Editorial

Isolation Rooms for Tuberculosis Control

Mark Nicas, PhD, MPH, CIH; Joan E. Sprinson, MPH, CIH; Sarah E. Royce, MD, MPH;
Robert J. Harrison, MD, MPH; Janet M. Macher, ScD, MPH

A survey of respiratory isolation rooms in seven St. Louis hospitals reported in this month's issue.[1] begins to verify a general suspicion that many hospitals lack adequate facilities for treating patients with airborne infectious diseases such as tuberculosis (TB). Respiratory isolation rooms should be under continual "negative pressure" relative to hallways and anterooms, so that air flows *from* the more travelled areas into the isolation rooms, even when connecting doors are opened. To highlight their findings, Fraser et al[1] reported that 45% of designated respiratory isolation rooms in their study failed this test. Although a larger number of isolation rooms in newer hospitals had anterooms, even these did not ensure the desired direction of airflow. None of the hospitals had a regular program to evaluate the airflow rates and pressure differences for their isolation facilities.

These findings complement other recent surveys on the adequacy of respiratory isolation rooms. In 1992, the Centers for Disease Control and Prevention (CDC) and the American Hospital Association surveyed a statistical sample of U.S. hospitals to evaluate the status of their TB control measures and to identify areas needing improvement. Preliminary results indicated that 27% of the hospitals[2] lacked isolation rooms meeting minimum CDC recommendations.[3] It is likely that if the rooms in the presumably complying hospitals were tested, a number would be found deficient.

In the commentary below, we offer our thoughts on designing and testing respiratory isolation rooms. We also address several issues specifically related to TB control: estimating the number of isolation rooms needed, protecting high-risk healthcare workers, the physical science underlying airborne infection control, and principles of infection risk assessment and risk management.

CONTAINING TB BACILLI IN ISOLATION ROOMS

The reason for housing TB patients in negative pressure isolation rooms is to prevent release of *Mycobacterium tuberculosis* into hallways and other areas, and thereby to protect susceptible patients and hospital staff. However, as discussed later, containing *M tuberculosis* in an isolation room does not protect staff who enter that room to care for a TB patient.

Negative pressure is created in a room by exhausting more air than is supplied. The CDC currently recommends a minimum supply rate of six air changes per hour (ACH).[3] Thus, if a room's volume is 2,000 feet,[3] the supply ventilation rate should be 12,000 feet[3] per hour. In part, the purpose of this supply air is to dilute the airborne *M tuberculosis* in the room. To maintain a slight negative pressure (a vacuum of approximately 0.05 inches water gauge has been suggested),[4] the exhaust system should remove the hourly supply air volume plus 10%.[5] In our example, the room's exhaust air rate would be 13,200 feet[3] per hour.

The optimum direction for airflow inside an isolation room is uncertain. Some designers believe that supply air should be delivered near the entry door and be removed at the opposite side of the room, thereby causing air to flow away from the door (and away from persons entering the room), past the patient's bed, and out. However, if a wall- or ceiling-

From the Center for Occupational and Environmental Health, School of Public Health, University of California, Berkeley, California (Dr. Nicas), and the California Department of Health Services, Division of Communicable Disease Control, Tuberculosis Control Branch (Dr. Royce and Ms. Sprinson), Division of Environmental and Occupational Disease Control, Occupational Health Surveillance and Evaluation Program (Dr. Harrison), and the Environmental Health Laboratory Branch, (Dr. Macher) Berkeley, California.

Address reprint requests to Janet M. Macher, ScD, MPH, Environmental Health Laboratory Branch, California Department of Health Services, 2151 Berkeley Way, Berkeley, CA 94704-1011.

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mounted supply air diffuser were just above or inside a doorway, the turbulence created by the supply air could facilitate escape of airborne *M tuberculosis* when someone opened the door.

The CDC recommends that air removed from an isolation room be exhausted directly outside a building and that the point of external exhaust be remote from air intakes." If isolation room exhaust air is recirculated, contrary to recommendations,[3] it must first pass through an air cleaner, such as a high-efficiency particulate air (HEPA) filter, to remove suspended pathogens.

Isolation rooms should be equipped with manometers, which measure room air pressure relative to adjoining spaces such as anterooms and hallways. Manometers should have visible displays, so that hospital staff can read pressure differences directly and note how various activities affect containment. Further, a manometer should have an audible or visible alarm that activates when the desired negative pressure fails. Hospital engineers also should measure isolation room supply and exhaust rates periodically (eg, every 6 to 12 months). These determinations can be made by measuring airflow rates inside the supply and exhaust air ducts (if accessible), or by measuring airflow directly at the supply air diffusers and exhaust air grills.

The use of smokesticks to visualize the direction of airflow at doorways and inside rooms (as described by Fraser et al[1] is simple and convenient, and a useful complement to manometer readings, but not without potential problems. First, it is possible for air to flow into (or out of) some sections of an open doorway, but in the opposite direction elsewhere.[6] Therefore, releasing smoke at only one location in a doorway (eg, at floor level) may fail to detect other patterns of air movement. Second, when visualizing airflow direction in a closed room, it is advisable to release smoke on both sides of the door to ensure detection of all leaks. Third, the smoke from a titanium tetrachloride smokestick is very irritating, so no one (especially, no patients) should occupy the rooms being tested, and the tester should wear an appropriate respirator and eye protection. Alternatively, staff might use other visible tracers such as dry ice in water when conducting a containment test.

PLANNING RESPIRATORY ISOLATION FACILITIES

Fraser et al[1] recommend that hospital administrators consider increasing the numbers of functional isolation rooms, but do not discuss how a facility determines how many rooms it needs. Ideally, institutions should address this issue as part of regional planning directed by state and local TB control programs. Institutions also must comply with existing state codes concerning isolation facilities. Planners need basic information to make these decisions: the number of hospitalized patients with diagnosed or suspected TB, the number of multidrug-resistant TB patients admitted (because these patients require longer isolation), trends in TB prevalence in the general community and in the hospital patient population, and the availability of functional isolation rooms locally. We recognize that such data are seldom readily available, in which case the first step is to acquire or estimate them. At times, hospitals may be unable to accommodate known or suspected TB patients because the facility lacks functional isolation rooms or because all such rooms are occupied. Therefore, every hospital needs a policy to ensure that such patients can be referred to facilities where they will be cared for properly.

PROTECTING HEALTHCARE PERSONNEL

Establishing and maintaining effective isolation rooms is fundamental to controlling TB transmission to other patients and the general hospital staff, but use of isolation rooms per se does not offer sufficient protection for healthcare workers who care for TB patients. Although many expelled aerosol droplets are large when initially released, they quickly evaporate to become smaller droplet nuclei that can reach the alveolar region of the respiratory tract.[3,7,8] A healthcare worker who is physically close to a TB patient will be exposed to this infectious aerosol *before* dilution ventilation (even at 6 ACH) has a chance to reduce the aerosol concentration significantly. Therefore, what Fraser et al[1] term *extraordinary measures,* such as respirators for employees entering isolation rooms, in fact should be required routinely. The California Department of Health Services (CDHS) recommends that healthcare workers caring for patients in isolation rooms wear HEPA-filter respirators at a minimum.

To the extent feasible, hospitals should use specially exhausted tents, hoods, and booths for known or suspected infectious TB patients undergoing procedures that generate respiratory aerosols, eg, sputum induction and bronchoscopy. These enclosures reduce release of droplet nuclei into the general room air and into the breathing zones of healthcare workers. However, even with such source control, the CDHS recommends that healthcare workers wear HEPA-filter respirators. Where exhaust-ventilated enclosures are not available, the CDHS recommends that healthcare workers wear powered air-purifying respirators with HEPA filters during high-risk medical procedures.

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We acknowledge that the above recommendations are controversial. The use of patient enclosures and the wearing of respirators may frighten and alienate patients, restrict movement, impede verbal and other communication, and in general, interfere with healthcare delivery. While these arguments have merit, they do not justify allowing healthcare workers to avoid using proper protective equipment. Instead, healthcare professionals should bring their objections to the attention of equipment manufacturers so that they can redesign their products.

Although the physical principles governing the aerodynamic behavior of droplet nuclei may appear to come from a science far removed from infection control, practitioners cannot afford to be unfamiliar with these concepts because the behavior of droplet nuclei ultimately determines a worker's exposure to airborne pathogens.

APPLYING PHYSICAL SCIENCE PRINCIPLES

M tuberculosis droplet nuclei follow the same physical laws as nonviable particles. The best available evidence indicates that the aerodynamic diameter of droplet nuclei is 1 to 5 μm.[3,7,18] There is a substantial body of knowledge on the aerodynamic behavior of nonviable particles in this size range and, absent any evidence to the contrary, one reasonably may apply this knowledge to TB control. Given this framework, we draw several conclusions.

First, removing droplet nuclei at their point of generation using exhaust-ventilated enclosures will be more effective than diluting droplet nuclei after their release into room air. Second, where respirators are used, HEPA-filter media will be more efficient at capturing droplet nuclei than the filter media in particulate respirators. Note that what the CDC terms a "particulate respirator," respirator manufacturers and the National Institute for Occupational Safety and Health (NIOSH) call a "disposable dust/mist-filter respirator." Third, all air-purifying respirators permit some inward leakage of droplet nuclei around the face seal perimeter, but a powered air-purifying respirator (recommended by NIOSH)[9] permits far less leakage (eg, 2%) than a particulate respirator (eg, 10% to 20%). Because no air-purifying respirator can exclude all droplet nuclei, it is preferable to use engineering controls, such as exhaust-ventilated enclosures, to reduce the initial release of *M tuberculosis* as much as possible.

RISK ASSESSMENT

The preceding framework allows us to estimate quantitatively the risk of *M tuberculosis* infection for healthcare workers, and other staff and patients. Such estimation is based on a TB transmission model termed the Wells-Riley equation.[8] In brief, a susceptible person's risk of infection depends on the number of TB patients in a room, the per-patient emission rate of droplet nuclei containing viable *M tuberculosis*, the removal rate of these particles by ventilation and other control mechanisms, and the subject's breathing rate and time in the room. Not surprisingly, the model predicts that by reducing the expected number of *M tuberculosis* droplet nuclei inspired, one reduces the risk of infection. More importantly, by examining the ability of various control measures to reduce the expected number of inhaled *M tuberculosis*, one can estimate the reduction in risk associated with different controls and compare their cost effectiveness.

We admit that there is much uncertainty associated with such risk estimates and that presently there is no simple way to determine how many *M tuberculosis* an infectious patient emits. At the same time, physical science principles and the Wells-Riley equation provide an objective and consistent approach for assessing and managing *M tuberculosis* infection risks.

RISK MANAGEMENT

There are two basic questions relevant to TB risk management that the infection control profession and government agencies do not appear to have considered fully. First, what is an acceptable annual risk of *M tuberculosis* infection for susceptible healthcare workers? Second, on what type of evidence should a TB control program base decisions?

To address the first question, we ask readers to consider if it is allowable for 1 in 10 workers to be infected each year; 1 in 100; 1 in 10,000; or some other number? Based on unofficial statements made at conferences and meetings, it appears that many practitioners would accept a 1% to 2% annual *M tuberculosis* infection rate across all hospital staff. We believe such rates are too high and are inconsistent with the level of protection provided workers in other industries.

When computing an infection rate across all hospital personnel, the denominator typically includes a large number of individuals not exposed directly to TB patients and a smaller number who are exposed. Consequently, the true infection rate in the exposed group is understated, eg, although the rate computed across all hospital personnel might be only 1 (0.1%) in 1,000, the exposed group might have an alarming 10% infection rate. Agencies regulating occupational exposures typically use a rate of 1 in 1,000 to 1 in 10,000 as a permissible lifetime cancer risk for workplace exposure to carcinogenic chemicals. This level is much higher than risk criteria used by environmental regulatory agencies for general public exposure to hazardous materials, eg, 1 in 100,000 or 1 in l,000,000 We

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propose that the annual infection risk for workers exposed to TB patients be limited to 1 (0.01%) in 10,000. This annual risk will result in a cumulative infection risk of 4 (0.4%) in 1,000 over a 40-year working lifetime.

A practical reason for asking infection control practitioners to define acceptable risk is that, to make choices in a control program, one needs a target risk level. For example, if 6 ACH corresponded with an annual infection rate of 0.1% for personnel working in isolation rooms, while 60 ACH reduced this rate to 0.01%, should we recommend 6 ACH or 60 ACH? We realize that providing 60 ACH is unreasonable, but government advisors currently are reviewing the basis for recommending 6 ACH and likely may suggest increasing the ventilation rate. The air change rate they choose should be both achievable and scientifically supportable.

The second basic question related to risk management asks whether we should base risk management decisions solely on institutional *M tuberculosis* infection rates (using these to assess the efficacy of control measures retrospectively) or whether these decisions should be made proactively with the best available evidence and a firm basis in physical science. Although this question is primarily philosophical in nature, it involves some of the ideas already presented and deserves to be addressed more thoroughly at another time.

CONCLUSIONS

Fraser et al[1] have done a great service by collecting baseline information on respiratory isolation rooms and by reminding us that we must measure pressures and airflow rates routinely. Nevertheless, the provision of respiratory isolation is but one component of a comprehensive program to prevent TB transmission in hospitals. Controls must include prompt reporting of all known or suspected TB cases, thorough contact investigations, rapid diagnosis of infectious cases so that they can be placed in isolation, adequate initial treatment, routine TB skin testing and training of staff, and medical follow-up of discharged patients. We strongly encourage close collaboration between hospital epidemiologists, infection control practitioners, and state and local health departments.

As discussed in this article, measures to protect exposed healthcare workers must be based on physical science concepts and sound risk assessment/risk management principles. If we ignore these concepts and principles, or reject them as inconvenient, the practice of TB control becomes subjective and prone to great error. We thereby create the potential to protect inadequately not only healthcare workers and other staff but also patients. An occupationally exposed staff member with infectious TB could put literally hundreds of patients at risk, some of whom may be immunocompromised. We hope that our arguments and the experience of Fraser et al[1] will convince readers who have not examined their isolation facilities recently to do so without delay and also to review other aspects of their TB control programs.

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