UVGI for Hospital Applications

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INTRODUCTION

Health Care facilities are subject to microbiological airborne hazards that can cause infections in both patients and health care workers. Hospital-acquired, or nosocomial, infections have been a persistent problem in hospitals and they can have complex multifaceted etiologies. It is possible that as much as a third or more of all nosocomial infections may be the result of airborne transmission at some point and, if so, air disinfection technologies may be able to reduce the nosocomial infection rate.

If the direct contact route predominates, as many experts believe, then surface disinfection technologies could also have a major impact. Combining air and surface disinfection may be an optimum approach to reduce infection rates and may very well be economical to implement. Existing health care guidelines for ventilation system design, pressurization, filtration, and disinfection procedures have historically held the problem at bay, but emerging nosocomial hazards and increasingly complicated etiologies are creating a demand for new control technologies.

This evolving and growing problem has spawned interest in both existing and developmental technologies, especially among engineers and health care professionals. This presentation summarizes applicable codes and standards, examines the epidemiology of airborne nosocomial infections and their aerobiological pathways, and reviews air and surface disinfection technologies such as ultraviolet germicidal irradiation (UVGI), which may offer more effective solutions. A summary of results from implementation of UVGI systems in hospitals is provided which demonstrates average nosocomial infection rate reductions of over 65%.

Guidelines, Codes, and Standards

Various guidelines, codes, and standards exist that offer details for designing health care facility ventilation systems (AIA 2001, ASHRAE 2003a & 2003b, CDC 1996 & 2003). Some guidelines specifically address problems like TB, nosocomial infections, and surgical site infections (CDC 2005, Wenzel 1981, Mangram et al 1999, Tablan et al 1994). While these guidelines provide adequate design information relating to airflow, air exchange rates, and filtration, they do not contain any specific guidelines for UVGI applications and are not reviewed here. In fact, the only current guidelines that provide any detailed information relating to UVGI air and surface disinfection are the draft IUVA guidelines (IUVA 2005).

The IUVA Guidelines include a description of the operating parameters of UVGI systems intended for effective air treatment, and these are equally applicable to health care applications as well as to commercial buildings and other facilities. The operating characteristics for successful UVGI system implementation do not differ (i.e. are not more stringent) for hospitals since performance criteria are already near a maximum for any UVGI system that meets the suggested guidelines. Included in the operating parameters are a recommended minimum of 0.25 seconds of UV exposure, an air velocity within the range of 500 fpm +/-100 fpm, and a recommended rating of URV 10 or higher, which corresponds to a minimum UV dose of 5 J/m2. Coupled with the requisite filters for hospital applications (per ASHRAE) such combined UVGI/filtration air cleaning systems will provide high removal rates for all nosocomial bacteria, fungi, and viruses.

Airborne levels in hospitals are not routinely monitored or regulated. For hospital air, WHO recommends relatively relaxed limits of 100 cfu/m^3 for bacteria and 50 cfu/m3 for fungi, but many facilities would fail to meet these (WHO 1988). Environmental fungal spores should be completely removed per filtration guidelines, and so the presence of any fungal spores in an OR should warrant investigation. According to the criteria of Federal Standard 209E (FD 209E) on cleanrooms, conventionally ventilated operating rooms rank less than class 3.5 (Durmaz et al 2005). A limit of 10 cfu/m3, 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, would probably be a more appropriate criterion for hospital ORs and ICU.

Airborne Nosocomial Epidemiology

Airborne nosocomial infections are those that transmit directly or indirectly by the airborne route, and they may cause respiratory (primarily pneumonia) and surgical site infections (SSIs). The cost of nosocomial infections in the U.S. is estimated to be about $4-5 billion annually and various sources estimate that they cause between 2 and 4 million nosocomial infections with some 20-80 thousand fatalities annually (Kowalski 2006). It is not known what fraction of these infections are due specifically to airborne microbes, but since many of these microbes are potentially airborne it could be assumed that a large fraction, perhaps 25% or more, involve airborne transmission at some point in the nosocomial etiology.

One source estimates that 10% of nosocomial infections are airborne while another suggests that 16% of ICU infections result from airborne pathogen transmission (Eickoff 1994, Durmaz et al 2005). In Intensive Care Units (ICUs), almost a third of nosocomial infections are respiratory in nature, but not all of these are necessarily airborne since many transmit by contact (Wilson 2001, Wenzel 1981). SSIs are non-respiratory but may be partly airborne in origin, such as when common microbes like *Staphylococcus* and *Streptococcus* settle on open wounds, burns, or medical equipment (Fletcher et al 2004).

Methicillin-resistant *Staphylococcus aureus* (MRSA) is a major nosocomial pathogen in many hospitals and is isolated with increasing frequency. According to one study, MRSA is the most frequently isolated airborne microbe (Durmaz et al 2005). SARS virus is one of the most hazardous nosocomial agents for hospital personnel, although no outbreaks have yet occurred in the US.

Health care professionals are routinely exposed to contagious respiratory infections like TB and influenza. In most cases where medical workers have contracted respiratory infections from inhalation, the root cause has often been inadequate local ventilation, malfunctioning systems and equipment, or administrative control problems (Castle and Ajemian 1987). Tuberculosis infections among health care workers are strongly associated with inadequate ventilation in general patient rooms and with the type and duration of work but no associations have been identified with ventilation of isolation rooms, based on a study by Menzies et al (2000).

Nosocomial Aerobiology

A review of the variety of pathogens responsible for nosocomial infections indicates that almost all of them are potentially airborne. However, most of these infections are probably produced by direct contact and contact with equipment. This does not mean that UVGI would not reduce the infection rate but merely that the etiology is complicated and that solutions may involve more than simple cleaning the air. If we examine the aerobiology of open areas in hospital facilities we often find that the airborne levels of microbes are not significantly different from levels we might find in ordinary office buildings. In a study of mold spores in the air of a hospital ward, Tormo et al (2002) found twenty-two different types of spores, with total concentrations of 175-1396 spores/m^3. The most frequently isolated were *Cladosporium*, *Ustilago* and various basidiospores. For *Aspergillus-Penicillium* spores, the concentration was higher indoors than outdoors, although for most spores lower levels were found indoors, with a mean indoor/outdoor ratio of 1:4.

In one study of airborne microbial contamination in the operating room and ICUs of a surgery clinic, Holcatova et al (1993) measured bacterial concentrations of 150-250 cfu/m^3. The most frequently isolated microorganisms included *Staphylococcus epidermis, S. haemolyticus, Enterococcus* spp., *Enterobacter, Pseudomonas* spp., *Micrococcus, Corynebacteria*, and *Streptococcus faecalis*. The microbes most frequently cultured in the air of operating rooms include *Staphylococcus epidermis* and *S.aureus. Streptococcus pyogenes* has been found in about 15% of preoperative throat swabs from patients (Dubuc et al 1973). The number of personnel in an operating suite influences the total counts of airborne bacteria

(Hambreaus et al 1977). Conversation among personnel can increase the bacterial load of the air, and contaminated face masks (measured postoperatively) occur in 9-10% of surgeons and nurses (Ritter 1984).

In general, hospitals do not normally sample their air, since there are no codes or guidelines that require such sampling, and they are often unaware of the indoor concentrations of airborne microbes in their operating rooms and ICUs. There would seem to be a general assumption that if the ventilation system is designed according to existing codes (i.e. ASHRAE or AIA) then the air will be of acceptable quality. A general review of the data for facilities that have attempted to measure airborne microbial levels indicates that this assumption needs reconsideration. In fact, these results beg the question of why there is no current requirement for hospitals to sample their indoor air, especially in operating rooms.

Aerobiological Pathways of Nosocomial Infections

Nosocomial infections can include so many potential pathways and stages that they are surely the most complex of all aerobiological etiologies. Sources can include bacteria and viruses from other patients, microbes from doctors and nurses, contamination of equipment, and environmental microbes from outdoor air (Kowalski 2006). It is thought that clouds of bacteria and skin squames released by persons tend to float around them before precipitating downwards (Sherertz et al 2001). Flatulence may explain how bacteria can get from the colon of operating room personnel into the open wound of a surgery patient.

The major sources of *S. aureus* in hospitals are septic lesions and carriage sites of patients and personnel. The anterior nares are the most common carriage site, followed by the perineal area. The principal mode of transmission is via transiently contaminated hands of hospital personnel, but airborne MRSA plays a role in respiratory tract MRSA infections. MRSA has been found in air samples collected in single-patient rooms and has been isolated from sinks, floors, and bed sheets, as well as from the patients' hands. MRSA recirculation in the air is enhanced by activity in the rooms, including changing of bed sheets.

Evidence suggests aerosol transmission of SARS virus has occurred through ventilation systems although the major transmission routes are close proximity airborne droplet infection and close contact infection. In previous outbreaks, index patients caused secondary infections in medical staff and inpatients. Ho et al (2003) found that hospital outbreaks of SARS typically occurred within one week after first admission of a SARS patient, and before isolation measures were implemented. Nosocomial transmission was effectively halted by enforcement of standard procedures to control transmission of high-risk airborne infections

Nosocomial Control Options

Current methods of controlling nosocomial infections, including isolation rooms and disinfection procedures, have proven adequate in the past but there is room for improvement, especially in the US health care system. New nosocomial hazards demand new focus on both causes and solutions.

Laminar airflow systems with 16-17 ACH supplied through HEPA filters are capable of holding OR airborne concentrations below 10 cfu/m^3 (Friberg and Friberg 2005). The use of HEPA filters, designed for radioactive contamination control, may represent uneconomical overkill when applied to the control of airborne microbes, and in one operating room test the HEPA filter provided no better reduction in airborne bacterial load than a 95% DSP filter (Luciano 1977). The combination of UVGI and high efficiency filters in the MERV 13-15 range may be able to provide performance virtually equivalent to HEPA filtration, thus offering health care facilities the possibility of reducing energy costs without increasing health risks. Current practices and guidelines concerning filtration levels in hospitals may be worth reconsideration from an energy point of view if nothing else.

A major potential source of fungal contamination in hospitals is filter bypass and maintenance problems. Filters should be checked for bypass and maintenance procedures requiring shutdown of the fans should be followed diligently; otherwise spores may enter the ventilation system and accumulate in carpeting and furnishings. Periodic inspection and sampling of the cooling coils and drain pans can help identify potential problems. Sampling floors and carpets for contamination is another prudent practice, and heavily contaminated carpets should be removed rather than cleaned.

UVGI systems have been in use in some operating rooms since at least 1937 and the results of these applications have been very promising. Reductions in post-operative infection rates of between 24-44% have been demonstrated (Goldner and Allen 1973). Overhead UVGI systems have been used to control surgical site infections and Upper Air UVGI systems have been used for the control of respiratory infections with similar success. The Home for Hebrew Infants in New York was able to bring a halt to a Varicella epidemic using UVGI. One study showed that UVGI could reduce airborne microbial concentrations to below 10 cfu/m^3 in the operating room (Berg-Perier et al 1992).

In spite of these early triumphs, UVGI continues to be largely ignored as an option by the health care field and regulatory agencies hardly mention their use. Upper Air UVGI systems can be cost-effective and simple to install but still require experienced consultation.

A review of the handful of UVGI applications in hospitals indicates that the net reduction in SSIs from overhead UVGI surgical systems averages about 78%, while the net reduction from Upper Air UVGI systems averages about 65% (Kowalski 2007). In-duct, forced air UVGI systems may be the safest, most effective, and most efficient type of installation for large facilities, but since few, if any, hospitals have yet installed them, no data are available regarding reduction of nosocomial infection rates.

Perhaps the one change that would have the most impact on nosocomial infections in this country is to establish national standards for aerobiological quality. Routine air sampling, practiced now in some other countries like Japan, will then provide a clearer picture of the relationship between airborne microbes and infection rates, and this will lead to measurement of nosocomial infection reduction rates for facilities that install air disinfection systems.

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