Hospital infection control: Ultraviolet germicidal irradiation's role in the war against infectious diseases

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UV-C energy can fortify hospital defences against infectious diseases by reducing their concentrations without increasing their resistance to medicines.

1. Introduction

Each year, more than two million people in the USA contract a hospital-acquired infection (HAI) that can also be antibiotic-resistant. In 2013, these infections resulted in at least 23,000 deaths.[1] In fact, HAIs, kill more people than AIDS, breast cancer and automobile accidents combined. Emerging diseases—such as sudden acute respiratory syndrome (SARS) and Middle East respiratory syndrome (MERS)—demand vigilance from the managers of healthcare facilities to protect external contract workers, facility staff, patients and visitors from the spread of the causative pathogens. There is, essentially, a war being fought on three fronts of infection control: HAIs, antibiotic-resistant microorganisms and emerging diseases.

Engineering for infection control systems in healthcare facilities plays a pivotal role in fighting this battle. Guidelines exist;[2] however, no single guide encompasses all of the information—including the successfully-tested suggestions—engineers will need.

Because ultraviolet germicidal irradiation (UV-C) kills all known microorganisms, it has attracted attention as an engineering solution to the problem. This article outlines some basics of infectious diseases and points to engineering-level guidance for continuously reducing or, in some cases, preventing infectious pathogens from growing on or circulating in hospital spaces and heating, ventilation and air-conditioning (HVAC) systems using UV-C.

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[1] US Department of Health and Human Services, Centers for Disease Control (CDC), *Antibiotic Resistance Threats in the United States* (2013).

[2] E.g., *Ventilation of Health Care Facilities* (ANSI/ASHRAE/ASHE Standard 170-2013).

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2. Basic background

It helps to know pathogen types and how they are manifested as diseases (their aetiology), which includes virulence (how they affect people); transmission (how they're spread), and which interventions are shown to work best for which diseases.

2.1. Types of pathogens

We'll focus on two types of pathogens that are of concern—bacteria and viruses.

- **Bacteria.** Bacteria inhabit soil, water, humans etc. and are responsible for strep throat, urinary tract infections and tuberculosis to name a few. A growing issue with bacteria is their resistance to available drugs, and those manifesting such resistance are known as antibiotic-resistant microorganisms (ARMs), such as MRSA (methicillin-resistant *Staphylococcus aureus*).
- **Viruses.** Viruses are small infectious agents that replicate in the living cells of other organisms such as in humans, animals and plants. They are typically smaller than bacteria, and are difficult to treat with drugs. Viruses include Ebola, coronaviruses (e.g., Enterovirus D68), and those responsible for SARS, MERS, colds and 'flu.

2.2 Transmission

This basic knowledge provides a foundation to design interventions that intercept or interrupt, and therefore reduce, the risk and spread of infectious agents. There are many forms of transmission; they include (but are not limited to) the following:

- **Direct contact:** Physical contact and transfer of microorganisms occurring during hand touching, kissing and contact with blood and other bodily fluids;[3]
- **Indirect contact:** Contact with a contaminated surface, such as doorknobs, bed rails and medical instruments;[3]
- **Droplet contact**: Infested droplets generated by an infected person by breathing, coughing, sneezing or talking, and directly reaching another person's eyes, nose or mouth. Droplets can also be generated during bronchoscopy, surgery, autopsy and other medical procedures;[3]
- **Airborne transmission:** Droplet nuclei and/or residues from evaporated droplets or dust particles containing microorganisms, all of which can remain and survive suspended in air for long periods of time, and some are resistant to drying out (e.g., as spores);
- **Faecal–oral transmission:** Digestive tract microorganisms can be spread to food, water or medicine and ingested by another person, or spread through indirect contact with flushing toilets and medical instruments;
- **Close contact:** A term used today to signify the means of transmission of the Ebola virus. According to the Centers for Disease Control (CDC), "close contact" includes: caring for or living with an infected person; having direct contact with a patient's respiratory secretions or

[3] Mt Sinai Hospital Dept Microbiology (http://microbiology.mtsinai.on.ca/faq/transmission.shtml, accessed 6 October 2014).

bodily fluids; sharing eating or drinking utensils; or touching someone directly. Close contact does not include walking past a person or briefly sitting across from a person in a waiting room, for example. For other airborne infectious diseases, the concept can be generalized to the statement that the longer an individual is exposed to a nearby infected patient, the greater the chance of transmission. Hence, sitting immediately next to an infected person for two hours on an aeroplane makes transmission more likely than standing next to the same person for two minutes in a queue at the post office.

2.3 Virulence, infectiveness and treatability

Virulence is the potential to impact an infected person's health, including mortality rate (how many people die after becoming infected). Apart from pathogen specifics, virulence depends on many person-specific factors, including age, health, vaccinations and the patient's access to healthcare.

Infectiveness is a disease's ability to spread. The term "reproduction number" (R_0) is used to numerically rate the infectiveness. The higher the R_0, the more contagious the disease.

Treatability is an informal term signifying the difficulty of treating an infection with vaccinations or medicines. Viruses are difficult to treat; and bacterial infections formerly treatable with antibiotics are now mutating into multidrug-resistant forms.[4]

3. The war

As previously mentioned, the war against diseases is being waged on three fronts—hospital-acquired infections; antimicrobial resistance to known drugs; and emerging diseases.

3.1 Hospital-acquired infections (HAIs)

HAIs are high in US hospitals. Research on US acute care hospitals by the CDC found that in 2011, about 1 in 25 patients had at least one healthcare-associated infection. This amounts to about 722,000 HAIs during 2011; about 75,000 of those infected died during their hospitalizations. More than half of these infections occurred outside an intensive care unit.[5]

Furthermore, diseases normally spread via air or by contact can also spread by alternative transmission routes. For example, the *Clostridium difficile* ("C. diff") bacterium, a common HAI pathogen, is usually spread through faecal–oral transmission. However, several studies have found that it can become airborne during room cleaning to spread both within and outside a room.[6, 7]

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[4] *Antimicrobial Resistance: Global Report on Surveillance 2014*. Geneva: World Health Organization (WHO) (2014).

[5] S.S. Magill et al., Multistate point-prevalence survey of healthcare-associated infections. *New Engl. J. Med.* **370** (2014) 1198–1208.

[6] M.F. King, C.J. Noakes, P.A. Sleigh and M.A. Camargo-Valero, Bioaerosol deposition in single and two-bed hospital rooms: A numerical and experimental study. *Building Environ.* **59** (2013) 436–447.

[7] E.L. Best et al., The potential for airborne dispersal of *Clostridium difficile* from symptomatic patients. *Clinical Infectious Diseases* **50** (2010) 1450–1457.

Box 1: HAIs and Medicare

The prevalence and costliness of hospital-acquired infections has not gone unnoticed by Medicare administrators. Two Medicare payment adjustments have been put in place to increase pressure on hospitals to reduce HAIs through preventive measures.

The first was established in 2006 with the Deficit Reduction Act (DRA), which contained language such that "after October 1, 2008, hospitals will not receive additional payment for cases in which one or more of the selected conditions were not present on admission".[8] This, in collaboration with the CDC, established tracking and nonpayment of selected HAIs. The programme was designed to increase in stringency over time.

The second was established in 2013 when the Centers for Medicare & Medicaid Services (CMS) instituted the Hospital Value-Based Purchasing Program, which pays more to hospitals with performance indicators above a threshold considered "good" and less to hospitals below the threshold.[9] In the programme, payment adjustments are developed using a methodology that includes "hospital-acquired conditions," some of which are selected hospital-acquired infections. In 2014, 1,451 hospitals began a period of receiving reduced payments for each Medicaid patient they treat for one year beginning 1 October 2014. Bonuses in payments to 1,231 hospitals will also occur during the same interval.[10] Increasing stringency over time is also expected in that programme.

3.2 Antibiotic resistance

Resistance of pathogens to medicines is occurring at a shocking rate, and no major new antibiotics have been developed in the last 30 years.[4] The situation elicited a warning from the World Health Organization: "Without urgent action we are heading for a post-antibiotic era, in which common infections and minor injuries can once again kill".[4]

In 2014, the US President's Council of Advisors on Science and Technology released a report on antibiotic resistance, stating that the "evolution of antibiotic resistance is occurring at an alarming rate and is outpacing the development of new countermeasures".[11] The report's recommended strategies included: improved stewardship of antibiotics (reducing unnecessary use of antibiotics); increased surveillance of antibiotic-resistant strains of bacteria for earlier identification of outbreaks; limiting the spread of resistant organisms; and accelerating the development of new antibiotics.

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[8] National Conference of State Legislators (NCSL). *Medicare Nonpayment for Medical Errors* (August 2008) (http://www.ncsl.org/Portals/1/documents/health/MCHAC.pdf, accessed 7 October 2014).

[9] Centers for Medicare & Medicaid Services (CMS), webpage for the Value-Based Purchasing Program (http://www.cms.gov/Medicare/Quality-Initiatives-Patient-Assessment-Instruments/hospital-value-based-purchasing/index.html, accessed 6 October 2014).

[10] J. Rau, National Public Radio, "Medicare Penalizes Nearly 1,500 Hospitals for Poor Quality Scores." *Morning Edition* (15 November 2014).

[11] President's Council of Advisors on Science and Technology (PCAST). *Report to the President on Combating Antibiotic Resistance* (September 2014).

It's unclear when the focus on antibiotic-resistant bacteria will take place or whether it will yield results. While these efforts are ramping up, hospitals will need to continue to refine their protocols and infrastructures to protect against antibiotic-resistant bacterial infections and outbreaks.

To help fight this battle, and the battles on the fronts of emerging diseases and hospital-acquired infections, engineers have one major and extremely well-tested tool they can turn to, namely ultraviolet energy in the "C" band, a broadly-used technology that kills bacteria and viruses in room air and in HVAC supply airstreams and surfaces.[12]

3.3 Emerging diseases

Emerging diseases are a threat because they skirt treatment by masquerading as known diseases with similar symptoms. Instead of being a known variant of, say, the cold or 'flu, it may be a new pathogen or disease, or a more virulent and/or infectious genetic variant of a known disease.

The impact of emerging diseases is not always identical in different countries. US healthcare workers exposed to SARS did not contract the disease. However, in other countries there were infections, sufficient to close hospitals.

Ebola has been extremely detrimental to healthcare workers. As of 23 September 2014, the World Health Organization reports that more than 240 healthcare workers have died from the disease, some of whom were their countries' most prominent doctors.[13]

4. Infection control

Within the healthcare environment, the CDC recommend the use of environmental controls to prevent the spread of infectious diseases. Among such recommended controls are building and room pressurization, filtration, and the use of the UV-C band. Although UV-C is sometimes referred to as "supplemental",[14] all these approaches are individually effective in fighting infectious diseases. No known microorganisms are completely resistant to the physical effects of the UV-C frequency, however. UV-C can be installed inexpensively throughout healthcare facilities by using "upper-room" units that create a zone of UV-C energy in the upper-air section of interior spaces, and lamps in HVAC ducts and exhaust systems for airstream disinfection and in air handlers to disinfect airstreams, coils, air filters, drain pans and other potential reservoirs for microbial growth and proliferation. These upper-room units are wall-mounted seven feet or higher above the floor.

The following notes are intended for applications that focus on airborne transmission and other modes of transmission that have airborne components.

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[12] J. Atkinson et al., Annex C—Respiratory droplets. In: *Natural Ventilation for Infection Control in Health-Care Settings.* World Health Organization (2009).

[13] World Health Organization, *Unprecedented number of medical staff infected with Ebola* (http://www.who.int/mediacentre/news/ebola/25-august-2014/en/, accessed 6 October 2014).

[14] F. Memarzadeh et al., Applications of ultraviolet germicidal irradiation disinfection in health care facilities: Effective adjunct, but not stand-alone technology. *Am. J. Infection Control.* **38** (2010) S13–S24.

4.1. Fortification

UV-C supplements infection control protocols for disinfection, sterilization and manual cleaning. In addition to their 24/7 operation to kill pathogens, they also provide some level of protection when staff do not or cannot follow protocols, or if existing protocols are sidestepped by emerging diseases and when HVAC or room pressurization systems are compromised.

The "fortification" approach simply means an additional level of protection, exploiting the fact that UV-C is effective against all pathogens from either emerging or known diseases, and does not contribute to drug resistance or secondary contamination.

4.2 Combating airborne transmission

UV-C installations are positioned in key spaces and/or HVAC equipment where pathogen sources and pathways exist. Interior and perimeter spaces are protected using upper-room units; air handling systems serving high-risk areas are protected using airstream-disinfection systems; and areas of HVAC systems known to be reservoirs of pathogens are bathed with surface-cleaning UV-C systems.

Upper-air units

Infections from airborne pathogens (which fall out or plate out onto equipment surfaces and floors) are sourced from people.[15, 16] Upper-air UV-C systems reduce these microorganisms by effectively intercepting them in the room air.[17]

Another use is to intercept microorganisms from other sources or where cross-contamination pathways exist. They kill pathogens circulated into their zone by draughts, pressure differentials or the movement of people, such as those entering or leaving a room or during cleaning. They are also effective against droplet nuclei from coughing, sneezing or the changing of bed linen.

Upper-room units are installed in patient rooms, emergency rooms, waiting rooms, isolation rooms/wards, surgery suites and childcare rooms—anywhere infectious agents exist. Guidelines are available from the National Institute for Occupational Safety and Health[18] or from manufacturers.

Airstream disinfection

Airstream disinfection systems employ UV-C lamps to target pathogens from outdoor and/or return air (which contains airborne pathogens). Kill ratios over 99.9% on a first-pass basis have

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[15] E.A. Nardell and J.M. Macher, Respiratory infections—transmission and environmental control. In: *Bioaerosols: Assessment and Control* (ed. J.M. Macher). Cincinnati: American Conference on Governmental Industrial Hygienists (1999).

[16] E. Nardell et al., Upper-room ultraviolet germicidal irradiation (UVGI) for air disinfection: a symposium in print. *Photochem. Photobiol.* **89** (2013) 764–769.

[17] M.W. First et al., Guidelines for the application of upper-room ultraviolet germicidal irradiation for preventing transmission of airborne contagion—Part 2: Design and operational guidance. *ASHRAE Trans.* **105** (1999) 869–876.

[18] National Institute for Occupational Safety and Health (NIOSH), *Environmental Control for Tuberculosis: Basic Upper-Room Ultraviolet Germicidal Irradiation Guidelines for Healthcare Settings* (DHHS (NIOSH) Publication No 2009-105) (2009).

been modeled in various scenarios and, as air is recirculated, concentrations are further reduced by each subsequent pass.[19–26]

Airstream disinfection is used in high-risk areas, such as surgical suites, neonatal care centres and isolation rooms/wards. Guidance may be found in the 2011 ASHRAE *Handbook of Applications*, as well as in the *Ultraviolet Germicidal Irradiation Handbook*.[26]

Notable applications include in the Pentagon, for protection against bio-terror agents; the CDC, for protection against catastrophic spillages of infectious agents; and the isolation units at Emory University hospital, where Dr Kent Brantly and Nancy Writebol, who both were infected with Ebola, were taken to recover.

HVAC surface cleaning

Surface-cleaning UV-C systems provide 24/7 irradiation of HVAC components to destroy bacteria, viruses and moulds that settle and proliferate on coils, air filters, ducts and drain pans. UV-C prevents them from becoming microbial reservoirs for pathogen growth and subsequent entrainment into airstreams. They also provide first-pass kill rates of airborne pathogens of up to 30%, with ancillary benefits of restored cleanliness, heat exchange efficiency and energy use.[27–30] The first-pass kill rate of 30% for systems designed for "24/7/365" surface irradiation (e.g., cooling coil irradiation) is lower than that for those systems specifically designed for airborne disinfection as less UV-C energy (i.e., fewer UV-C lamps) is necessary, given the constant bombardment of UV-C energy onto the target surface throughout the year. Conversely, when attempting to kill a pathogen in a fast-moving airstream, a greater UV-C intensity is required due to the limited contact time and, therefore, more lamps are used.

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[19] S.A. Aaronson, Effect of ultraviolet irradiation on the survival of simian virus 40 functions in human and mouse cells. *J. Virol.* **6** (1970) 393–399.
[20] T. Albrecht, Multiplicity reactivation of human cytomegalovirus inactivated by ultra-violet light. *Biochim. Biophys. Acta* **905** (1974) 227–230.
[21] G. Abraham, The effect of ultraviolet radiation on the primary transcription of influenza virus messenger RNAs. *Virology* **97** (1979) 177–182.
[22] E.H.S. Bay and M.E. Reichman, UV inactivation of the biological activity of defective interfering particles generated by vesicular stomatitis virus. *J. Virol.* **32** (1979) 876–884.
[23] D.E. Bergstrom, H. Inoue and P.A. Reddy, Pyrido[2,3-d]pyrimidine nucleosides, synthesis via cyclization of C-5-substituted cytidines. *J. Org. Chem.* **47** (1982) 2174–2178.
[24] M.M. Becker and Z. Wang, Origin of ultraviolet damage in DNA. *J. Molec. Biol.* **210** (1989) 429–438.
[25] D.A. Battigelli, M.D. Sobsey and D.C. Lobe, The inactivation of hepatitis A virus and other model viruses by UV irradiation. *Water Sci. Technol.* **27** (1993) 339–342.
[26] W. Kowalski, *Ultraviolet Germicidal Irradiation Handbook*. Berlin: Springer (2009).
[27] F. Fencl, Rightsizing UV-C lamps for HVAC applications: Using ASHRAE recommendations to simplify sizing. *HPAC Engineering* (October 2013) (available at http://bit.ly/1lKJ2jk).
[28] F. Fencl. Illuminating info: UV-C for HVAC. *Engineered Systems* (September 2013) (available at http://bit.ly/1iygqXH).
[29] F. Fencl, Maintaining energy efficiency with UV. *Filtration & Separation* (July/August 2014).
[30] F. Fencl, Dirty sock syndrome: What it is, how to prevent it. *Air Conditioning, Heating & Refrigeration News* (September 2014).

HVAC surface-cleaning was recently documented in a neonatal intensive care unit (NICU) case study at the University of Buffalo Women and Children's Hospital.[31] The study found substantial reductions in microbial loading on NICU surfaces to near zero colony-forming units (cfu) after four months of operation. The study concluded that "decreased HVAC microbial colonization was associated with reduced NICU environmental and tracheal microbial colonization. Significant reductions in VAP [ventilator-associated pneumonia] and antibiotic use were also associated with UV-C".

5. Summary

Healthcare leaders are necessarily uniting in this war against infectious diseases. The toll in human lives, lost productivity, healthcare costs and diversion of healthcare resources is huge. Although focused efforts are underway to address new medicines, surveillance systems and diagnostic procedures, the outcome of these efforts is unknown, and, there will always be the need to underwrite any new measure to compensate for error, negligence and the unceasing genetic mutations and evolutions that bacteria, viruses and fungi can undergo.

UV-C systems are a cost-effective, proven and a readily available means to address all three fronts of the war on infectious diseases. The variety of ways that UV-C can be applied enables engineers and operators to tailor UV-C technologies to meet desired outcomes, and to do so within real-world budgets.

As examples, upper-room UV units cost as little as $2.50–$3.10 per square foot of treated space. The cost of airstream disinfection systems ranges from $0.60–$0.80 per cfm (cubic feet per minute) and HVAC surface disinfection systems cost approximately $0.10–$0.15 per cfm, literally bargains when compared to human lives, lost productivity, healthcare costs and otherwise wasted healthcare resources.

Box 2: Useful links to infection information

Hospital-acquired infections: http://www.cdc.gov/hai/
Antimicrobial-resistant microorganisms: http://www.cdc.gov/drugresistance/
Emerging diseases: http://www.cdc.gov/ncezid/
Ebola: http://www.cdc.gov/vhf/ebola/
Middle East Respiratory Syndrome (MERS): http://www.cdc.gov/coronavirus/mers/
Non-polio Enterovirus D68: http://www.cdc.gov/non-polio-enterovirus/index.html
Morbidity and Mortality Weekly Summary Report: http://www.cdc.gov/mmwr/
Coronavirus (including SARS and MERS): http://www.cdc.gov/coronavirus/about/index.html

[31] R.M. Ryan et al., Effect of enhanced ultraviolet germicidal irradiation in the heating, ventilation and air conditioning system on ventilator-associated pneumonia in a neonatal intensive care unit. *J. Perinatol.* **31** (2011) 607–614.