

SECTION I

INTRODUCTION

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1. INTRODUCTION

1.1 Brief Overview of Tuberculosis

Patients in hospital isolation rooms constantly produce transmissible airborne organisms by coughing, sneezing or speaking. These actions, if not under control, commonly result in spreading airborne infection.

Tuberculosis (TB) infection occurs after inhalation of a sufficient number of bacteria-carrying air droplets that are expelled during coughing, sneezing, laughing or even talking by an infected person (Federal Register (1993)). TB is a chronic or acute bacterial infection that primarily attacks the lungs, but which may also affect the kidneys, bones, lymph nodes, and brain. When particles of this infection are inhaled, bacteria lodge in the lungs and multiply. Symptoms include coughing, chest pain, shortness of breath, loss of appetite, weight loss, fever, chills, and fatigue. The elderly, children and people with weakened immune systems, including AIDS, cancer and diabetes sufferers, are most susceptible to the disease.

In the mid-1800s, tuberculosis was considered a disease that affected mainly the upper class society. However, as the epidemic continued and claimed a larger and larger circle of people, often the poor and disadvantaged, the victims themselves were often blamed for contracting the infection. The development of effective antibiotics during from the 1940s to the 1960s led the medical establishment to believe that the disease had been eradicated. During the early 1980s the number of cases began to increase and new strains of drug-resistant TB emerged. Since TB is an airborne disease, public concern was high and pressure was placed on Congress and the medical establishment to solve the problem. Funding for TB research at the National Institute of Health increased tenfold between 1991 and 1995 from \$3.5 million to \$35 million.

In 1996, the United States enjoyed its fourth consecutive year of declining TB case rates with just over 21,000 recorded cases, the lowest number since 1985. However, by 1996 the rate had stayed the same or actually increased in 23 states relative to 1995 (Centers for Disease Control and Prevention (US), 1997) and the incidence of multi-drug resistant TB were rising at an alarming rate.

Globally, TB is the most infectious disease, accounting for approximately three million deaths in 1995 (Raviglione (1997)), with one third of the global population believed to be infected with *Mycobacterium Tuberculosis*. Further, it is responsible for a total of one-fourth of all preventable deaths among adults in the rest of the world, and is the leading cause of death among people with AIDS.

Contamination depends on a number of things, including principally the rate at which bacilli are discharged and the number of bacilli released from the infectious source. Other factors include the virulence of the bacilli and more external factors, such as the ventilation flow rate in the space. Finally, the potency of airborne bacteria has a significant effect on the contamination level. Primary TB, for example, does not have noticeable symptoms and is not, in its early stages, contagious. During this spell, immune cells form a protective wall between inactive bacteria and the surrounding organs. As long as the immune system remains strong, the TB bacteria can remain dormant for many years. If the immune system becomes weakened by HIV infection, malnutrition, aging, or other factors, the infection may develop into secondary TB. In secondary TB, the formerly dormant bacteria break through the protective wall, destroy tissue in the lungs, and may invade the rest of the body via the bloodstream. At this stage, carriers of TB may begin to infect other individuals.

The past few years have seen remarkable productivity in the development of understanding of transmissible airborne diseases such as tuberculosis. Active discussions are underway within research communities regarding how best to design clinical trials of the most promising potential testing, isolation, and vaccination procedures. The challenge in the near future includes furthering basic comprehension of the human host response to mycobacterium tuberculosis while applying this knowledge to rational candidates and planning out the future of removing this threat to human health.

1.2 Control of Tuberculosis in Populated Buildings

The solutions available to current health care providers are often considered inadequate and expensive, since most involve extensive research, drug therapy, and costly vaccines. Treating a patient infected with a drug-resistant form of TB can cost as much as \$125,000. A much better tool for fighting airborne diseases is the long-term control and elimination of the infection as a threat in the United States and the rest of the world.

In order to prevent the transmission of airborne infections patients with diagnosed TB are generally placed in isolation rooms equipped with high efficiency ventilation systems operating at high supply flow rates in order to remove airborne bacteria from the rooms. However, extremely large ventilation rates are needed to effectively remove the infectious particles from the room, and the effectiveness of the removal becomes progressively less as ventilation rate is increased. Research has shown that although ventilation systems lessen the chance of infection by dispersing bacteria, the increase of ventilation rate does not, as a whole, guarantee good control to the spreading airborne infection. Also, negative pressure can be used as a preventative measure, and this is created by exhaust fans which remove the contaminated air and create a pressure differential that reduces the flow of bacteria to other areas. In locations where airflow control is not feasible or cost-effective, high efficiency particulate air (HEPA) filters are used in

air ducts to disinfect the air. However, proper installation, maintenance and monitoring of the HEPA filters are essential.

Another means of minimizing the risk from airborne bacteria within an isolation room is to apply ultraviolet germicidal irradiation (UVGI) to the area. UVGI is defined as optical radiation in the short-wave UV-C spectrum capable of killing certain airborne bacteria. Ultraviolet lighting has been shown to reduce, but not eliminate, the threat of infection by killing bacteria in confined spaces. UVGI potentially holds promise of greatly lowering the concentration of airborne bacteria and thus controlling the spread of airborne infection among occupants in an enclosed space.

Ultraviolet radiation has a wavelength range that is shorter than visible light but longer than x-rays; its range extends from 100 to 400 nanometers (nm) and is divided into three zones; UV-A, long wave (320 nm – 400 nm); UV-B, medium wave (280 nm – 320 nm); and UV-C, short-wave (100 nm-280 nm). Ultraviolet radiation is a component of sunlight. UV-A is responsible for the tanning effect, whereas UV-C contains the most effective disinfection wavelengths. Close-range exposure to the bare lamps that emit UVGI can cause superficial eye and skin irritation. However, the use of specially designed lamp fixtures for upper-room UVGI applications ensures that occupants will only be exposed indirectly to low UV-C intensities. UVGI is generated by lamps made specifically for this purpose and should not be mistaken with lamps that produce higher UV wavelengths that are used for tanning, medical (e.g., psoriasis therapy), industrial (e.g., curing plastics), or commercial (i.e., black light) purposes. Nor should the short-wave ultraviolet wavelengths produced by germicidal lamps be confused with the long wave UV in sunlight that can cause skin cancers and cataracts of the eye due to overexposure.

The use of UVGI is not a new phenomenon. Simple UV fixtures were developed and used during the 1940s and 1950s for air disinfection. During the 1980s, when the cases of TB rose dramatically, these machines were unsuitable for modern medical facilities due to lower ceiling heights. In particular, patients were subject to unacceptable levels of radiance to their eyes and skin. However, more recent lamp designs, which utilize louvers to reduce exposure in the lower regions of the room, are capable of maintaining UV intensities to around $0.1 \mu\text{W}/\text{cm}^2$.

Currently, the most widely used applications of UVGI are in the form of passive upper-room fixtures containing UVGI lamps that irradiate a horizontal layer of airspace above the occupied zone. These units are quiet, easy to maintain and very cost-effective. These lamps are designed to kill bacteria that enter this upper irradiated zone, and are highly reliant on vertical room air currents. The survival probability of bacteria after being exposed to UVGI depends on the UV irradiance as well as the exposure time in a general form (Federal Register (1993)):

$$\% \text{ Survival} = 100 \times e^{-kt} \quad (1.1)$$

Where I = UV irradiance, $\mu\text{W}/\text{cm}^2$
 t = time of UV exposure
 k = microbe susceptibility factor, $\text{cm}^2/\mu\text{W}\cdot\text{s}$

Increasing room air mixing enhances upper-room UVGI effectiveness by bringing more bacteria into the UV zone. However, rapid vertical air circulation also implies insufficient exposure time. It must be understood and considered that the ability to remove or kill bacteria in isolation rooms is greatly influenced by the flow pattern of ventilation air. Some of the parameters which affect these matters are listed below:

- Ventilation flow rate
- Locations of air supplies/exhausts
- Supply air temperature
- Location of the UV fixture(s)
- The power of the UV output
- Room configuration
- Susceptibility of the particular species of bacteria

In order to achieve a better performance of UVGI, as well as higher removal effectiveness within the ventilation system, the airflow patterns need to be fully understood and well organized. Therefore, it is necessary to conduct a systematic study in order to address minimizing the risk from airborne organisms in hospital isolation rooms while all the important parameters are being analyzed.

Previous research has been almost entirely based on empirical methods (Chang et al. (1985), Macher et al. (1992), Mortimer et al. (1995)), which are time-consuming and tend to be limited by the cost of modifying physical installations of the ventilation systems. The absence of UV treatment systems has also imposed limitations on previous research. Therefore, design guidance for isolation rooms in the past has often relied on gross simplifications without fully understanding the effect of the complex interactions of room airflow and UV treatment systems. It should be noted that, although this study looks specifically at isolation rooms, same principles

can be applied to other regions in which infection from TB is a possibility, such as waiting rooms, or other areas within a healthcare facility.

Computational Fluid Dynamics, or CFD, (sometimes known as airflow modeling) expresses the principles of conservation of mass, momentum and thermal energy within a fluid. The basis of CFD is formed into a solution that may be expressed in terms of partial differential equations and has been proven to be very powerful and efficient in research projects involving parametric studies on room airflow and contaminant dispersion (Jiang et al.(1997), Jiang et. al (1995), Haghghat et al. (1994)). The solution is carried out iteratively based on a set of coupled algebraic equations that relate the value of many small volumes (grid cells) within a system. For this reason, CFD is employed as the main approach in the present study. The output of CFD simulations can be presented in many ways, adding to the value of the method. For example, useful details such as field distributions can be displayed, as well as overviews on the effects of parameters involved. Further, an algorithm was developed which allowed the particles to be tracked through the room studied, and which allowed the UV dosage to be calculated for the particle. From this data, such information such as the number of particles vented by the ventilation system, the number of particles killed by UV, and the number of viable particles in the room at any time could be established.