Engineering Control of Airborne Disease Transmission in Health Care Facilities

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Abstract—**Hospital acquired illness or "nosocomial" illness is of increasing concern to public health administrators, hospitals, physicians and patients. Engineering infection control measures are used to reduce the concentration and prevent the spread of these particles throughout a building in order to decrease exposure to and risk of illness from infectious pathogens. The engineer who attempts to deal with microbial indoor air quality finds that pertinent microbiological information exists in abundance but not in easily digestible forms. This paper will provide a brief review of the problem of controlling airborne disease transmission in healthcare facilities with emphasis on medical microbiology and aerobiology in order to offer some conclusions regarding the potential for engineering control of infectious diseases.**

Keywords—**microorganisms, airborne, infection control, healthcare, environment.**

I. Introduction

The importance of good air quality in controlling and preventing airborne infections in healthcare facilities cannot be neglected. Healthcare facilities, such as hospitals, have to pay particular care to prevent the spread of airborne infectious diseases. Many of those who are susceptible to these problems may be patients such as people with pre-existing health problems, the frail elderly, people with cancer who are going through treatment, and those who may have depressed immune systems. Some hospitals also have special units that need particular care in terms of indoor air quality such as bone marrow units, neonatal intensive care units, and burn units. It is not only patients who are at risk. Healthcare workers have a higher risk than most people of being infected by airborne diseases. For example, healthcare workers who work at facilities in cities have positive tuberculosis (TB) skin tests (meaning they have been exposed to the TB bacteria) about eight times more often than the rest of the population. In addition, at least 17 healthcare workers have developed drug-resistant TB as a result of working in these environments [1].

Infection control is achieved by a combination of administrative, engineering, and personal protection methods. Engineering methods that are usually carried out by the building's heating ventilation, and air conditioning (HVAC) system function to prevent the spread of airborne infectious pathogens by diluting (dilution ventilation) and removing (exhaust ventilation) contaminated air from a room, controlling the direction of airflow and the air flow patterns in a building. These control measures are not mutually exclusive but rather each is an essential and necessary component of a comprehensive infection control program in any health care facility.

This article summarizes the relevant literature of medical microbiology and aerobiology in a manner that engineers may find useful and informative and that will facilitate the design of HVAC systems intended to reduce the threat. The general principles presented here can be applied to any indoor environment, including office buildings, schools, residences, hospitals, and isolation wards.

II. Airborne transmission of infectious diseases

Controversy still exists over the role of airborne transmission in infectious disease although, for some diseases, air is clearly the principal carrier. Airborne transmission is the spread of infectious pathogens, which may include fungi, bacteria, and viruses, through the air over large distances. Infectious pathogens vary in size and can be dispersed into the air in *drops of moisture* after coughing or sneezing.

Exposure to microorganisms in droplets produced during a sneeze or cough constitutes a form of direct contact transmission because these large particles >5 μm in size tend to fall out of the air within a matter of minutes, resulting in the potential exposure of susceptible persons within about 1 meter of the source person. Examples of pathogens spread in this manner are influenza virus, rhinoviruses, adenoviruses, and respiratory syncytial virus. Because droplets do not remain suspended in the air, special air handling and ventilation are not required to prevent droplet transmission. Droplet transmission *must not* be confused with airborne transmission.

In dry atmosphere, many of the micron-sized droplets will rapidly evaporate to *droplet nuclei*. Droplet nuclei (the residuals of droplets ranging in size from 1–5 μm) as well as dust particles containing the infectious agent, can remain suspended for hours and spread by diffusion or air currents. This is called airborne transmission. The spread of airborne infectious diseases via droplet nuclei is a form of indirect transmission. Moreover, if inhaled, they are small enough to

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bypass the protective mechanisms of the respiratory tract and settle in the lung where they may cause infection. Microorganisms transmitted by airborne transmission include diseases such as tuberculosis, rubeola and varicella. For microorganisms carried in this manner special air handling and ventilation are required to prevent airborne transmission.

Several environmental pathogens have life-cycle forms that are similar in size to droplet nuclei and may exhibit similar behavior in the air. The spores of *Aspergillus fumigatus* have a diameter of 2–3.5 μm, with a settling velocity estimated at 0.03 cm/second (or about 1 meter/hour) in still air. With this enhanced buoyancy, the spores, which resist desiccation, can remain airborne indefinitely in air currents and travel far from their source [2].

In case of new emerging infectious disease, because the route of transmission initially may not be known, it is prudent to suspect there is airborne transmission until otherwise proven.

III. Airborne Pathogens in Health Care Facilities

Pathogens are any disease-causing microorganism, but the term applies to any microbial agent of respiratory irritation, including allergens or toxigenic fungi. An airborne pathogen database includes approximately one hundred viruses, bacteria, and fungi that may pose health hazards in indoor environments. The fungi and some bacteria, most notably the actinomycetes, form spores. Since spores are characteristically larger and more resistant to factors that will destroy viruses and bacteria, the engineer may find it more convenient to consider spores a definitive and separate category.

The single most important physical characteristic by which to classify airborne pathogens is size since it directly impacts filtration efficiency [3]. Figure 1 presents a graphic comparison of airborne respiratory pathogens in which the spores, bacteria, and viruses can be observed to differentiate well, based on size alone.

Airborne respiratory pathogens in health care facilities are numerous and dangerous, although non-respiratory pathogens can also be airborne. Certain infections of the skin or eyes, nosocomial infections of open wounds and burns, and contamination of medical equipment may occur by the airborne route. One of the most important classifications of airborne respiratory pathogens, which have both medical and engineering relevance, is according to his contagiousness. Communicable (contagious) diseases come mainly from humans, while non-communicable diseases hail mostly from the environment.

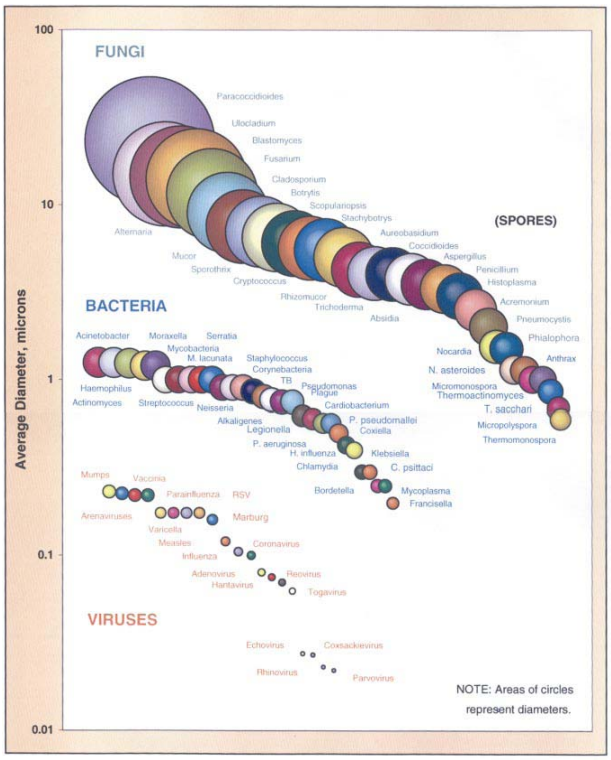

Fig. 1 Relative size of airborne respiratory pathogens [3]

However, many microbes that are endogenous to humans or are environmentally common may cause opportunistic infections in those whose health has been compromised. These occur primarily as nosocomial, or hospital-acquired infections. Table 1 lists communicable respiratory pathogens.

Non-communicable pathogens are almost entirely represented by fungal or actinomycete spores and environmental or agricultural bacteria that cause respiratory infections, allergic reactions, and toxic reactions (Table 2). The abbreviation "spp." denotes that infections may be caused by more than one species. Bacteria and viruses are commonly introduced into the healthcare environment from infected patients: they can be violently dispersed through sneezing or coughing, or released into the air through the shedding of skin squames [4]. Fungi enter the hospital through infiltration or because of incomplete filtration [5]. Aspergillus is a particularly dangerous fungus in healthcare environments. Because this species is ubiquitous throughout the northern hemisphere, its spores are ubiquitously found in air and contaminate anything in contact with air [6].

The composition of fungal species indoors tends to reflect that of the outdoors.

Table 1 Communicable Respiratory Pathogens

Airborne pathogen	Disease	Source	Diameter microns
VIRUS			
Adenovirus	colds	humans	0.08
Coronavirus	colds	humans	0.11
Cocxackievirus	colds	humans	0.027
Echovirus	colds	humans	0.028
Morbilivirus	measles	humans	0.12
Influenza	flu	humans, birds	0.1
Parainfluenza	flu	humans	0.22
Paramyxovirus	mumps	humans	0.23
Parvovoirus B19	fifth disease	humans	0.022
Reovirus	colds	humans	0.075
Respiratory Syncytial Virus	pneumonia	humans	0.22
Rhinovirus	colds	humans	0.023
Togavirus	rubella	humans	0.063
Varicella-zoster	chikenpox	humans	0.16
BACTERIA			
Mycobacterium tuberculosis	TB	humans	0.86
acinetobacter	opportunistic infections	environmental	1.3
Actinomyces israelii	actinomycosis	humans	1.0
Alkaligenes	opportunistic infections	humans	0.75
Bordetella pertusis	whooping, cought	humans	0.25
Cardiobacterium	opportunistic infections	humans	0.63
Corynebacteria diphteria	diphteria	humans	1.0
Haemophilus influenzae	meningitis, pneumonia	humans	0.43
Haemophilus parainfluenzae	opportunistic infections	humans	1.0
Klebsiella pneumoniae	opportunistic infections	environmental	0.4
Moraxella catarrhalis	opportunistic infections	humans	1.3
Mycobacterium avium	cavitary pulmonary dis.	environmental	1.2
Mycoplasma pneumoniae	pneumonia	humans	0.25
Neisseria meningitis	meningitis	humans	0.8
Pseudomonas aeruginosa	opportunistic infections	environmental	0.57
Serratia marcescens	opportunistic infections	environmental	1.3
Staphylococus aureus	opportunistic infections	humans	1.0
Streptococus pneumoniae	pneumonia, otitis media	humans	0.9
Streptococus pyogenes	scarlet fever, pharyngitis	humans	0.9
FUNGI			
Pneumocystis carinii	pneumocystosis	environmental	2
Cryptococus neoformans	cryptococcosis	environmental	5.5

Table 2 Non-communicable Respiratory Pathogens

Airborne pathogen	Disease	Source	Diameter microns
FUNGI			
Aspergillus spp.	aspergillosis	environmental	3. 5
Absidia corymbifera	zygomycosis	environmental	3. 8
Rhizopus stolonifer	zygomycosis	environmental	8
Mucor plumbeus	mucomycosis	environmental	7. 5
Histoplasma capsulatum	histoplasmosis	environmental	3
Blastomyces dermatitidis	blastomycosis	environmental	14
Coccidioides immitis	coccidioidomycosis	environmental	4
Penicillium spp.	respiratory irritation, allergic reactions	environmental	3. 3
Micromonospora faeni	respiratory irritation, allergic reactions (farmer's lung)	environmental (agricultural)	1
Thermoactinomyces vulgaris	respiratory irritation, allergic reactions (farmer's lung)	environmental (agricultural)	1
Alternaria alternata	miycotoxicosis / respiratory irritation	environmental	14. 4
Cladosporium spp.	chromoblastomycosis / respiratory irritation	environmental	9
Helminthosporium	exrtinsic allergic alveolitis/ respiratory irritation	environmental	12.2
BACTERIA			
Legionella pneumophila	Pontiac fever, Legionnaires' dis.	environmental	0. 6
Mycobacterium intracellulare	cavity pulmonary dis.	environmental	1. 2
Mycobacterium kansasii	cavity pulmonary dis.	unknown	0. 86

Some fungal species, most notably A*spergillus* and *Penicillium*, are often found to account for 80 percent of indoor spores [3]. Spores will germinate and grow in the presence of moisture and nutrients in locations such as basements, drain pans, and on refrigerator coils. If spore concentrations indoors consistently exceed outdoor levels, the building can be inferred to contain an indoor amplifier [3]. Table 3 identifies some pathogenic environmental bacteria that have been found growing indoors or on HVAC equipment. Amplification may result in airborne concentrations above the outdoors and may reach unhealthy levels. Legionnaire's Disease provides a sentinel example of pathogenic microbial amplification by an engineered system. Occasionally, some contagious bacteria disseminated from humans can be found in water, equipment, or in dust, but these are transient occupants and unlikely to grow or survive long outside of human hosts.

Table 3 Bacteria that may grow indoors

Airborne pathogen	Location of growth
Acinetobacter	potable water
Klebsiella pneumoniae	potable water
Legionella pneumophila	potable water, cooling towers
Micropolyspora faeni	humidifiers
Pseudomonas aeruginosa	indoor dust, potable water, evaporative air cooler, humidifiers
Pseudomonas spp.	filters
Serratia Marcescens	potable water
Thermoactinomycetes vulgaris	air conditioners, humidifiers

IV. Airborne pathogens control

A facility's HVAC system is its first line of defense against airborne pathogens. Effective filtration of airborne microorganisms can limit the introduction of environmental fungi into the hospital environment and check the spread of internally generated airborne bacteria and viruses throughout the facility. Likewise, effective filtration of healthcare exhaust air protects the immediate community from the discharge of potentially infectious air generated within the facility.

Some environmental bacteria and fungi can grow in HVAC systems. In one study, nine of 11 air filters that had been in use less than 1 month showed fungal growth on them. The two filters that did not have growth on them had been treated with an antimicrobial agent [7]. One bone marrow unit learned the hard way about the importance of cleaning filters when a 6-year-old patient developed pneumonitis and died. The child's autopsy showed that the child had been infected with *Aspergillus fumigatus*. When investigators found that staffs on the unit were also suffering some health problems, they inspected the air filters, which were found to be completely clogged with high levels of *Aspergillus fumigatus* [8]. The niches for microbial growth must be identified and then controlled. These components should be disassembled and cleaned with a strong disinfectant, such as chlorine, when fungal or bacterial growth is found. Some systems provide built-in ultraviolet germicidal irradiation (UVGI) for continuous disinfection.

Isolation through pressurization control is commonly used to prevent migration of microbes from one area to another. The design principle is to ensure that airflow proceeds from areas of low contamination potential to those of high contamination potential. Negative air pressure is recommended for contaminated areas and is required also for isolation of patients with infections spread by the airborne route. To do this, the air is exhausted from the room at a rate that's greater than air being delivered to the room. High-risk areas such as operating rooms, critical care units and transplant units require to be positively pressurized. Ultra clean unidirectional air may be required in some units such as hematology or intensive care due to the level of immunosuppression of the patients. To minimize airborne particles, air must be circulated into the room with a velocity of at least 0.25m/sec through a high efficiency particulate air (HEPA) filter. If particles 0.3 microns in diameter are removed, the air entering the room can be classified clean and free of bacterial contamination [9].

V. Conclusions

The infectious aerosols of consideration are those that are generated as particles of respirable size by both human and environmental sources and that have the capability of remaining viable and airborne for extended periods in the indoor environment. Appropriate engineering design and maintenance can play a significant role in reducing the risks for medical professionals as well as for patients. Each of the available engineering controls alternatives has advantages and limitations, but optimization for any application is always possible if the microbial indoor air quality goals are clearly specified.

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