the room or distant from the units when they are in use.)

Notwithstanding such largely preventable risks, the more pressing problem facing the UVGI industry's lack of wider acceptance in hospitals, according to Kowalski and Bahnfleth, is that unlike water and equipment disinfection applications, "the disinfection of air streams using UVGI has a history of varying success and unpredictable performance." Despite testimonials and a century worth of laboratory tests showing that UVGI kills the DNA of disease germs, the published, peer-reviewed data are relatively scarce, they note, and the results are often flawed or ambiguous. Some are very positive; none is a deal breaker; but most contain serious caveats. Here's a sampling:

- Industrial scientists at the University of Tokyo, in a report published in 2010 in the ASHRAE journal *HVAC&R Research*, tested the disinfection performance of UVGI systems for microbial contamination on an evaporative humidifier. Bacteria and fungi were isolated from the surfaces and drain water of the humidifier, and airborne microbes coming from the contaminated unit were identified. After using UVGI in the humidifier's duct works for six months, the researchers reported that "microbial contamination was reduced," but microbes could still "consistently be isolated from the surfaces and drain water. This was likely due to internal contamination of the humidifier beyond the reach of the UVC band irradiation."

- In an article published in the *Journal of Perinatology* in 2011, researchers described a pre- and post-UVGI intervention study in the neonatal intensive care unit (NICU) at The Women and Children's Hospital of Buffalo. The scientists set out to test the hypothesis that enhanced UVGI installed in the NICU heating ventilation and air condition system would decrease microbes, and tracheal colonization and ventilator-associated pneumonias among the high-risk infants in the unit. The team concluded that UVGI "was associated with reduced NICU environmental and tracheal microbial colonization," but also cautioned that the study was limited by the fact that the children could not be randomized, i.e., separated into groups that were treated in UVGI beds and not treated in UVGI beds. The authors of the study, one of whom is married to the former CEO of Vigilair Systems, also noted that "concepts of airborne transmission of hospital infection are evolving," and that "often overlooked" is the capacity of microbes to undergo "genetic repair and secondary rehydration with ambient humidity that virtually ensure spread of disease…."

- In a study of UV light used to disinfect hospital water, Barry Farr, M.D., an epidemiologist at the University of Virginia Medical Center, collected 13 years' worth of information on rates after a new hospital opened with UVGI systems in place. Some 27 percent of water samples from taps in the old hospital contained the bacteria. Not a single one of the 930 cultures of new hospital water taps (as of 2003 when he published the study) were positive for *Legionella*. Although some patients developed the infection, none was from hospital water, and most were brought into the hospital. Farr and his team concluded that "ultraviolet light usage was associated with negative water cultures and lack of clearly documented nosocomial *Legionella* infection for 13 years at this hospital."

- In a study in a tuberculosis ward in Lima, Peru, researchers from the Wellcome Trust Centre for Clinical Tropical Medicine at Imperial College London in 2009 hung UVC lamps in areas housing 69 patients undergoing treatment for HIV and TB. Researchers pumped air from the ward up to a guinea pig enclosure on the roof of the hospital for 535 consecutive days. The guinea pigs were split into three even groups: The first got air exposed to UV lights; the second got air treated with negative ionizers, air purifying equipment that uses high voltage to electrically charge air molecules and essentially manufactures static electricity to trap particulates; and the third got untreated air straight from the TB ward. The guinea pigs were skin-tested monthly for TB antibodies. By the end of the experiment, 35 percent of the guinea pigs exposed to direct ward air got infected, compared to 14 percent of the ionized air group and 9.56 percent of the UVC-exposed group. The team concluded that UV lights could reduce the spread of TB in hospital wards and waiting rooms by 70 percent. (TB is a classical airborne infection, mainly spread when an infected

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person coughs, and the bacteria responsible for the lung disease are sprayed into the air, from where they are inhaled by others.) Although transmission of the disease germs was not eliminated, on the basis of the study findings, the researchers were planning to install upper room UV lights in the chest clinic at St. Mary's Hospital in London, the first such installation in the UK.

- In a presentation at the 2011 APIC meeting, researchers at Highland Hospital, a 260-bed community teaching facility affiliated with the University of Rochester Medical Center in New York, reported use of a portable UVGI device that employed mirrors to reflect UVC emissions around patient rooms. John Boyce, M.D., clinical professor of medicine at Yale University, and William Rutala, Ph.D., director of the Statewide Project for Infection Control and Epidemiology at the University of North Carolina, had, in a previous study, shown the device to be effective against *C. diff*. The Rochester hospital had 18 years' worth of rigorous data on hospital- and community-acquired *C. diff*, and during the first quarter of 2009, experienced its highest rate of the infection, 2.2 per 100 patient days. This rate amounted to 42 cases and three deaths. At the time of the study, the group had already tried all of the SHEA Compendium prevention strategies but to no avail. For the study, the hospital first closed the unit with the highest incidence (11 cases against an expected three cases, and two deaths), and "terminally cleaned" each room with bleach. Then each room was cleaned again with a portable UVGI machine moved around in a priority fashion based on the incidence of *C. diff*. Each treatment lasted 45 to 60 minutes, depending on room size. Results showed that in the three months following the use of the UVGI equipment, the *C. diff* rate dropped to 16 per 1,000 patient days. And in the following quarter, it dropped to 0.8—the lowest documented rate in 10 prior quarters. The number of cases that arose during hospitalization dropped from 14 to eight after UV treatment. Despite the success, the team acknowledged that successful UVGI implementation required "intense coordination between nursing, cleaning services, and admitting," and that special education and reassurance for patients, visitors, and health-care workers were needed because of the ozone-like odor generated by the treatment. The team also concluded that the UV replacement bulbs, while relatively cheap, had to be replaced and cleaned frequently to ensure they were intense enough to kill microbes. And it also emphasized that "stringent safety measures must be in place to protect patients and health-care workers from inadvertently entering the room during treatment with portable units." The investigators probably could not rule out that the bleach used in the primary cleaning muddied the results. In sum, they said, "Portable UV light is not meant to be a stand-alone intervention, but rather another tool in our prevention tool belt."

- Muskogee Community Hospital, a rural, 45-bed facility in Oklahoma, installed a custom-designed Steril-Aire system to sterilize all seven of its operating rooms and procedure rooms each night. The hospital president, Mark Roberts, said the hospital bought the unit based on evidence from the use of portable UVGI systems, and used the lights after regular business hours for eight hours per room per day, admittedly without any clear sense about whether they would work. Evidence that the lights were working came later from a study by the Oklahoma Hospital Association, which found zero HAIs in the hospital throughout a 21-month period. Small hospitals in Buffalo, NY; Bucks County, PA; Florida; and Orangeburg County, SC, have also installed the units.

- In a study of factors affecting "upper room" or ceiling level UVGI, a team of investigators from the Harvard School of Public Health's Department of Environmental Health used a room-sized simulator to test the value of UV lamps against nebulized *Serratia marcescens, Bacillus subtilis* spores, and vaccinia virus. They concluded that the UV power level had a strong influence but was only fully effective in the presence of air mixing that produced vigorous vertical air currents. Countering the notion that UVGI is a quick or easy fix for HAIs, the team said, "…upper room UV installation is a complex system that requires careful integration of UV luminaires, UV power, and room ventilation

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arrangements." In short, there is a need for ideal controlled conditions, which are rarely present in hospitals.

- A 2002 study by researchers under contract with the National Institute of Occupational Safety and Health, a division of the National Institutes of Health, looked at the efficacy of UV irradiation in controlling the spread of TB. (Again, TB is a classic airborne infection, and thus an ideal candidate for HVAC&R UVGI treatment studies.) Considered by many to be the only truly controlled trial of UVGI in a physically realistic setting as of 2010, this study was conducted by investigators from the University of Colorado, and led by Shelly Miller, a Ph.D. in mechanical engineering. Over a six-year period, Miller and her team re-created a hospital setting, using mannequins as patients, to test the value of UV light in reducing health-care workers' exposure to TB infection. The study was designed to take into account the impact of in-room distribution of airborne TB bacteria, and the effects of room air circulation, ventilation, and humidity on UVGI's ability to inactivate the bacteria. The study also looked at the effects of air mixing at a variety of different intensities. The researchers used new commercially available UVGI fixtures, consisting of five lamps—four mounted in each corner of the room and a fifth in the center of the ceiling. The mannequins were heated to human body temperature to re-create one of the subtle factors that influences air movement in a room, and affects the amount of bacteria that comes into a breathing zone. Results showed that increasing the irradiance level of UVGI lamps increased effectiveness, and that the effects of UVGI were "dose related," meaning results varied depending on light intensity. The researchers also found that high relative humidity lowered effectiveness; and that when warm air came in via ducts near the ceiling (as in winter), the warm air simply rested on the cooler air below and UVGI worked "dramatically" less well. As with other studies, this one also found that optimal UVGI results are difficult to obtain in "real life" settings.

- In 2007, due to concerns among orthopedic staff about unspecific skin and eye symptoms, officials at Brigham and Women's Hospital in Boston asked NIOSH to review the safety of UVGI lamps mounted in the ceilings of some operating rooms. As a result of the review, the hospital ultimately moved its orthopedic operating suite to an area with laminar airflow, and stopped using UVGI for intraoperative infection control. Orthopedic surgeries are often unusually lengthy. NIOSH and other agencies have reported it is best to use other means of disinfection for such purposes.

Perhaps the best summary of the seesaw of evidence for and against the value of UVGI is found in a 2010 report in the *American Journal of Infection Control* in which researchers from the National Institutes of Health reviewed a plethora of studies of

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Results of one study showed that increasing the irradiance level of UVGI lamps increased effectiveness, and that the effects of UVGI were "dose related," meaning results varied depending on light intensity.

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UVGI disinfection in health-care facilities, some noted above. The review concluded that "the balance of scientific evidence indicates that UVGI should be considered as a disinfection application in a health-care setting only in conjunction with other well-established elements, such as appropriate heating, ventilating, and air conditioning systems; dynamic removal of contaminants from the air [i.e., HEPA and other filters]; and preventive maintenance in combination with thorough cleaning of the care environment." The authors wrote that although UVGI is microbiocidal, it is not "ready for prime time" as a primary intervention to kill or inactivate infectious micro-organisms; "rather it should be considered an adjunct." Moreover, the NIH team concluded that factors such as the

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design of facilities, the installation and operation of the HVAC system, and attention to traditional cleaning and disinfection are all confounding factors in measuring the impact of UVGI and "must be assessed before a health-care facility can decide to rely solely on UVGI to meet indoor air quality requirements for health care" and certainly to reduce infection transmission. Finally, the team called for "more targeted and multiparameter studies" to evaluate the "efficacy, safety, and incremental benefit of UVGI for mitigating reservoirs of micro-organisms and ultimately preventing cross transmission of pathogens that led to HAIs."

In a review of the promise and limitations of UVGI published in 2004 in the journal *Managing Infection Control*, David Shagott, an engineer and founding president of Abatement Technologies, lends industry support to the NIH view, concluding that UVGI "can complement …other infection-control measures," adding protection for isolation rooms, labs, morgues, and autopsy rooms. And notably, the CDC's 2003 *Guidelines for Environmental Infection Control in Health Care Facilities* state that "as a supplemental air cleaning measure, UVGI is effective in reducing the transmission of airborne bacterial and viral infections in hospitals…[and] can be placed in [air] ducts as an adjunct measure in HEPA filtration but …cannot replace the HEPA filter."

Tellingly, many commercial experts—even those who want to see broader use of UVGI—are hard put to disagree, although they are more likely to bring up the "catch-22," which, they say, occurs when trying to fulfill the demand for those "more targeted and multiparameter studies."

One problem, Steril-Aire's Scheir acknowledges, is that most of the testing done to prove the killing ability of UVGI is done in the laboratory under ideal conditions, and that it is virtually impossible or prohibitively costly to faithfully reproduce conditions that reflect the infectious environment in a given hospital on a day-to-day basis.

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Understandably, many of the experts interviewed say hospitals want peer-reviewed studies and published proof of UVGI's added value, and are reluctant to move toward UVGI without such evidence, not least of all because of the expense involved.

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Another problem, he says, is that it's difficult to get access to all strains of the organisms companies want to test. (Think anthrax.) And a third is that even if studies could replicate the "real world" of hospital air handling, outcomes based on "before and after" measurements of pathogen counts are complicated by hospitals' reluctance to share infection risk data, and their simultaneous use of other disinfection technologies and traps (like HEPA filters, chemicals, hand washing, and alcohol gels). Hospitals can't stop using these evidence-based cleaning protocols owing to ethical and regulatory guidelines for patient and worker protection.

Understandably, many of the experts interviewed say that hospitals want peer-reviewed studies and published proof of UVGI's added value, and are reluctant to move toward UVGI without such evidence, not least of all because of the expense involved.

One satisfied customer is Earnie Standley, director of facilities management at Baltimore's Mt. Washington Pediatric Hospital, who was involved in hiring Chris McCarthy and Leach Wallace to install UVGI in a renovation for an infant unit at the hospital.

"We looked into evidence-based facility design and came across the available information on exposing circulating air to UV light's short wave length germicidal action," says Standley. "We have babies here with immune suppression and at high risk of bacterial, viral, and fungal infections, and wanted to go the extra mile." Before the renovation, the unit had "standard filtration with HEPA filters, and he acknowledged there "were never any problems with that." But with the renovation "there was the opportunity to try the new technology," although the hospital did not abandon HEPA. Currently, Mt. Washington uses both HEPA and UVGI, and as yet has no data on whether infection rates or cultures of various infectious agents will show a reduction. "It will take a year or so to get those data," says Standley. "We're hoping UVGI will show reductions in

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HAIs, and we're pleased that the UVGI involved was not much more expensive than HEPA."

OTHER NOVEL TECHNOLOGIES

Although UVGI is the main focus of this Abell report, other relatively new technologies are being investigated and used. Chief among them is hydrogen peroxide vapor, or HPV. Hopkins' Perl notes that HPV is reliable for bacterial kills, and effective for all surfaces, but it takes one to two hours or more to work, and is relatively expensive.

Some hospitals in Maryland are using HPV to treat equipment after contamination, but others are using it preventively. Data show substantial reduction in contamination in the incidence of *C. diff* and VRE outbreaks.

Less high-tech novelties include regular auditing of mattresses to keep colonies of MRSA and *C. diff* at bay. Makary, the Hopkins surgeon, conducted a study showing that something as simple as properly positioning "red bag" trash waste containers that make it easier for surgeons, nurses, and clean-up crews to put contaminated waste in the right receptacle can save big bucks in every major hospital.

Hospitals are also experimenting with other tactics, including antimicrobial surface coatings, single-patient rooms, and emergency-department entrance alternatives for infected patients designed to reduce cross contamination. Motion-sensor room lights and doorways not only save energy costs in hotels, but they also reduce infection transmission in hospitals, and according to a Health Technology Center study in 2007, going green is trending upward nationwide as a result. "The high cost of energy and operations, coupled with increasing environmental consciousness, has elevated the importance of green design for health-care facilities," says Molly Coye, M.D., CEO of Health Technology Center.

Hospitals are also increasingly emphasizing green cleaning to not only prevent infections, but to also increase patient satisfaction, as many cleaning agents produce unintended annoying or harmful effects on human health. Disinfectant chemicals, in particular, may increase asthma and skin problems, and damage ecosystems, water sources, and plastic surfaces. The Center for Health Design and Health Care Without Harm has partnered with Healthier Hospitals Initiative, for example, to launch research projects at Dartmouth Hitchcock Medical Center, Cleveland Clinic, and other institutions to test the use of green cleaners with fewer harmful ingredients. Maryland has an active Hospitals for a Healthy Environment initiative based at the University of Maryland School of Nursing. Just the practice of pouring chemicals on cloths, instead of spraying them on, can reduce indoor air pollution. Architects are even designing new hospitals that reduce horizontal surfaces, and use more movable furniture to make cleaning easier.

There is also another technology on the horizon for controlling the most intrepid hospital infections: rapid genetic sequencing of deadly bacteria to track delayed or complex transmission routes and environmental contamination. A recent report in the journal *Science Translational Medicine* described one example at the Clinical Center of the National Institutes of Health in Bethesda.

A woman was admitted to the hospital with *Klebsiella pnemoniae,* and although the strictest forms of infection control were used to prevent it from spreading, 17 patients got it, and six of them died. Infection-control officers were desperate to learn not only how the bacteria escaped infection controls, but also how to stop it. Using rapid genetic sequencing, they determined the genetic makeup of the original bacterium in the woman and learned that the chain of transmission was wiley, and that the germ managed to infect people in an undetectable way for weeks—so that in effect, it had a long latency period.

Not many places have the expertise and tools to perform rapid genomic sequencing, but this case clearly demonstrates that a) even strict infection-control standards aren't always enough to prevent contamination; b) infections can exist without symptoms for long periods of time, and can be undetectable even with the usual "culture swabs" from the throat or groin; and c) the bacteria was so environmentally stable that it persisted in sink drains even after disinfection. In fact, the hospital had to remove plumbing to get rid of the bacteria, and employ specialized testing on every patient to rule out infection transmission.

BARRIERS TO WIDER USE OF UVGI

As suggested by the research reviews cited earlier, it is almost universally the case that experts in engineering, infection prevention, and hospital risk management currently consider UVGI as, at best, a supplement to HEPA filtration and other more orthodox means of cleaning

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hospitals and reducing HAIs. But the same experts, with often-equal unanimity, agree that much can—and should—be done to break down the barriers to increased application of UVGI technology.

The main barriers, they say, can be categorized as commercial, regulatory, engineering, practical, scientific, safety, regulatory, cultural, and, for want of a better term, philosophical. Each category poses distinct challenges.

Commercial/Industrial Practicalities

UVGI engineering expert William Bahnfleth summarized this challenge by noting the relative absence of UVGI industrywide standards that support the application and use of UVGI. Just as with television sets, automobiles, and other successfully mass-marketed appliances, UVGI systems need some standardization to allow for confidence in, and consumer understanding of, the power and design of UVGI components. Standardization is also needed for installation and retrofitting, equipment monitoring and replacement protocols, maintenance procedures, and hospital staff training.

Companies, say Bahnfleth and Kowalski, can compete effectively in terms of quality, lamp life, and ease of installation and maintenance, for example, but as the industry stands now, there is too much emphasis on the proprietary aspect and not enough cooperation to allow for meaningful comparisons of technology, price, and value.

A few years ago, according to Kowalski, the International UV Air Treatment Group tried to get all the engineering, infection-control, and design and commercial stakeholders together to formulate standardized guidelines, but efforts stalled for years, with companies suing each other over patent infringements. There are some relatively standardized guidelines available, but they are not universally accepted, nor are they officially blessed by CDC, NIOSH, AIA, or ASHRAE.

Bahnfleth and his co-authors in the 2008 review article were clear that "although application support for UVGI technologies is growing, and many successful systems have been installed, there are still no industry standards for rating the effectiveness of UVGI devices and systems." Citing a recent Environmental Protection Agency publication, Bahnfleth said the most important next steps in moving UVGI along "are industry standards to rate devices and installations, as well as guidance for maintenance." ASHRAE now has standing committees working to bring UVGI makers together for that purpose, but it will be some time, he says, before the industry agrees to testing standards or design principles "applicable to all UVGI systems." Until that time, say Bahnfleth and Kowalski, systems should be sized and designed using the best available information and guidance from ASHRAE handbooks to lend some measure of standardization to HVAC&R units.

For hospitals that want to try novel technologies for HAI reduction and greener cleaning, however, that advice falls short of what many need to part with their dollars and give up the security of HEPA and other proven technologies. In short, they need standardization and predictable reliability. Moreover, the absence of these standards creates significant confusion not only within the UVGI market sector, but also among competing technologies.

"There is an explosion of companies, some green and with novel technologies, offering new ways to prevent HAIs, including UV lights," says Peter Pronovost, whose focus on evidence-based safety protocols and systems is too often blurred by industry marketing techniques. "I am pitched frequently by those promoting one system or another." He recalls that just recently, "a company presented information about a coating you paint on hospital walls, or apply with mists, sprays. Another promotes anti-infective polymers attached to spikes or nails that can be hammered into walls, a technology that the company says disinfects for 90 days and kills MRSA. Another one sells a coating for surfaces that turns purple in the presence of MRSA, and scrubs and exam room curtains with anti-infective technology built in. Why wouldn't I want to buy any of these? Because I have no idea which ones—even within a category—are best. No one knows. There are no reliable, up-to-date standards or head-to-head comparisons, which are needed when resources are not unlimited. There's no question that UV light kills germs, but controlled clinical trials with them are scarce. If I get pitched 20 good ideas, which one do I spend my nickel on?"

On the subject of standard designs and integrated systems, Pronovost is almost apoplectic with frustration. "You know," he says, "if an airline wants to build a new plane, it doesn't order the wings from a company that doesn't talk to the company building the fuselage or the engine or the hydraulics or the landing gear. The airline goes to a systems integrator to not

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only assure the selection of the best technologies, but also to make sure all the parts fit and work together smoothly with each plane's design in order to optimize safety and maintenance."

Hospital engineers, facilities managers, infection-control specialists, and safety officers likely have neither the time nor the resources to test "each widget separately," Pronovost says, although he does think that academic medical centers with broad expertise in infection control and safety could play a bigger role as "learning labs" to test systems in a simulation center. "What we have here with UVGI, I think, is market failure. Companies need a place to test but also to work with integrators. That's why hospitals may not be adopting these technologies more quickly."

Chris McCarthy, the senior VP at Leach Wallace engineering firm, which has installed UVGI in Maryland hospitals, understands the dilemma faced by hospitals that want to try new technologies. "They have to see it to believe it," he says, "and HEPA is a solid choice, especially if an institution can't afford custom or semi-custom installations." The costs and uncertainties, McCarthy says, make it hard for them to try UVGI, and frankly, he adds, most of the prepackaged HVAC equipment can't accommodate the UVGI lamps. "So unless an institution can afford a custom-built HVAC system," he says, "UVGI isn't going to make it in. There is no standard HVAC system I've seen that can accommodate existing lamps."

Anatoly Gimburg, director of facilities at Hopkins, played a large role in developing infection control and other safety design features for the new $1.1 billion Johns Hopkins Hospital buildings. He summed up the concerns of his colleagues well when he noted that "we looked at UV light [for the new buildings], but the problem is that other technologies are better known and standardized, and with UV light, if something happens to the lamp or the power, you could be unprotected for that time. We decided for air handling to stick with HEPA filtration."

Particularly during a recession, the cost of satisfying regulatory requirements for new technologies is a serious issue, but Scheir and others in the industry are frustrated by the general unwillingness of the health-care industry, along with the NIH, to fund more studies of UVGI's potential.

McCarthy agrees that as things stand now, UVGI is "one more thing hospitals can do, not a replacement." He explains that, "chlorine tablets in air refrigeration drain pans work, too, and although with UVGI, nothing will grow, institutions still for the most part don't see the benefit in doing the more expensive thing even when maintenance crews like the idea of an easier way to keep things microbe free. It's an up-the-chain issue. Custom systems cost three times more than conventional air-handling systems."

Regulatory

Regulatory problems with UVGI remain an issue, according to almost everyone interviewed for this report. The CDC, for example, has become a notable target, criticized for being too slow to put its investigatory power to work on behalf of UVGI and other new technologies. So far, according to UVGI research engineer Kowalski, the CDC has only chosen to seriously examine UVGI's effect on TB control. "Eight different CDC guidelines address UV in positive ways, but sometimes in negative ways," he says. "The hope is that CDC, as a lead agency on infection control, would champion more rigorous research against other pathogens and UVGI, the way it did for TB. That would move things along more quickly."

Particularly during a recession, the cost of satisfying regulatory requirements for new technologies is a serious issue, but Scheir and others in the industry are frustrated by the general unwillingness of the health-care industry, along with the NIH, to fund more studies of UVGI's potential. The bottom line is that "hospitals are very conservative about infection control," according to Gimburg, "and although we test some technologies, federal and state regulations block our ability to easily swap out old technologies for new. We need to go through many liability hoops and spend a lot of money and effort to

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prove we are not making city water or patient safety worse. HEPA filters are included in many code regulations and because UV light is not included in those codes for hospitals, we can't justify it."

Hopkins' Trish Perl, who is also the former SHEA president, says, "UV light is reliable for bacterial kills, good for all surfaces, and relatively quick, but there are huge cost and sustainability uncertainties, and a lack of clinical trial data." She adds that at Hopkins, transmission of bugs through air handling is far less a worry than what happens on surfaces and on walls, and UVGI is only effective in such settings when in direct contact with contaminated surfaces, with all the attendant safety and operational concerns such irradiation brings with it. "It's not that hospital epidemiology and infection-control officers are disinterested in UVC, but we must go where the biggest problems are for us. Transmission through air handling is far less a worry in the big picture. Much more worry is what is happening on surfaces."

Engineering

Kowalski, Bahnfleth, and other engineers who have spent their professional lifetimes working on improving UVGI, agree that while the concept of incorporating UV light-emitting systems into HVAC&R has been relatively well defined, many engineering details required for installation and implementation remain complicated because of the high variability of each hospital's air-handling systems, building designs, geography, and patient population.

Among the technical engineering elements always in need of consideration for UVGI to work, says David Shagott of Abatement Technologies, is the distance between UVGI lamps and the pathogens that are their targets: To kill pathogens, they must be captured within a relatively close and closed-in area, and those distances vary among species. Other factors include proper calculation of the intensity of the UVGI lamps and length of exposure required in a particular situation, which vary enormously from one product to another.

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In addition to the health hazards already described, UVC radiation also poses a threat to plastics, rubber, and insulation around wiring and other equipment because of its ability to break down chemical bonds.

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Mechanical engineers and building designers also have concerns with the complexities of both "upper room" and in-duct fixtures. The upper room units—which according to Shagott, look "like an upside-down fluorescent light fixture"—are supposed to irradiate the air at or near the ceiling without exposing persons below. But "they rely on consistent, measurable, and modifiable air currents to bring the pathogens in close enough proximity to the lamps to kill them," he says. From an engineering standpoint, it is probably best to attach the units to HEPA filtration, but this can't always be done without ripping out, replacing, or expensively retrofitting HVAC&R systems. In-duct UVGI lamps installed in HVAC&R systems have their own difficulties: They are often harder to inspect, service, or replace without disturbing ceiling tiles or other mechanical parts.

In a 2001 article in *Environmental Engineering Policy*, Christopher F. Green and Pasquale V. Scarpino, of the Department of Civil and Environmental Engineering at the University of Cincinnati, noted that the "efficiency of UVGI units depends largely on other engineering controls designed specifically for each site," and that the opportunities for mismatches and "leaks" in the systems are literally endless.

"Although it is clear that UVGI can be effective in test chambers," according to Nicholas G. Reed of the U.S. Army Center for Health Promotion and Preventive Medicine in a 2010 *Public Health Reports*, "engineering specifications for a given room application [of UVGI] remain elusive and are currently based more on common sense and historical practice than on actual evidence."

Safety

As noted earlier, exposure to UV radiation during disinfection continues to pose challenges for hospitals. With portable units, rooms can be cleared; however, in some institutions, patient rooms and ORs are at a premium and

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cannot always be taken out of circulation for treatment. During lamp maintenance and replacement, exposure is also a threat to maintenance crews who work close to the units, and equipment breakdowns can occur.

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Research and Scientific Issues

In a review article in the June 2010 issue of the *American Journal of Infection Control*, a blue ribbon team of specialists and patient safety experts from the National Institutes of Health; the St. Joseph Mercy Health System in Ann Arbor, MI; and Epidemiology Consulting Services, wrote that "most of the experimental data that led to the development of UVGI systems [and used for the reviews] were decades old. Aside from anecdotal observations, little information about the actual performance of these systems in hospital rooms was available…."

The authors went on to say that, to date, most of the existing evidence was collected "under simulated conditions that are generally more ideal than what is to be found in everyday operations of hospitals." Authors Farhad Memarzadeh, Russell Olmstead, and Judene Bartley also noted that even small air pressure differences, induced by air temperature changes and mechanical fans, complicate the efficacy and efficiency of UVGI and the movement of airborne pathogens in and out of the room, and around patients, caregivers, and visitors. Moreover, depending on the pathogen, survival times under various conditions—including outside air temperatures and humidity—vary enormously, making the value of UVGI "extremely series dependent."

Further, they said, "tests to determine the relative sensitivity of microorganisms to UVGI are not standardized among laboratories and thus difficult to rely upon." Guidelines are needed to determine the most practical method for planning effective UVGI systems in a variety of rooms or areas and "many marketing claims suggesting UVC systems…have not been substantiated…" against a variety of germs.

Along with the scarcity of rigorously controlled clinical trials of UVGI in realistic hospital settings, scientists are seriously worried about the inability or unwillingness of hospitals to accurately measure pathogen loads in various hospital settings. In the absence of such details—which bugs are most prevalent where, which germs are mutating, and which are the biggest threats in micro-environments—it's hard to know which technologies are best, and when supplemental treatments such as UVGI might significantly contribute to HAI reduction. As Perl states, "if you don't know where you are, it's hard to say where you want to go or how to get there."

Martin Makary, Hopkins surgeon and author of *Unaccountable: What Hospitals Won't Tell You,* recently conducted a study suggesting that U.S. patients would be far better serviced by national standards for hospital infections tolerance, and that more publicity about infection rates would boost a variety of efforts to reduce them, pressuring hospitals to conduct more rigorous measurement of their own problems, and adopting or intensifying existing technologies to reduce the prevalence of infection.

Perl, Scheir, and other infectious disease experts also report that more research needs to be done on the capacity of some bacterial cells to reactivate once exposed to visible light after UVGI treatment, as well as on what might be done to reduce the risks of allergic and hypersensitivity reactions to many microbes even when they are killed and rendered noninfective by UVGI light. Their dormant or dead shells contain antigens that, like the dead skin and fur that make up animal dander, can continue to cause such reactions. Combining UVGI with HEPA filtration takes care of a lot of the problem, but also begs the question as to why HEPA filtration alone is not enough in many hospital applications.

To be sure, progress is being made in both useful research and codification of knowledge. Wally Kowalski recently published the book *Hospital Airborne Infection Control*, which tabulates microbe counts and evaluations of suitable technologies for each of the 20 traditional airborne infections as well as the infections that in recent years have been recognized to be transmitted and spread in the air, even though they are not classical airborne infections such as measles and TB. Others in his field consider the compendium a tool that should make it easier to match up infectious disease risks and evidence-based solutions.

Nevertheless, as Kowalski himself says, far more research is needed to convince hospital epidemiologists and administrators to embrace UVGI. "It's easy," Kowalski says, to show that UV kills microbes in air, on surfaces, and in water, and that it reduces airborne concentrations of microbes.

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"What's hard is to demonstrate a statistically significant reduction in disease *prevalence* as a result. That has been done in office buildings, but not yet in hospitals. CDC would *have* to take notice of a hospitalwide study of air ducts, but no companies have done this and no institutions have."

RECOMMENDATIONS

Sources interviewed for this report acknowledge that breaking down the barriers to wider use of UVGI will require resources, time, and cooperation within the UVGI industry, and between the industry, hospital and infection-control interest groups, and regulators. As for a list of "priority steps" they would like to see taken, or taken further, they mostly agreed on the following:

- Intensified efforts to achieve some national standards for component design, testing, and training within the industry, assisted by ASHRAE and other professional societies and organizations.
- Greater transparency about the specifications of their technology among UVGI manufacturers to facilitate competition with other clean HAI-reducing technologies and strategies.
- Coordination among industry and health-care experts to seek support from the NIH, CDC, and NIOSH for simulation studies and hospitalwide demonstration projects.
- Coordination of efforts to seek public and private organization research grants to advance comparative effectiveness studies and fill in gaps in knowledge about optimal UVGI use.
- Performance of head-to-head studies comparing various UVGI equipment, and comparing UVGI to other disinfection and sterilization techniques.
- A commitment by UVGI experts across disciplines to develop public awareness and education programs about the benefits and risks of UVGI.
- Wider information sharing among hospitals and with the public of hospital infection rates and efforts to monitor them.
- Sharper focus by the industry on the "supplemental" value of UVGI, as opposed to its "standalone" value.
- An industry commitment to fund and support rigorous research of UVGI technology claims, submitted for peer review and publication.
- Commitment to conducting cost-effectiveness research.
- Increased focus on research that not only demonstrates microbial kills, but also demonstrates a direct impact of UVGI on reduced HAI rates, controlling for other confounding factors such as traditional disinfection.

Whether or not the UVGI industry, hospitals, regulators, and agencies act on these recommendations anytime soon, those who know the most about UVGI share the view that without such action, UVGI is unlikely to become a top choice among those charged with reducing HAIs.

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