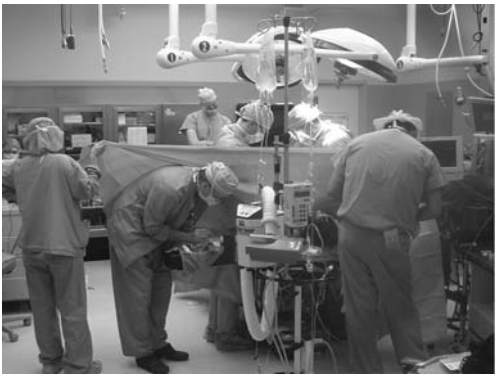

Chapter 17

Health Care Facilities

17.1 Introduction

This chapter addresses applications of ultraviolet germicidal irradiation (UVGI) in health care facilities, including laboratories and animal or veterinary facilities. This chapter does not review the applicable guidelines or standards for air quality in these facilities, which typically do not mention UVGI, but the references and Chapter 11 may be consulted for more detailed information. The types of UV systems covered in this chapter have been addressed in detail in previous chapters and these designs are not revisited here. Instead, this chapter discusses the various applications of UV to the indicated facilities, how they have been applied in the past, what effectiveness they have previously demonstrated, and how new UV systems may be applied to reduce the microbiological hazards associated with each type of facility. Also addressed here are the types of pathogens that are unique to certain facilities and, in particular, nosocomial pathogens and the problem of increasing drug resistance.

The use of ultraviolet germicidal irradiation in hospitals to control hospital acquired, or nosocomial, infections represents some of the earliest and most important applications of this technology. UVGI has been used for the disinfection of medical equipment, entire rooms, ventilation air, and surgical sites for well over half a century, often with definitive results. New applications are being developed even today and although UVGI is not a total solution to the problem of disease transmission in health care facilities, it can be an effective and economic component of any program designed to reduce hospital-acquired infections. This chapter discusses the various ways in which UVGI systems can be applied in hospitals and related health care facilities, including dental offices, laboratories, and veterinary facilities. Limited mention is made in most health care literature of UVGI, although some recent guidelines have acknowledged its potential effectiveness (CDC 2003, ASHRAE 2008). Chapter 11 can be consulted for more detailed information on the various standards and guidelines that address the use of UVGI in health care facilities. For a complete review of codes and standards for hospital ventilation and air quality see, for example, Kowalski (2006) or ASHRAE (2003).

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17.2 Nosocomial Infections

Hospital acquired, or nosocomial, infections include any type of microbiological infections acquired in hospital environments, and since some of these have spread to communities, this category may be considered to include community-acquired infections also. Airborne and surface borne microbiological hazards in health care facilities can cause infections in both patients and health care workers. Nosocomial infections have proven to be a persistent problem in hospitals and some drug-resistant infections have transitioned from being hospital-acquired to community-acquired, including Methicillin-resistant *Staphylococcus aureus* (MRSA). Nosocomial infections can have complex, multifaceted etiologies that involve one or more routes of transmission and so the solution may involve more than one type of disinfection system (i.e. air disinfection, surface disinfection, water disinfection, equipment disinfection, personnel decontamination, etc.), procedural methods, and formal standards for air quality (Kowalski 2008a).

Drug resistance among nosocomial microbes is a growing problem. Bacteria that cause respiratory infections have developed increased drug resistance over the past ten years. Drug resistance is defined in terms of an IC_{50} value, or the concentration that causes 50% growth inhibition, and resistance is defined as a ten-fold increase in the IC_{50} value (Andrei et al. 2004, Andersson et al. 2004). The number of microbes that have demonstrated increased drug resistance in recent years is extensive and growing (Kowalski 2007b). The drug resistance of Streptococcal infections, which can cause Scarlet Fever, has increased from 0.8% to 28% in the past decade. MRSA has shown up repeatedly outside hospital settings and has become a contamination problem in athletic environments. Multidrug-resistant tuberculosis (XTB) has caused a resurgence in TB infections worldwide, and close to a million people die each year from this disease. Strains of multiple drug resistant (MDR) *Haemophilus influenzae* are being increasingly reported from around the world (Jain and Agarwal 1996). Multidrug resistant strains of *Acinetobacter baumannii, Pseudomonas aeruginosa*, and *Klebsiella pneumoniae*, have been recognized among casualties returning from battlefields (Davis et al. 2005). Various fungi can also cause nosocomial infections and unlike viruses and bacteria, most fungi hail from outdoors but can grow indoors (Kowalski and Bahnfleth 1998).

Evidence has been mounting over the years that the airborne transmission route plays a significant role in nosocomial infections (Fletcher et al. 2004). It has been estimated that the airborne transmission route may be responsible for as much as 10–20% of all endemic nosocomial infections (Brachman 1970). Airborne concentrations of bacteria in the OR bear a direct relationship to surgical site infections or sepsis. Figure 17.1 plots the rate of joint sepsis versus the airborne bacterial count in operating rooms from six hospitals. The data has been fit to a logarithmic equation as shown.

Mycobacterium tuberculosis, long known for its airborne transmission potential, is now a multi-drug resistant airborne pathogen that can cause outbreaks in hospitals (Breathnach et al. 1998). Evidence exists for airborne nosocomial transmission of *Acinetobacter, Pseudomonas*, and MRSA (Allen and Green 1987, Farrington et al.

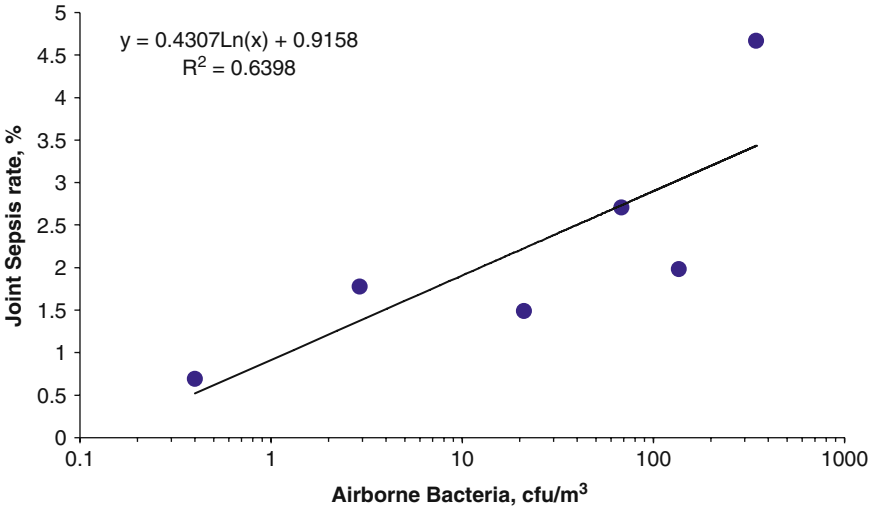

Fig. 17.1 The relationship between airborne bacteria and the incidence of joint sepsis. Adapted from Lidwell et al. (1983)

1990, Grieble et al. 1970). Table 17.1 summarizes the various nosocomial microbes that have airborne potential. Most nosocomial infections have been identified as having at least some potential for airborne transmission although most of them are primarily spread by other routes, such as direct contact. These microbes are ranked by estimated order of occurrence and are classified as Contagious, Noncontagious, and Endogenous (present as part of normal human flora). The last column in this table indicates whether or not the microbe has demonstrated any evolving drug resistance. It is clear from this tabulation that drug resistance is a growing and widespread problem and that all three microbial categories, viruses, bacteria, and fungi, have been developing such resistance. As drugs for treating these nosocomial infections become less effective and less available, increasing reliance on engineering methods such as UVGI may be one of the few remaining means of effectively dealing with the problem.

17.3 Operating Rooms and ICUs

Operating rooms (ORs), surgery suites, procedure rooms, treatment rooms, intensive care units (ICUs), and related facilities generally have very high levels of surface and air cleanliness, but these facilities are still far from being sterile. Many managers assume that if the design requirements for ventilation are met then the air is sterile, but this is rarely, if ever, the case. Levels of airborne contaminants in ORs are often lower than in the general wards, but not significantly so. For hospital air, WHO recommends the limits of 100 cfu/m^3 for bacteria and 50 cfu/m^3 for fungi (WHO 1988). There are currently no standards for OR aerobiology in the USA, but the

Table 17.1 Potentially airborne nosocomial microbes

Pathogen	Group	Type	Annual cases (USA)	Primary infections	Increasing resistance
Corynebacterium diphtheriae	Bacteria	Contagious	10	diphtheria	Yes
Acinetobacter	Bacteria	Endogenous	147	SSI, meningitis	Yes
Serratia marcescens	Bacteria	Endogenous	479	SSI, pneumonia, bacteremia	Yes
Aspergillus	Fungi	Noncontagious	666	Aspergillosis	Yes
Histoplasma capsulatum	Fungi	Noncontagious	1,000	Histoplasmosis	Yes
Haemophilus influenzae	Bacteria	Contagious	1,162	SSI, pneumonia, meningitis	Yes
Legionella pneumophila	Bacteria	Noncontagious	1,163	pneumonia	?
Klebsiella pneumoniae	Bacteria	Endogenous	1,488	SSI, pneumonia	Yes
Pseudomonas aeruginosa	Bacteria	Noncontagious	2,626	SSI, pneumonia	Yes
Staphylococcus aureus	Bacteria	Endogenous	2,750	SSI, pneumonia	Yes
Rubella virus	Virus	Contagious	3,000	rubella	?
Bordetella pertussis	Bacteria	Contagious	6,564	Whooping cough	Yes
Mycobacterium tuberculosis	Bacteria	Contagious	20,000	TB	Yes
Parainfluenza virus	Virus	Contagious	28,900	flu, pneumonia	?
Varicella-zoster virus	Virus	Contagious	46,016	VZV	Yes
Respiratory Syncytial Virus	Virus	Contagious	75,000	RSV	No
Streptococcus pyogenes	Bacteria	Contagious	213,962	Scarlet fever, SSI	Yes
Streptococcus pneumoniae	Bacteria	Contagious	500,000	pneumonia, meningitis	Yes
Measles virus	Virus	Contagious	500,000	measles	No
Influenza A virus	Virus	Contagious	2,000,000	flu	Yes
SARS virus	Virus	Contagious	10 (China)	SARS	?
Cryptococcus neoformans	Fungi	Noncontagious	high	cryptococcosis	Yes
Alcaligenes	Bacteria	Endogenous	rare	SSI	Yes
Bacteroides fragilis	Bacteria	Endogenous	rare	bacteremia, SSI	Yes
Blastomyces dermatitidis	Fungi	Noncontagious	rare	Blastomycosis	?

Table 17.1 (continued)

Pathogen	Group	Type	Annual cases (USA)	Primary infections	Increasing resistance
Burkholderia pseudomallei	Bacteria	Noncontagious	rare	melioidosis	Yes
Cardiobacterium	Bacteria	Endogenous	rare	endocarditis	Yes
Chlamydia pneumoniae	Bacteria	Contagious	rare	pneumonia	No
Coccidioides immitis	Fungi	Noncontagious	rare	coccidioido-mycosis	?
Haemophilus parainfluenzae	Bacteria	Endogenous	rare	pneumonia, meningitis	Yes
Moraxella	Bacteria	Endogenous	rare	otitis media	Yes
Mucor plumbeus	Fungi	Noncontagious	rare	mucormycosis	No
Nocardia asteroides	Bacteria	Noncontagious	rare	nocardiosis	Yes
Nocardia brasiliensis	Bacteria	Noncontagious	rare	nocardiosis	Yes
Pneumocystis carinii	Fungi	Noncontagious	rare	pneumocystosis	Yes
Rhizopus stolonifer	Fungi	Noncontagious	rare	zygomycosis	No

Note: *SSI = Surgical Site Infections*

current standard used in China is 200 cfu/m^3, while the EU has suggested a limit of 10 cfu/m^3, based on the ISO Class 7 cleanroom limit (EU Grade B) used in the pharmaceutical industry and as a target for ultra clean ventilation (UCV) systems (Durmaz et al. 2005, Kowalski 2007a). It is doubtful any ORs could achieve a limit of 10 cfu/m^3 unless the OR was unoccupied, but it is a target worth striving for.

Figure 17.2 is a figurative diagram showing the various sources of microbiological contamination in an operating room. If the supply air is assumed to be sterile (which is not always the case), then the main sources are the occupants, local internal surfaces, and infiltration. Although ORs are generally under positive pressure with respect to external areas, this may not always be the case and even if it is, the opening of doors can allow contaminants to enter.

The concentration of airborne bacteria in any OR is proportional to the number of personnel in the room (Mangram et al. 1999, Duvlis and Drescher 1980, Moggio et al. 1979, Kundsin 1976). The amount of surface contamination is also likely to be related to the level of airborne contamination since microbes aerosolize and settle continuously during occupation and activity. Air supplied to ORs, especially through HEPA filters, may be highly disinfected or even sterile, but most of the airborne bacteria hail from the room occupants, including the patient, and so increasing the rates of supply air above design guidelines is an approach that brings diminishing returns, often at high economic cost. Figure 17.3 plots the airborne concentrations of bacteria for six operating rooms representing measurements from 13

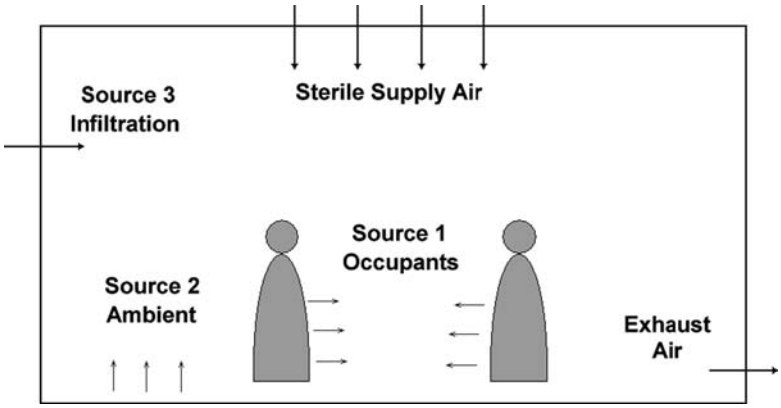

Fig. 17.2 Schematic of an OR with three major sources of contamination, the occupants, the ambient surfaces, and outside infiltration

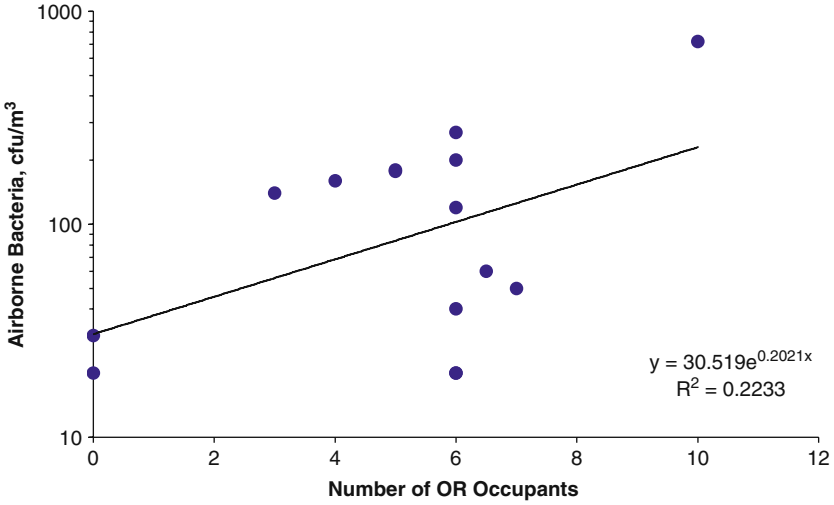

Fig. 17.3 Relationship between occupancy and airborne bacteria in ORs during surgery. Data taken by author (Kowalski 2008b)

operations and two empty ORs that had been cleaned and disinfected. A curve-fit of the data is shown.

Options for dealing with air and surface contamination coming from inside ORs include Upper and Lower Room UVGI systems, local recirculation units, continuous UV exposure systems, equipment disinfection systems, barrier UV systems, and Overhead Surgical UVGI systems. Overhead UVGI systems have been in use in some operating rooms since at least 1936 (Hart and Sanger 1939, Brown et al. 1996). Duke University has successfully used overhead UVGI systems since 1940 to maintain a low level of orthopedic infections (Lowell et al. 1980, Goldner and Allen 1973). Table 17.2 summarizes the various studies that have been performed

Table 17.2 Results of UV hospital field trials in operating rooms

System	Location	Infection/Operation	Infection Cases		Decrease		Reference
			Before (%)	After (%)	Net (%)	%	
Overhead	Duke University Hospital	SSI	5	1	4	80	Kraissl et al. (1940)
Overhead	NE Deaconess Hospital	SSI	13.8	2.7	11.1	80	Overholt and Betts (1940)
Barrier	Infant & Children's Hospital, Boston	SSI	12.5	2.7	9.8	78	Del Mundo and McKhann (1941)
Overhead	Montreal Neurological Inst	SSI	1.1	0.36	0.7	67	Woodhall et al. (1949)
Overhead	MA General Hospital	Craniotomies	5.3	0.70	4.6	87	Wright and Burke (1969)
Overhead	MA General Hospital	Laminectomies	4.1	0.30	3.8	93	Wright and Burke (1969)
Overhead	Duke University Hospital	Hip arthroplasty infection	5	0.5	5	90	Lowell et al. (1980)
Overhead	Brigham Hospitals	Hip & Knee	3.5	0.89	3	75	Young (1991)
Overhead	Watson Clinic, FL	Mediastinitis	1.4	0.23	1.2	84	Brown et al. (1996)
Overhead	St. Francis Hospital	SSI	1.77	0.57	1.2	68	Ritter et al. (2007)
Overhead	Average Reduction					80	

on operating rooms, including all those equipped with Overhead UV systems, and these show a net average reduction of 80% (barrier system results not included). One study showed that UVGI can reduce airborne microbial concentrations to below 10 cfu/m^3 in the operating room (Berg et al. 1991, Berg-Perier et al. 1992). Moggio et al. (1979) demonstrated a 49% decrease in airborne bacteria with an Overhead UV system. Lowell and Kundsin (1980) reports on an Overhead UV system that produced a 99–100% decrease in aerosolized *E. coli*, and that resulted in a 54% decrease in airborne bacteria during procedures.

The Overhead Surgical System implemented by Ritter et al. (2007) consists of a series of UV lamp fixtures suspended overhead in the OR in recessed lighting troffers. This system includes 8 UV lamps that produce a net average of about 25 $\mu W/cm^2$ at operating table height. According to Ritter et al. (2007), this system was able to reduce the surgical site infection rate from 1.77 to 0.5%. The study did not report airborne concentrations of bacteria in the ORs but it is possible that this system could reduce airborne levels significantly, even with personnel present. It is likely that this UV system inhibited both airborne transport and survival of bacteria on surfaces, including microbes that settle on equipment, on personnel and on floors. Since the irradiance of the UV in this system exceeds ACGIH limits, personnel are required to be completely covered, including eye protection, during operating procedures. Systems can be operated for short periods during surgery, but can also be operated for longer periods when the operating room is unoccupied to provide area decontamination between procedures. Figure 17.4 shows a diagram of how the UV lamp fixtures are located relative to the operating table. In older systems, UV lamp fixtures were often hung below the ceiling directly above the operating table.

Lower Room UV systems also have potential value in ORs, since most nosocomial bacteria will gravitate towards the floor, may settle, and may be stirred up again by activity. Figure 17.5 shows an example of how a Lower Room UV system may be applied to an operating or procedure room. Such systems will keep the floor and lower air (below about 18 in.) virtually sterile and turn the most contaminated portion of the room, the floor, into the cleanest area. Legwear would be required, depending on the irradiance produced, but UV levels above 18 in. would be below ACGIH/NIOSH 8-hour limits and upper body coverings and eyewear would not necessarily be required.

17.4 Isolation Rooms

Isolation rooms, like ORs, incorporate pressurization control to protect those inside or outside the room and often include supply air filtration. Isolation room systems are essentially 100% outside air purge air systems, and their performance characteristics are similar to ORs except that airflow rates and filtration levels may be different. Isolation rooms can be classified in three basic categories:

- Negative Pressure Isolation Rooms
- Positive Pressure Isolation Rooms
- Dual Purpose Isolation Rooms (Positive or Negative)

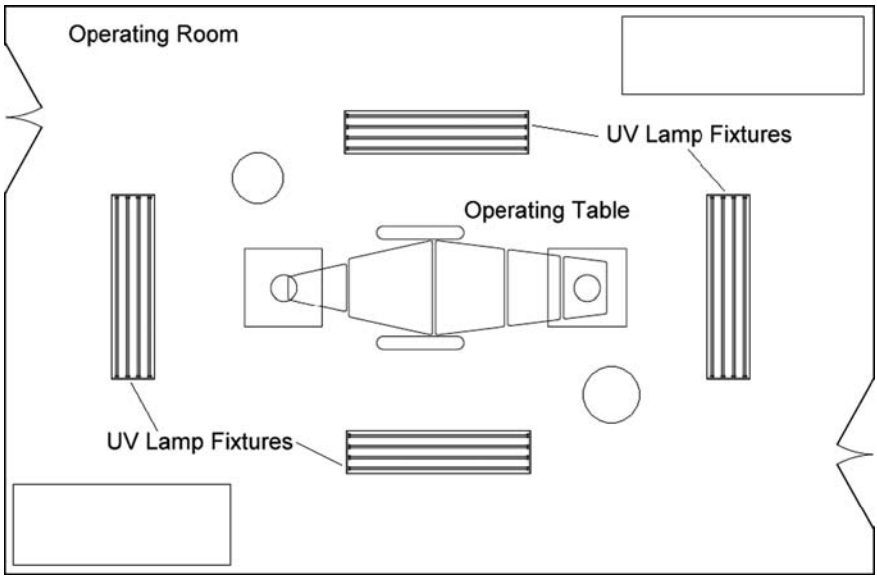

Fig. 17.4 Diagram of typical placement of recessed UV lamp fixtures in an operating room. Lamps are often located in recessed troffers in the ceiling

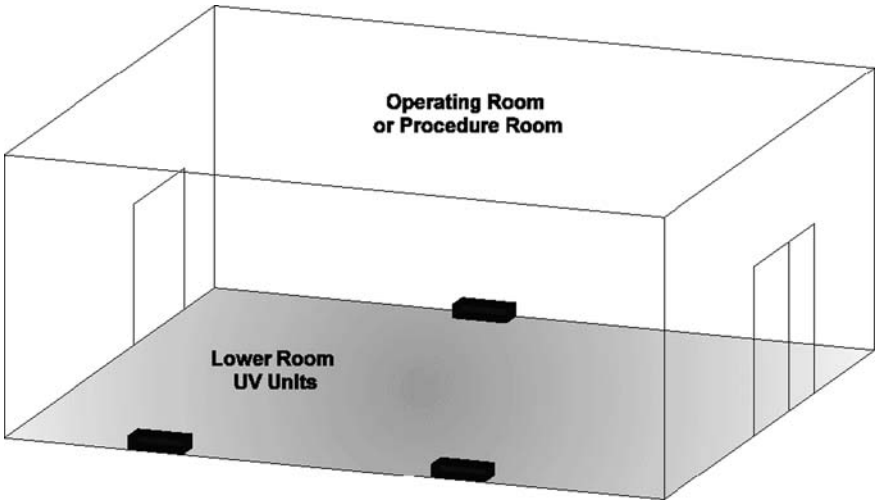

Fig. 17.5 Lower Room UV units can be used to disinfect floors and maintain high levels of disinfection in ORs without undue exposure hazards to occupants. UV levels above 18 in. would be below ACGIH TLVs and NIOSH RELs

The modern approach to designing isolation rooms is to include an anteroom that separates the isolation room from the corridor of the facility, thereby maintaining pressurization integrity during access (ASHRAE 1999). Air is supplied to the isolation room and typically exhausted from both the isolation room and the anteroom.

TB rooms are isolation rooms that maintain negative pressure so as to protect those outside the room. TB rooms often include internal recirculation units situated above the patient's bed which draw air across the bed. These recirculation units may include HEPA filters and UV lamps.

Schneider et al. (1969) applied in-duct UV for the supply air of an isolation ward and simultaneously irradiated the surrounding corridors, effectively controlling pathogens in the wards. UV recirculation units are routinely used in TB isolation rooms. Options for applying UV in isolation rooms are the same as those for ORs: Upper Room systems, Lower Room systems, Area Disinfection systems, After Hours systems, UV Barrier systems, and UV recirculation units can all be applied to improve conditions and reduce the risks to both patients and health care workers.

17.5 General Areas

Various types of UV systems have been applied successfully to hospitals to reduce infection rates in the General Areas, including In-duct airstream disinfection systems, Upper and Lower Room systems, and UV Barrier systems (Kowalski 2007a, Dumyahn and First 1999). Barrier systems in doorways between isolation wards were found to be effective in preventing the spread of chickenpox (Wells 1938). Barrier systems were found to reduce cross-infections across patient cubicles (Del Mundo and McKhann 1941, Sommer and Stokes 1942, Robertson et al. 1943). Upper room UVGI systems have been used successfully to control disease transmission in hospitals (see Fig. 17.6).

Upper Room systems were used at The New England Deaconess Hospital, The Infant and Children's Hospital in Boston, The Cradle in Evanston, and St. Luke's Hospital in New York, for the control of respiratory infections, which decreased by a net average of 50% (Overholt and Betts 1940, Del Mundo and McKhann 1941, Sauer et al. 1942, Higgons and Hyde 1947). Table 17.3 summarizes the results

Fig. 17.6 Upper Room UV system (located on wall below ceiling) in a hospital ward. Image provided courtesy of Chuck Dunn, Lumalier, Memphis, TN

Table 17.3 Results of hospital field trials of Upper Room systems

System	Location	Infection	Infection cases		Decrease		Reference
			Before	After	Net	%	
Upper room UVGI	The Cradle, Evanston	Respiratory infection	14.5	4.6	9.9	68	Sauer et al. (1942)
	St. Luke's Hospital, NY	Respiratory infection	10.0	6.6	3.4	33	Higgons and Hyde (1947)
	Home for Hebrew Infants, NY	Varicella epidemic	97	0	97	100	Wells (1955)
	Livermore, CA Veteran's Hospital	Influenza epidemic	19.0	2.0	17.0	89	McLean (1961)
	North Central Bronx Hospital	TB conversions among staff	2.5	1	2	60	EPRI (1997)
	Average Reduction					70	

of field trials of Upper Room systems, and these show a net average reduction of infections of 70%. The Home for Hebrew Infants in New York successfully brought a halt to a Varicella epidemic using UVGI (Wells 1955). The Electric Power Research Institute (EPRI) Community Environmental Center funded the installation Upper Room fixtures in the VA Medical Center in Memphis in 1993 (EPRI 1996). The Memphis VA hospital found that the UV installations provided cost-effective protection against airborne pathogens. New York Central Bronx Hospital installed Upper Room UVGI systems in 1995 to successfully control TB and nosocomial infections, in a project that was supported by The New York Power Authority (NYPA), who provide electricity to all the NYC Health and Hospitals Corporation facilities (EPRI 1997).

Lower Room UV systems have not previously been used in hospitals (to this author's knowledge) but Wheeler et al. (1945) and Miller et al. (1948) used lower room UV systems to reduce respiratory infections at a Naval barracks, in conjunction with upper room systems. Since most bacteria and spores tend to settle downwards over time (and to get re-aerosolized by foot traffic) it is likely that Lower Room UV systems could have a major impact on airborne microbial contamination and should be able to help reduce infection rates.

In-duct air disinfection systems have been used in hospitals but there is no epidemiological data available on their effectiveness, although it is likely they would contribute to overall improvements in air quality of general areas (Luciano 1977). Another application in which hospitals may find UVGI beneficial is to reduce microbial contamination of cooling coils, an approach which pays energy dividends and saves costs (Keikavousi 2004). The latter approach can be combined with UV air disinfection to provide both cost savings and improved air quality. Also available for use in health care facilities are area decontamination units such as the one shown in Fig. 17.7, which is designed for rapidly disinfecting areas of MRSA and other microorganisms.

17.6 Hallways and Storage Areas

Hallways and storage areas surrounding operating rooms and ICUs can be a source of biocontamination that may be tracked into the ORs and isolation rooms by foot traffic. Hallways are also often used as storage areas (see Fig. 17.8) and both types of areas can accumulate microbiological contamination due to the greater surface area, which can act as both a microbial substrate and as protection (i.e. from sunlight or desiccation). The greater the total surface area in any given environment, the greater the potential for accumulated microbial contamination, which may include bacteria, fungal spores, and viruses.

Storage areas for supplies and equipment are often located adjacent to ORs and ICUs so that materials may be delivered expediently. Such storage areas can provide vast amounts of surface area on which microbial contamination may accumulate over time. Since such areas are only transiently occupied, UV area decontamination systems may be appropriately applied to provide high levels of cleanliness and

Fig. 17.7 Portable UV area disinfection system suitable for decontaminating entire hospital rooms. Photo of Tru-D disinfection unit provided courtesy of Lumalier, Memphis, TN

Fig. 17.8 Hospital hallways and other areas used for storage provide increased surface area for the accumulation of microbiological contamination

sterility, and to augment manual cleaning and disinfection procedures. In such areas it is also feasible to apply Upper Room systems which will not only disinfect the air but will tend to disinfect the lower room surfaces over time via the stray irradiance. Although the stray irradiance is below ACGIH/NIOSH limits for human safety, the accumulated dose to surfaces over time will provide fairly high levels of disinfection (see Chap. 9).

Bacteria and spores tend to settle downwards over time and accumulate near the floor, and are re-aerosolized by traffic or tracked into hallways by foot. The

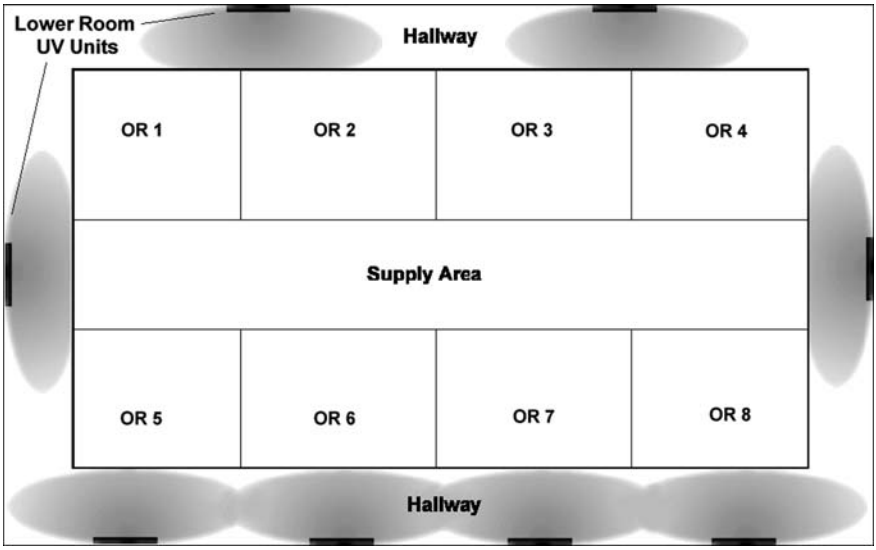

Fig. 17.9 Hallways surrounding Operating Rooms can be continuously irradiated with Lower Room UV Systems

placement of Lower Room UV units along the walls in several places will maintain the hallway floors under sterile conditions. NIOSH RELs for human exposure would not be exceeded above a height of about 18 in. if the system is designed appropriately. Lower Room units will produce no hazardous levels of UV above 18–24 in. and do not require any special protection other than normal leg attire and footwear. Figure 17.9 shows an example of how Lower Room UV systems may be applied in hallways surrounding a group of ORs, and which will help protect the ORs against contamination brought in from foot traffic.

17.7 Dental Offices

Dental offices have needs that are similar to operating suites except that the hazards are generally considered to be less severe. These hazards include airborne pathogens settling on open wounds during dental surgery or procedures, settling on equipment and being transferred to open wounds, and inhalation of microbes from patient to dentist. Face masks are in common use by dental workers and these are adequate for the most common threats. Dental workers are at risk for infection with various airborne pathogens such as *Mycobacterium tuberculosis*, influenza, and cold viruses (Araujo and Andreana 2002). The various types of UV systems that may be appropriately applied in dental offices are the same as those that are used in other health care applications: UV recirculation units, Upper and Lower Room systems, equipment disinfection systems, and area disinfection systems.

17.8 AIDS Clinics

Acquired Immune Deficiency Syndrome (AIDS) patients need heightened levels of protection against airborne microbes and other sources of contamination by bacteria, viruses, and fungal spores. Ideally, AIDS patients require sterile air, but this is difficult to achieve even in hospital settings. The use of air filtration combined with UV can go a long way towards providing a near-sterile environment.

Both ambient environmental microbes and normal commensal human microflora can present health threats to AIDS patients. A positive pressure isolation room, as described previously, can protect immunodeficient patients from possible contaminants and pathogens that might otherwise enter from the ambient environment (Linscomb 1994). Design criteria for HIV Rooms are similar to those for TB Rooms and isolation wards (see Fig. 17.10). Air supplied to, or recirculated in, HIV Rooms is normally filtered through HEPA filters, and UVGI systems are sometimes used in combination. The requirements for maintaining air pressure differential are the same as those for negative pressure rooms – airflow direction must be maintained from the positive pressure area to the negative pressure area.

Approximately 15% of AIDS patients also suffer from tuberculosis infection, and this presents a unique design problem (ASHRAE 1999). One possible solution is to nest a positive pressure (HIV) room within a negative pressure (TB) room or vice-versa (Gill 1994). Another approach is to modify a house such that the entire building is under positive pressure while the outdoor air (which is self-sterilizing) acts as a barrier to protect outsiders. The use of various UVGI systems can greatly enhance the ability of any building system to reduce airborne and surface microbial contamination. Recirculation units, Upper Room systems, Lower Room systems, and area decontamination units can all provide greater levels of protection to AIDS patients.

Fig. 17.10 Example of an Upper Room UV system (located at the ceiling) in a TB clinic. Photo provided courtesy of Pablo R. Antonio Designs and Consultancy, Inc. Makati City, Philippines

17.9 Hospital Laboratories

Any laboratories that deal with biological agents face potential inhalation hazards from handling mishaps and casual exposure (Kowalski 2006). Hospital laboratories have serious risks from pathogenic microorganisms brought in with infected patients and sometimes these risks are unknown until analyzed and identified. Therefore it is essential that the highest levels of air and surface cleanliness be maintained. Biological laboratories normally have a variety of systems and protocols to protect workers from such laboratory hazards, including laboratory hoods, air cleaning systems, pressurization zones, sterilization equipment, biohazard-rated facilities, personnel protective suits, and strict procedures for handling hazardous agents.

Existing procedures are considered adequate to protect workers and these are typically applied rigidly and diligently. All of the existing guidelines and standards offer similar guidance about the design and operation of the ventilation or air cleaning systems (for a review of these documents see, for example, Kowalski 2006 or ASHRAE 2003). Typically these guidelines recommend about 6–15 air changes per hour (ACH). The use of filtered 100% outside air is generally specified as an option and this is the most common approach taken today. Air is typically exhausted to outside, and certain codes may require HEPA filtration of the exhaust air, although the necessity for this is open to question. For systems that recirculate air, a minimum of 50% outside air (or maximum 50% return air) is suggested by some of the guidelines. HEPA filtration is also recommended for recirculated or exhaust air from biosafety cabinets (ASHRAE 1999).

There are four levels for categorizing containment laboratories, Biosafety Level 1, 2, 3, and 4 (DHHS 1993, CDC 2003). The basic characteristics of these laboratories are summarized in Table 17.4. There are no specific requirements for the use of UVGI in any biosafety laboratories, but UV systems are often used in them, especially in biosafety cabinets and for equipment disinfection, and all BSL containment laboratories may benefit from UV in various applications.

Since the use of 100% outside air systems consumes considerable energy in warm and cold climates the question may be raised as to whether it is not more economical to recirculate disinfected air, something that may be accomplished using UVGI combined with filtration. Filtration in combination with UVGI can also offer performance comparable to HEPA filtration without increasing risks (Kowalski 2006). Other applications for UVGI in laboratories include biosafety cabinets, equipment disinfection, surface disinfection systems, area decontamination systems, Upper and Lower Room systems, in-duct air disinfection, and unitary or local recirculation systems.

17.10 Animal Laboratories and Veterinary Facilities

Animal laboratories and veterinary facilities have unique hazards from zoonotic diseases that may be transmitted not from animals to humans but also between animals (Besch 1980, Tuffery 1995). Laboratories that handle animals are subject

Table 17.4 Basic characteristics of BSL containment laboratories

BSL	Requirements	Recommendations (ACH = Air Changes per Hour)	Application
1	No specific HVAC requirements	3–4 ACH, slight negative pressure	Microbial agents of no known hazard or minimal hazard
2	No specific HVAC requirements	100% OA, 6–15 ACH, slight negative pressure, use of safety cabinets	Microbial agents of moderate potential hazard
3	Physical barrier, double doors, no recirculation, maintain negative pressure	Exhaust may require HEPA filtration	Microbial agents that pose a serious hazard via inhalation
4	Physical barrier, double doors, no recirculation, maintain negative pressure, etc.	Requirements determined by biological safety officer	Microbial agents that pose a high risk of lethality via inhalation

to occupational hazards from a wide variety of infections, especially respiratory infections (Kowalski et al. 2002, Benirschke et al. 1978). In addition to pathogenic disease hazards, laboratory workers can develop allergies from prolonged or chronic exposure to animals (Hunskaar and Fosse 1993).Many species of animal diseases have the ability to transmit to humans or vice versa since the biological and physiological similarities between humans and animals are sufficient to permit such exchanges. Whenever such interspecies transmission occurs, secondary transmissions are rare. Often, such interspecies transmissions occur by direct contact or very close proximity, but airborne transmission is an ever-present possibility. Contact transmissions may be controlled procedurally, but the control of airborne transmission requires engineered systems. Table 17.5 lists the wide variety of zoonoses that can potentially transmit by the airborne route in animal laboratory or other animal facilities (adapted from Kowalski et al. 2002). Most of these pathogens and allergens can also transmit by direct contact and other means, such as ingestion or vie blood contamination. Few of the zoonotic microbes in the list have been evaluated for their UV susceptibility, but most of them are sufficiently physiologically similar to various human pathogens that the UV rate constants for the human pathogenic species may be used as an approximation. Genomic analysis of UV susceptibility is also possible (Kowalski et al. 2009).

Applications for UVGI systems in animal laboratories and veterinary facilities are much the same as for biological laboratories and are likely to be just as effective. These applications include biosafety cabinets, equipment disinfection systems, surface disinfection systems, area decontamination systems, Upper and Lower Room systems, in-duct air disinfection, and unitary or local recirculation systems.

Table 17.5 Airborne pathogens and allergens in animal laboratories

Airborne pathogen	Source or infected animal	Airborne pathogen	Source or infected animal
Acinetobacter	Env., soil, sewage, Rats, swine bldgs	Mucor plumbeus	Env., sewage, Guinea Pigs
Actinomyces bovis	Hamsters	Mumps virus	Humans, primates, Rodents
Actinomyces israelii	Humans, cattle, Rabbits, hamsters	*Mycobacterium africanum*	Monkeys
Aerococcus viridans	Rodents, Rabbits	*Mycobacterium avium*	Env., water, Mice
Aeromonas spp.	Env., rodents, soil	*Mycobacterium bovis*	Monkeys
Alcaligenes	Humans, soil, water, swine bigs	*Mycobacterium lepraemurium*	Rodents
Animal dander	Rats, dogs, cats, horses, etc.	*Mycobacterium microti*	Rodents
Avian adenovirus (FAV)	Birds	*Mycobacterium tuberculosis*	Humans, sewage, Monkeys
Bacillus anthracis	Cattle, sheep, Mice, Horses	*Mycoplasma pulmonis*	Rats & mice

Table 17.5 (continued)

Airborne pathogen	Source or infected animal	Airborne pathogen	Source or infected animal
Bacteroides fragilis	Humans, Rodents, Rabbits	Newcastle Disease Virus (NDV)	Birds
Bordetella bronchiseptica	Rabbits, Cats	Nocardia asteroides	Env., sewage, Rodents, Rabbits
Bovine adenovirus	Bovines	*Paecilomyces variotii*	Env., Rats
Brucella	Goats, cattle, swine, dogs.	Parainfluenza virus	Humans, Monkeys, dogs, rats
Burkholderia cepacia	Env., Rabbits	Paravaccinia	Cattle, humans
Burkholderia mallei	Env., Horses, mules, nosocomial	*Pasteurella lepisceptica*	Rabbits
Burkholderia pseudomallei	Env., rodents, soil, nosocomial	*Pasteurella multocida*	Rabbits, Rodents
Canine distemper virus (CDV)	Dogs	*Pasteurella pneumotropica*	Rodents
Chlamydia psittaci	Birds, fowl	*Pasteurella* spp.	Monkeys
Clostridium perfringens	Env., Humans, Animals, soil	Pneumococcus Type II	Rats, Guinea Pigs
Coccidioides immitis	Env., soil, Guinea Pigs, Rabbits	Pneumocystis carinii	Env., monkeys, animals
Corynebacterium bovis	Mice	Pneumonia Virus of Mice (PVM)	Mice
Corynebacterium kutscheri	Mice	Poxviruses	Rabbits, Sheep, Swine, Mice, Horses, Fowl, Goats, Cows
Coxiella burnetii	Cattle, sheep	*Pseudomonas aeruginosa*	Env., sewage, swine bldgs
Coxsackievirus	Humans, Mice, Rabbits, Hamsters, swine, primates	*Pseudomonas diminuta*	Rats, Guinea Pigs
Diplococcus pneumoniae	Monkeys	Reovirus	Humans, birds, mice
Echovirus	Humans, Mice. primates	Respiratory Syncytial Virus	Humans, Chimpanzees
Enterobacter cloacae	Humans, Env., Rabbits	Reston Virus	Monkeys
Equine rhinop-neumonitis	Horses	Rubella virus	Humans, Monkeys
Feline picomavirus	Cats	Sendai virus	Rodents, Hamsters
Francisella tularensis	Animals, Hamsters	Sialodacryoadenitis virus (SDAV)	Rats

Table 17.5 (continued)

Airborne pathogen	Source or infected animal	Airborne pathogen	Source or infected animal
Guineapig adenovirus	Guinea Pigs	Simian adenovirus	Primates
Haemophilus spp.	Rodents, Guinea Pigs, Rabbits	*Staphylococcus aureus*	Humans, sewage, rodents
Hantaan virus	Rodents	*Staphylococcus cohnii*	Rats
Influenza A virus	Humans, birds, pigs, nosocomial	*Staphylococcus haemolyticus*	Rats
Junin virus	Rodents	*Staphylococcus sciuri*	Rats
Klebsiella orthinolytica	Rodents, Rabbits	*Staphylococcus xylosus*	Rats
Klebsiella oxytoca	Rodents, Rabbits	*Streptobacillus moniliformis*	Rats
Klebsiella planticola	Rodents, Rabbits	*Streptococcus pneumoniae*	Rodents, Guinea Pigs, Rabbits
Klebsiella pneumoniae	Env., soil, Humans, Monkeys, Mice, swine bigs	*Streptococcus pyogenes*	Humans, Guinea Pigs
Marburg virus	Humans, monkeys	Theiler's virus	Mice
Measles virus	Humans, Monkeys	Vaccinia virus	Agricultural
Micromonospora faeni	Agricultural, moldy Hay, indoor growth	*Yersinia pestis*	Rodents, fleas, Humans
Micropolyspora faeni	Agricultural, indoor growth	*Yersinia pseudotuberculosis*	Rodents, Rabbits, Guinea Pigs

References

Allen K, Green H. 1987. Hospital outbreak of multi-resistant *Acinetobacter anitratus*: An airborne mode of spread? J Hosp Infect 9:110–119.

Andersson E, Horal P, Vahlne A, Svennerholm B. 2004. No cross-resistance or selection of HIV-1 resistant mutants in vitro to the antiretroviral tripeptide glycyl-prolyl-glycine-amide. Antiviral Res 61(2):119–124.

Andrei G, DeClercq E, Snoeck R. 2004. In vitro selection of drug-resistant varicella-zoster virus (VZV) mutants (OKA strain): Differences between acyclovir and penciclovir? Antiviral Res 61(3):181–187.

Araujo MW, Andreana S. 2002. Risk and prevention of transmission of infectious diseases in dentistry. Quintessence Int 33(5):376–382.

ASHRAE. 1999. Handbook of Applications. Atlanta: ASHRAE.

ASHRAE. 2003. HVAC Design Manual for Hospitals and Clinics. Atlanta: American Society of Heating, Ventilating, and Air Conditioning Engineers.

ASHRAE. 2008. Handbook of Applications: Chapter 16: Ultraviolet Lamp Systems. Atlanta, GA: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

Benirschke K, Garner FM, Jones TC, editors. 1978. Pathology of Laboratory Animals. New York: Springer-Verlag.

Berg M, Bergman BR, Hoborn J. 1991. Ultraviolet Radiation Compared to an Ultra-Clean Air Enclosure. Comparison of Air Bacteria Counts in Operating Rooms. JBJS 73(5):811–815.

Berg-Perier M, Cederblad A, Persson U. 1992. Ultraviolet radiation and ultra-clean air enclosures in operating rooms. J Arthroplasty 7(4):457–463.

Besch EL. 1980. Environmental quality within animal facilities. Lab Animal Sci 30(2):385–398.

Brachman P. 1970. Nosocomial infection – airborne or not?; American Hospital Association, pp. 189–192.

Breathnach A, deRuiter A, Holdworth G, Bateman N, O-Sullivan D, Rees P, Snashall D, Milburn H, Peters B, Watson J et al. 1998. An outbreak of multi-drug-resistant tuberculosis in a London teaching hospital. J Hosp Infect 39:11–17.

Brown IWJ, Moor GF, Hummel BW, Collins JP. 1996. Toward further reducing wound infections in cardiac operations. Ann Thorac Surg 62(6):1783–1789.

CDC. 2003. Guidelines for environmental infection control in health-care facilities. MMWR 52(RR-10).

Davis KA, Moran KA, McAllister CK, Gray PJ. 2005. Multi-drug resistant *Acinetobacter* extremity infections in soldiers. Emerg Infect Dis 11(8):1218–1224.

Del Mundo F, McKhann CF. 1941. Effect of ultra-violet irradiation of air on incidence of infections in an infant's hospital. Am J Dis Child 61:213–225.

DHHS. 1993. Biosafety in Microbiological and Biomedical Laboratories. Cincinnati, OH: U.S. Department of Health and Human Services.

Dumyahn T, First M. 1999. Characterization of ultraviolet upper room air disinfection devices. Am Ind Hyg Assoc J 60(2):219–227.

Durmaz G, Kiremitci A, Akgun Y, Oz Y, Kasifoglu N, Aybey A, Kiraz N. 2005. The relationship between airborne colonization and nosocomial infections in intensive care units. Mikrobiyol Bul 39(4):465–471.

Duvlis Z, Drescher J. 1980. Investigations on the concentration of air-borne germs in conventionally air-conditioned operating theaters. *Zentralbl Bakteriol [B]* 170(1–2):185–198.

EPRI. 1996. UVGI for Infection Control in Hospitals. Palo Alto, CA: Electric Power Research Institute. Report nr TA-106887.

EPRI. 1997. UVGI for TB Infection Control in a Hospital. Palo Alto, CA: Electric Power Research Institute. Report nr TA-107885.

Farrington M, Ling T, French G. 1990. Outbreaks of infection with methicillin-resistant *Staphylococcus aureus* on neonatal and burns units of a new hospital. Epidem Infect 105:215–228.

Fletcher LA, Noakes CJ, Beggs CB, Sleigh PA. 2004. The Importance of Bioaerosols in Hospital Infections and the Potential for Control Using Germicidal Ultraviolet Radiation. Murcia, Spain.

Gill KE. 1994. HVAC design for isolation rooms. HPAC July:45–52.

Goldner JL, Allen BL. 1973. Ultraviolet light in orthopedic operating rooms at Duke University. Clin Ortho 96:195–205.

Grieble H, Bird T, Nidea H, Miller C. 1970. Chute-hydropulping waste disposal system: A reservoir of enteric bacilli and *Pseudomonas* in a modern hospital. J Infect Dis 130:602.

Hart D, Sanger PW. 1939. Effect on wound healing of bactericidal ultraviolet radiation from a special unit: Experimental study. Arch Surg 38(5):797–815.

Higgons RA, Hyde GM. 1947. Effect of ultra-violet air sterilization upon incidence of respiratory infections in a children's institution. New York State J Med 47(7).

Hunskaar S, Fosse RT. 1993. Allergy to laboratory mice and rats: A review of its prevention, management, and treatment. Lab Anim 27:206–221.

Jain DL, Agarwal V. 1996. Multi-drug resistant invasive isolates of *Haemophilus influenzae*: A multi-center study in India: indiaclen ibis study group. J Clin Epidem 50(Suppl.1):16S.

Keikavousi F. 2004. UVC: Florida hospital puts HVAC maintenance under a new light. Engin Sys March:60–66.

Kowalski W, Bahnfleth WP. 1998. Airborne respiratory diseases and technologies for control of microbes. HPAC 70(6):34–48.
Kowalski WJ, Bahnfleth WP, Carey DD. 2002. Engineering control of airborne disease transmission in animal research laboratories. Contemporary Topics in Lab Animal Sci 41(3):9–17.
Kowalski WJ. 2006. Aerobiological Engineering Handbook: A Guide to Airborne Disease Control Technologies. New York: McGraw-Hill.
Kowalski WJ. 2007a. Air-treatment systems for controlling hospital-acquired infections. HPAC Eng 79(1):28–48.
Kowalski WJ. 2007b. Airborne superbugs: Can hospital-acquired infections cause community epidemics? Consult Specif Eng 41(3):28–36, 69.
Kowalski W. 2008a. UVGI for hospital applications. IUVA News 10(4):30–34.
Kowalski W. 2008b. Operating Room Aerobiology in the Alaska Native Medical Center: Air and Surface Sampling Results and Recommendations for Reducing Surgical Site Infections. Anchorage, AK: Alaska Native Medical Center.
Kowalski W, Bahnfleth W, Hernandez M. A Genomic Model for the Prediction of Ultraviolet Inactivation Rate Constants for RNA and DNA Viruses; 2009 May 4–5; Boston, MA. International Ultraviolet Association.
Kraissl CJ, Cimiotti JG, Meleney FL. 1940. Considerations in the use of ultra-violet radiation in operating rooms. Ann Surg 111:161–185.
Kundsin R. 1976. Operating Room as a Source of Wound Contamination and Infection. National Research Council, National Academy of Sciences, pp. 167–172.
Lidwell OM, Lowbury EJL, Whyte W, Blowers R, Stanley SJ, Lowe D. 1983. Airborne contamination of wounds in joint replacement operations: the relationship to sepsis rates. J Hosp Infect 4:111–131.
Linscomb M. 1994. AIDS clinic HVAC system limits spread of TB. HPAC February.
Lowell J, Kundsin R. 1980. Ultraviolet Radiation: Its Beneficial Effect on the Operating Room Environment and the Incidence of Deep Wound Infcetion Following Total Hip and Total Knee Arthroplasty. Murray Hill, NJ: American Ultraviolet Company. Report nr A-810.
Lowell JD, Kundsin RB, Schwartz CM, Pozin D. 1980. Ultraviolet radiation and reduction of deep wound infection following hip and knee arthroplasty. In: Kundsin RB, editor. Airborne Contagion, Annals of the New York Academy of Sciences. New York: NYAS, pp. 285–293.
Luciano JR. 1977. Air Contamination Control in Hospitals. New York: Plenum Press.
Mangram AJ, Horan TC, Pearson ML, Silver LC, Jarvis WR, HICPAC. 1999. Guideline for prevention of surgical site infection. Am J. Infect Control 27(2): 97–132.
McLean R. 1961. The effect of ultraviolet radiation upon the transmission of epidemic influenza in long-term hospital patients. Am Rev Resp Dis 83:36–38.
Miller WR, Jarrett ET, Willmon TL, Hollaender A, Brown EW, Lewandowski T, Stone RS. 1948. Evaluation of ultra-violet radiation and dust control measures in control of respiratory disease at a naval training center. J Infect Dis 82:86–100.
Moggio M, Goldner JL, McCollum DE, Beissinger SF. 1979. Wound Infections in Patients Undergoing Total Hip Arthroplasty. Ultraviolet Light for the Control of Airborne Bacteria. Arch Surg 114(7):815–823.
Overholt RH, Betts RH. 1940. A comparative report on infection of thoracoplasty wounds. J Thoracic Surg 9:520–529.
Ritter M, Olberding E, Malinzak R. 2007. Ultraviolet Lighting During Orthopaedic Surgery and the Rate of Infection. J Bone Joint Surg 89:1935–1940.
Robertson EC, Doyle ME, Tisdall FF, Koller LR, Ward FS. 1943. Use of ultra-violet radiation in reduction of respiratory cross-infections in a children's hospital. JAMA 121:908–914.
Sauer LW, Minsk LD, Rosenstern I. 1942. Control of cross infections of respiratory tract in nursery for young infants. JAMA 118:1271–1274.
Schneider M, Schwartenberg L, Amiel JL, Cattan A, Schlumberger JR, Hayat M, deVassal F, Jasmin CL, Rosenfeld CL, Mathe G. 1969. Pathogen-free isolation unit – three years′ experience. Brit Med J 29 March:836–839.

Sommer HE, Stokes J. 1942. Studies on air-borne infection in a hospital ward. J Pediat 21:569–576.
Tuffery AA, editor. 1995. Laboratory Animals: An Introduction for Experimenters. Chichester: John Wiley & Sons.
Wells WF. 1938. Air-borne infections. Mod Hosp 51:66–69.
Wells WF. 1955. Airborne Contagion and Air Hygiene. Cambridge, MA: Harvard University Press.
Wheeler SM, Ingraham HS, Hollaender A, Lill ND, Gershon-Cohen J, Brown EW. 1945. Ultraviolet light control of airborne infections in a naval training center. Am J Pub Health 35: 457–468.
WHO. 1988. Indoor air quality: Biological contaminants. Copenhagen, Denmark: World Health Organization. Report nr European Series 31.
Woodhall B, Neill R, Dratz H. 1949. Ultraviolet radiation as an adjunct in the control of post-operative neurosurgical infection. Clinical experience 1938–1948. Ann Surg 129:820–825.
Wright R, Burke J. 1969. Effect of ultraviolet radiation on post-operative neurosurgical sepsis. J Neurosurg 31:533–537.
Young DP. 1991. Ultraviolet Lights for Surgery Suites. Mooresville: St. Francis Hospital.