

EFFICACY OF PORTABLE FILTRATION UNITS IN REDUCING AEROSOLIZED PARTICLES IN THE SIZE RANGE OF MYCOBACTERIUM TUBERCULOSIS

William A. Rutala, PhD, MPH; Suzanne M. Jones, MT(ASCP), MPH; John M. Worthington, MPH; Parker C. Reist, ScD; David J. Weber, MD, MPH

ABSTRACT

OBJECTIVE: To evaluate engineering control measures to prevent nosocomial transmission of diseases such as tuberculosis, we studied four portable high-efficiency air filtration units, including three high-efficiency particulate air (HEPA) filtration units, for their ability to remove aerosolized particles.

DESIGN: Studies were conducted in either a non-ventilated aerosol chamber or in a hospital isolation room that met CDC guidelines for TB control (negative pressure, ≥ 6 air changes per hour, air exhausted directly to the outside). The rooms were challenged with aerosolized mineral oil in the size range of 0.3 to 5.0 μm at levels 10 to 20 times the normal airborne particle load in the room at baseline. Airborne particles were counted with a laser counter capable of simultaneously measuring sizes ≥ 0.3 , ≥ 0.5 , ≥ 1.0 , and ≥ 5.0 μm . Experimental runs were conducted with the filtration units in the center or corner of the chamber or room, and the particle counter in the center of the room or at the exhaust vent.

RESULTS: Portable filtration units were effective in accelerating the removal of aerosolized submicron particles. In the nonventilated room, time required by the various portable filtration units for removal of 90% of aerosolized particles (≥ 0.3 μm) ranged from a low of 5 to 6 minutes to a high of 18 to 31 minutes, compared to the control (no filtration unit), >171 minutes. In the hospital room, individual filtration units removed 90% of aerosolized particles (≥ 0.3 μm) in times ranging from 5 to 8 minutes to 9 to 12 minutes, compared to the control (no filtration unit), 12 to 16 minutes. The location of the portable filtration unit (center versus corner) did not affect the clearance rate of airborne particles.

CONCLUSION: Our data indicate that portable filtration units can rapidly reduce levels of airborne particles similar in size to infectious droplet nuclei and, therefore, may aid in reducing the risk of tuberculosis exposure (*Infect Control Hosp Epidemiol* 1995;16:391-398).

INTRODUCTION

Surveillance data reported by the Centers for Disease Control and Prevention (CDC) have revealed that the long-standing yearly declines in tuberculosis incidence halted in 1984. Since then, an estimated 52,000 excess cases have occurred in the United States.¹ Reasons postulated for the resurgence of tuber-

culosis include the human immunodeficiency virus (HIV) epidemic, a decrease in funding of healthcare agencies responsible for tuberculosis control, the epidemic of crack cocaine use, increased numbers of homeless individuals, increased prison populations, and increased immigration from areas with endemic tuberculosis. The increased susceptibility of patients infected

From the Department of Hospital Epidemiology, UNC Hospitals (Drs. Rutala and Weber, Ms. Jones); Division of Infectious Diseases (Drs. Rutala and Weber); Health and Safety Office (Mr. Worthington); and Department of Environmental Sciences and Engineering (Dr. Reist), University of North Carolina at Chapel Hill.

The authors wish to express gratitude to the following contributors to this study: Dr. Raymond W. Hackney, Mr. Premkumar Muthedath, and Mr. Chang-Fu Hsu for technical assistance with equipment; Ms. Pauline Lyna and Dr. Gregory Samsa for statistical assistance; and Ms. Eva Clontz for editorial assistance. They also would like to thank the manufacturers who loaned them their equipment.

Address reprint requests to William A. Rutala, PhD, MPH, Division of Infectious Diseases, 547 Burnett-Womack Bldg., CB #7030, University of North Carolina at Chapel Hill, Chapel Hill, NC, 27599-7030.

94-OA-045. Rutala WA, Jones SM, Worthington JM, Reist PC, Weber DJ. Efficacy of portable filtration units in reducing aerosolized particles in the size range of Mycobacterium tuberculosis. Infect Control Hosp Epidemiol 1995;16:391-398.

with HIV for developing tuberculosis is felt to be the major reason for the recent increase in tuberculosis incidence.^{1,2} Approximately 4% of all HIV-infected persons will develop disease with *Mycobacterium tuberculosis*. The management of HIV-infected persons has been associated with nosocomial transmission of *M tuberculosis* for several reasons, including the atypical presentation of tuberculosis in HIV-infected persons; the higher prevalence of nontuberculous infection, leading to failure to institute precautions in patients with positive acid-fast sputum smears; delayed recognition of *M tuberculosis* due to overgrowth with *M avium complex*; frequent use of cough-inducing procedures, such as aerosolized pentamidine treatment; and failures of standard treatment regimens in this immunocompromised group.^{2,4}

Further complicating the current epidemic of tuberculosis is the increased number of outbreaks with multidrug-resistant (MDR) strains.⁵⁻⁹ Several of these outbreaks have occurred in the healthcare setting⁵⁻⁹ and have involved both patients^{5,9} and healthcare providers.^{5,8}

The increased incidence of tuberculosis and reports of outbreaks of MDR strains have led the CDC and medical groups to promulgate guidelines concerning tuberculosis prevention and control in special population groups,¹⁰⁻¹² treatment,¹³⁻¹⁵ and prevention and control of nosocomial transmission.¹⁶ Recently, the CDC has published a guideline¹⁷ and the Occupational Safety and Health Administration has developed an enforcement policy¹⁸ designed to prevent transmission of tuberculosis within healthcare settings. This guideline states that an "effective tuberculosis infection control program requires early detection, isolation, and treatment of persons with active tuberculosis." This is to be achieved by the "application of a hierarchy of control measures, including 1) the use of administrative measures to reduce the risk of exposure to persons with infectious tuberculosis, 2) the use of engineering controls to prevent the dispersion and to reduce the concentration of infectious droplet nuclei, and 3) the use of personal respiratory protective equipment in areas where there is still a risk of exposure to *M tuberculosis*, such as tuberculosis isolation rooms."¹⁷ The suggested environmental controls for patients with known or suspected infectious tuberculosis include the use of private rooms maintained at negative pressure with respect to the corridor, a minimum of six air changes per hour, and air exhausted directly to the outside. Supplemental control measures include HEPA filtration of the air or placement of ultraviolet (UV) lights in exhaust vents.

Retrofitting existing hospital rooms and waiting rooms to meet these specifications will be difficult, time consuming, and expensive. For this reason, we

investigated whether portable room filtration units could effectively clear the air of particles (0.3 to 1.0 μm) smaller than or equal to droplet nuclei (1 to 5 μm). Clearance of submicron particles represents a greater challenge to the efficiency of portable filtration units than particles in the size range of droplet nuclei.

METHODS

Portable Filtration Units

The following portable filtration units were studied: Enviracaire, Compact Model RS0180 (BioSafety Systems, San Diego, CA); Microcon MAP-800 (Biological Controls, Eatontown, NJ); Model 7100B NSA Environmental Air System (National Safety Associates Limited, Memphis, TN); and ACCU V400 (Tri-Dim, Louisa, VA). For this study, the Microcon and Tri-Dim filter units were run at their mid-range airflow setting (ie, Microcon, 440 CFM; Tri-Dim, 175 to 210 CFM). The NSA unit was run at its "high" setting (120 CFM). Designation as HEPA filtration requires removal of at least 99.97% of particles $>0.3 \mu\text{m}$ in diameter. Three of the filtration units meet the criteria of portable HEPA filtration units (Table 1). The NSA unit, which has a 95% filtering capacity, does not meet this specification. For convenience, the term "portable filtration units" will be used to refer to all the units tested in this study. The Enviracaire unit (flow rate 150 CFM) was purchased specifically for this study. All other units were on loan from the manufacturers. The measured airflow rates at the settings employed in this study were as follows: Microcon, 390 CFM; Tri-Dim, 338 CFM; Enviracaire, 117 CFM; and NSA, 80 CFM. All units used new air filters at the commencement of the study. Further specifications of these units are detailed in Table 1.

AEROSOL GENERATION AND PARTICLE COUNTING IN AEROSOL CHAMBER

Initial tests were conducted in an aerosol chamber that measured 9.5 ft \times 10 ft and was 8 ft high. The room had a tight-fitting door and no air supply or exhaust vents.

Mineral oil aerosols were generated by a Laskin nozzle aerosol generator, which operated at 18 pounds per square inch gauge. For the aerosol chamber, a mean of 53.3% (standard deviation [SD], ± 6.0) of the particles were >0.3 to $\leq 1.0 \mu\text{m}$ and a mean of 43.4% (SD, ± 5.1) of the particles were >1.0 to $\leq 5.0 \mu\text{m}$. The concentration of airborne particles was detected by the APC-1000 Airborne Particle Counter, which employs an optic laser (Atcor, San Jose, CA; loaned by Tri-Dim). This counter is capable of simultaneously counting particles of sizes greater than 0.3

TABLE I
COMPARISON OF STRUCTURAL AND OPERATING CHARACTERISTICS OF PORTABLE FILTRATION UNITS

Machine	Machine Dimensions (HWD, in)	Filter Size (in ²)	Airflow (ft ³ /min)	Filter Efficiency*	Noise Levels (db[A])†	Cost (Unit/Filter)	Comments‡
Enviraicare	11×16 dia	264	150	99.97%	≤50	\$195/\$95	E,FI,a
NSA	28×18×16	100	90(low), 120 (high)	95%	≤50, ≤50	\$489/\$90	C,FI,b,c,d
Microcon	45×18×18	272	100-725	99.97%	51, 54, 61	\$2,195/\$185-245	B,D,E,G,H,I
Tri-Dim	32×14×14	144	400§	99.99%	≤50, 52, 62	\$2,100/\$89	A,D,E,G,H,I

‡ Advantages

- A—UV lamps standard
- B—UV lamps may be added
- C—2 airspeed settings
- D—Variable airspeed settings
- E—Multidirectional exhaust outflow
- F—Gas/odor filter standard
- G—Gas/odor filter optional
- H—Filtration unit sealed with leakproof gasket
- I—Indicator that filter needs to be changed

‡ Disadvantages

- a—Only a single airflow setting
- b—Unidirectional exhaust front-facing outflow
- c—Difficult to transport (small wheels)
- d—Does not meet HEPA filtration specifications (99.97%)

* Units of 99.97% filter efficiencies meet criteria for being classified as HEPA unit.

† As measured in this study.

‡ Comments

§ Average at maximum setting.

μm, 0.5 μm, 1.0 μm, and 5.0 μm. The counter was set to sample for the first 45 seconds of every minute. An electronic database was created for all experimental runs. Data were recorded as particles per cubic foot.

The aerosol was directed away from the wall. The aerosol generator was activated from outside the room and run for 10 seconds. The particle counter was located 3 ft from the aerosol generator (Figure 1A). Separate experimental runs were conducted with the portable filtration units near the center of the room or in the corner of the room.

AEROSOL GENERATION AND PARTICLE COUNTING IN HOSPITAL ROOM

Efficacy tests were conducted in a single hospital room of the University of North Carolina Hospitals (Figure 1B). The internal volume of the hospital room (excluding bathroom) was 1,824 cu ft. The room was maintained at negative pressure with respect to the corridor with the door closed (−170 cfm). The supply airflow was 200 cfm, and the exhaust airflow was 365 cfm, resulting in 6.5 air changes per hour, based on the supply airflow rate, and 12.2 air changes per hour, based on the exhaust airflow rate. The hospital room had air directly exhausted to the outside. All experi-

ments were conducted with the door to the bathroom closed, although the position of the door did not affect the negative pressure relationship between the room and the corridor. The room used a central ventilation system that provided a constant supply air volume.

As before, mineral oil aerosols were generated by a Laskin nozzle aerosol generator. Overall, a mean of 47.2% of the particles (SD, ±6.2) were >0.3 to ≤1.0 μm, and a mean of 48.0% (SD, ±5.0) were >1.0 to ≤5.0 μm. The aerosol generator was placed near the head of the patient's bed (Figure 1B). The aerosol generator was activated from inside the room and run for 20 seconds. Separate experimental runs were performed with the portable filtration units in either the corner of the room or the center of the room, and with the particle counter in the center of the room or at the exhaust vent (Figure 1B). This resulted in four sets of experiments for each machine. All experiments were run at least in duplicate.

ANALYSIS OF PARTICLE CLEARANCE RATES

Control runs were conducted without a portable filtration unit operating. For experimental runs, the portable filtration units were activated 3 to 7 minutes after the generation of an aerosol, when the particle

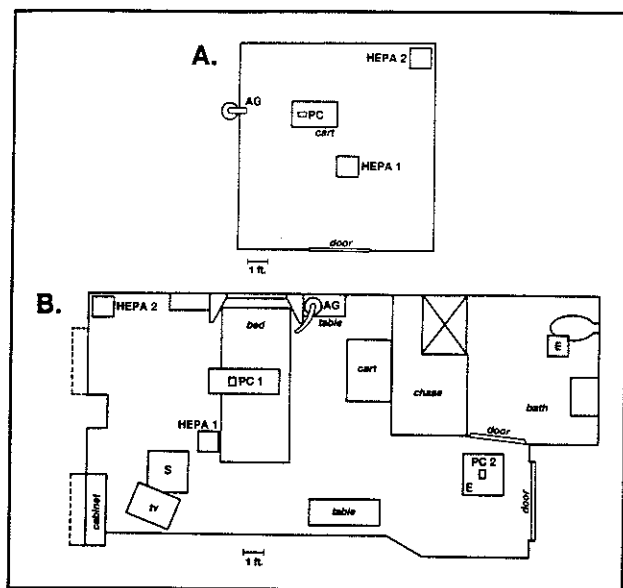


FIGURE 1. (A) Diagram of aerosol chamber demonstrating placements of aerosol generator, filtration unit, and particle counter. Abbreviations: AG, aerosol generator; PC, particle counter; HEPA 1, filtration unit, position 1; HEPA 2, filtration unit, position 2.

(B) Diagram of hospital room demonstrating placements of aerosol generator, filtration unit, and particle counter. Abbreviations: AG, aerosol generator; PC 1, particle counter, position 1; PC 2, particle counter, position 2; HEPA 1, filtration unit, position 1; HEPA 2, filtration unit, position 2; S, supply vent; E, exhaust vents.

levels in the room were no longer fluctuating. Efficiency was calculated as the time to achieve particle clearance of 50%, 90%, and 100%. The percentage of clearance was calculated as follows ($[\text{peak level of particles} - \text{background level of particles}] \times [1 - \text{clearance desired, ie, 0.50, 0.90, 1.00}] + [\text{background level of particles}]$). Baseline particle levels were determined just prior to aerosol generation for each experimental run.

The relative efficiency of the individual portable filtration units was determined by using the Wilcoxon Rank Sum test. Calculation of the Wilcoxon Rank Sum combined the data from the experimental runs regardless of filtration unit or counter placement. Statistical significance was set at alpha (P value) $\leq .05$.

MEASUREMENT OF NOISE LEVELS

Noise levels were determined in a single patient room in the hospital. Noise levels were measured by the Permissible Noise Dosimeter (Model Micro-15, Quest Electronics, Oconomowoc, WI), which was placed at the head of the patient's bed. The Micro-15 has a frequency response similar to that of the human ear (A-weighted response) and is capable of measuring levels between 50 and 146 decibels (dB[A]).

For all tests, the portable filtration units were placed in the corner of the room, 11 ft from the head of the bed. Portable filtration units were tested at all

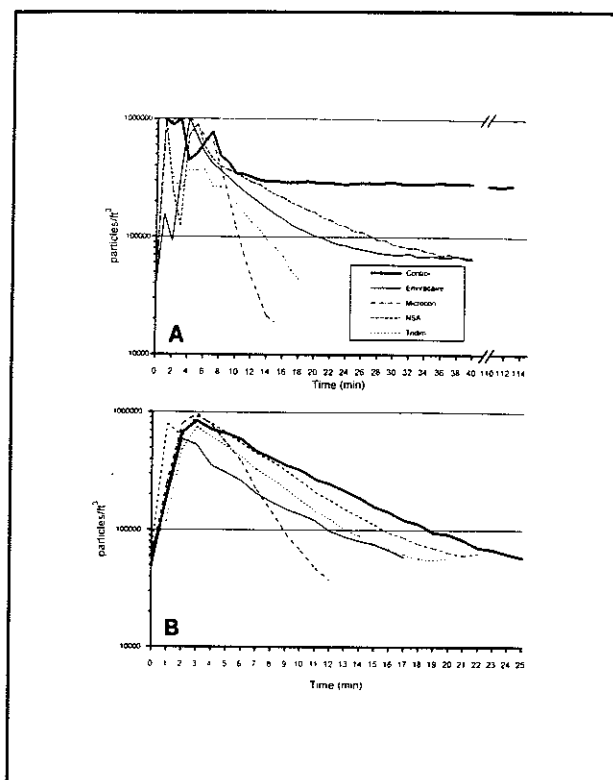


FIGURE 2. (A) Example of filtration efficiencies of portable filtration units in closed aerosol chamber. Data shown are derived from single runs for each filtration unit studied and a control run with no filtration unit operating. Data display clearance of particle $>0.3 \mu\text{m}$. Filtration unit was located in center of the room. See text for complete data.

(B) Example of filtration efficiencies of portable filtration units in hospital room. Data shown are derived from single runs for each filtration unit studied and a control run with no filtration unit operating. Data display clearance of particles $>0.3 \mu\text{m}$. Filtration unit and particle counter were located in center of the room. See Table 2 for complete data.

airflow settings. Noise levels were recorded after the measured level had stabilized.

RESULTS

Efficacy of Portable Filtration Units in a Nonventilated Aerosol Chamber

All four portable filtration units demonstrated the ability to clear aerosolized mineral oil droplets rapidly when tested in a nonventilated aerosol chamber (Figure 2A). The location of the portable filtration units did not affect clearance of aerosolized particles.

The time to achieve a 50% clearance of particles $\geq 0.3 \mu\text{m}$ was variable and due in large part to mixing. Results following two runs with portable filtration units in the center of the room and two runs with portable filtration units in the corner were as follows: NSA, 2, 9, 7, and 8 minutes; Tri-Dim, 5, 6, 6, and 7 minutes; Envirocaire, 3, 4, 2, and 4 minutes; Microcon, 2, 3, 3, and 3 minutes; and control (no portable filtration unit), 3 minutes. The time to achieve a 90%

clearance of particles $\geq 0.3 \mu\text{m}$ was as follows: NSA, 18, 31, 24, and 28 minutes; Tri-Dim, 11, 13, 12, and 14 minutes; Enviracaire 14, 15, 13, and 15 minutes; Microcon, 5, 5, 6, and 6 minutes; and control (no portable filtration unit), >171 minutes. Comparing the mean times for 90% clearance, the most effective machine was the Microcon (390 cfm), followed by the Tri-Dim (338 cfm), Enviracaire (117 cfm), and NSA (80 cfm). It is important to note that unit flow rates may be the most important factor in the rate of overall particle clearance. However, statistical evaluation of this question was not possible because of the limited number of experimental and control runs.

EFFICACY OF PORTABLE FILTRATION UNITS IN A VENTILATED HOSPITAL ROOM

Overview

Aerosolized particles were cleared much more rapidly in a hospital room than when generated in a nonventilated aerosol chamber without filtration units operating. This occurred because the dilution ventilation system also removed airborne particles, not because of improved unit performance. Excellent run-to-run consistency was demonstrated for clearance times when measuring clearance to 50% and 90% of peak levels. Particles were cleared in a nonlinear fashion (Figure 2B). Initial clearance was logarithmic, but at values near baseline levels, extended clearance was noted (Figure 2B). Further, more run-to-run variability was noted in the time to reduce peak particle levels to baseline.

Compared with control runs, each portable filtration unit effectively cleared aerosolized particles $\geq 0.3 \mu\text{m}$ (mean times for 90% removal): Tri-Dim, 10.2 minutes; Microcon, 6.3 minutes; NSA, 10.8 minutes; and Enviracaire, 10.5 minutes (all $P < .03$). In 2×2 comparison statistical tests, the Microcon unit was more effective than any other portable filtration unit, and the Enviracaire, Tri-Dim, and NSA were not statistically different.

Effect Of Portable Filtration Unit Placement and Counter Placement

We studied the effects of placing the portable filtration units either in the center of the room (recommended by Microcon) or in the corner of the room (as is likely to be done in clinical practice). We measured the concentration of aerosolized particles in either the center of the room or at the room's exhaust vent. Thus, for each portable filtration unit, a total of four combinations of portable filtration unit placements and counter placements were possible (Table 2). The location of the portable filtration units (center or corner) did not affect clearance of aerosolized particles. Placement of the

particle counter at the exhaust vent resulted in greater measured clearance times for the Enviracaire ($P = .038$) and Microcon ($P = .036$) units.

Clearance of Aerosolized Particles by Particle Size

The removal of particles by either normal room ventilation or portable filtration units appeared similar among particles $>0.3 \mu\text{m}$ or $>1.0 \mu\text{m}$ (Table 2). Approximately 50% of all particles were in the size range of 0.3 to $1.0 \mu\text{m}$.

Noise Levels

In all cases, noise levels were within accepted federal standards (Table 1).

DISCUSSION

The resurgence in tuberculosis and reports of multiple outbreaks of nosocomially transmitted tuberculosis have led to new control measures to prevent transmission within healthcare settings. Tuberculosis is transmitted by inhalation of droplet nuclei generated by patients with pulmonary tuberculosis. Such nuclei are in the size range of 1 to $5 \mu\text{m}$. Riley and colleagues demonstrated that the concentration of infectious droplet nuclei in the air in tuberculous wards was very low, averaging only one infectious dose per 11,000 cu ft of ward air.¹⁹ Because the average person breathes approximately 500 cu ft per day, the transmission potential ordinarily is quite low in the short term. However, prolonged exposure or contact with patients producing a large number of airborne organisms results in a significant risk for healthcare workers.

Prevention of transmission requires prompt identification and isolation of patients with active pulmonary tuberculosis, initiation of appropriate therapy, use of protective respiratory equipment (eg, HEPA-filter respirators) by healthcare personnel who must enter an infectious patient's room, patient education regarding minimization of aerosol generation (eg, covering the mouth when coughing), and use of ventilation controls. Ventilation controls are designed to decrease the concentration of droplet nuclei within the infectious patient's room and to prevent the recirculation of infectious particles to other hospital locations. Such ventilation controls include use of negative pressure isolation rooms, a minimum of six air changes per hour, and air exhausted directly to the outside. To prevent the escape of infectious droplet nuclei into adjacent areas, the isolation room door must be kept closed. Other supplemental control measures include the use of portable filtration units, germicidal UV lamps,^{16,17} and control booths for use during cough-inducing procedures. Retrofitting existing hospital rooms for air exhausted directly to the

TABLE 2
EFFICACY OF FILTRATION UNITS IN REDUCING AEROSOLIZED MINERAL OIL DROPLETS IN A HOSPITAL ROOM

Filtration Unit	Unit Placement	Counter Placement	% Decreases	Time (min) for Indicated Particle Size Decrease		
				>0.3 μm	>0.5 μm	>1.0 μm
None		Center	50%	5,5,5,5	5,5,5,5	4,4,4,5
			90%	14,14,14,16	13,14,14,15	13,13,13,14
			100%	26,26,>31,67	26,>26,>31,67	26,>26,>31,68
		Vent	50%	4,6	4,6	4,5
			90%	12,14	12,14	12,14
			100%	26,32	24,32	27,>35
Enviraicare	Center	Center	50%	3,3	3,3	2,3
			90%	7,9	7,9	8,9
			100%	11,14	12,14	>13,>14
		Vent	50%	4,5	4,4	4,4
			90%	10,19	10,19	10,15
			100%	16,29	>16,>29	>16,>29
	Corner	Center	50%	3,3	3,3	2,3
			90%	8,9	8,9	8,9
			100%	17,18	17,19	17,>22
		Vent	50%	3,6	3,6	3,6
			90%	9,13	9,14	9,14
			100%	18,20	18,22	18,>31
Microcon	Center	Center	50%	3,3	3,3	2,2
			90%	5,5	5,5	4,5
			100%	8,8	8,8	11,>11
		Vent	50%	3,3	3,3	3,3
			90%	6,8	6,8	6,8
			100%	7,15	7,16	8,21
	Corner	Center	50%	3,3	3,3	3,3
			90%	6,6	6,6	6,8
			100%	9,10	9,10	10,11
		Vent	50%	4,4	4,4	4,4
			90%	7,7	7,7	7,7
			100%	10,10	10,11	12,12
NSA	Center	Center	50%	4,4	4,4	3,4
			90%	10,11	11,13	10,11
			100%	17,18	18,18	>18,19
		Vent	50%	4,6	4,5	4,5
			90%	10,12	10,12	11,12
			100%	17,19	18,19	20,22
	Corner	Center	50%	5,5	5,5	4,4
			90%	12,12	11,12	11,11
			100%	19,20	19,20	>19,20
		Vent	50%	4,4	4,4	4,4
			90%	9,10	9,10	10,10
			100%	13,16	15,16	18,18

(Table continued on page 397)

outside or for HEPA filter units or germicidal UV lamps within the exhaust vents is technically difficult and expensive. For this reason, we explored the efficacy of portable filtration units in clearing rooms of aerosolized particles. For maximal efficacy, all portable filtration units should be maintained as specified by the manufacturer (eg, filter change) and recom-

mended by the CDC.¹⁷

Our tests suggest that portable filtration units are highly effective in clearing aerosolized particles in a room (760 cu ft) with no ventilation. In this setting, a portable HEPA filtration unit maximally can clear 90% of particles within 5 minutes, whereas 90% reduction did not occur in a control run monitored for greater than

TABLE 2 (Continued)

EFFICACY OF FILTRATION UNITS IN REDUCING AEROSOLIZED MINERAL OIL DROPLETS IN A HOSPITAL ROOM

Filtration Unit	Unit Placement	Counter Placement	% Decreases	Time (min) for Indicated Particle Size Decrease		
				>0.3 μm	>0.5 μm	>1.0 μm
Tri-Dim	Center	Center	50%	3,4	3,4	3,3
			90%	9,10	9,10	9,9
			100%	13,17	14,17	>17,18
		Vent	50%	4,5,5	4,5	4,5,5
			90%	10,11,11	10,11	10,10,10
			100%	17,>17,18	17,>17,18	17,>17,19
	Corner	Center	50%	4,7	4,7	4,6
			90%	9,12	9,11	9,11
			100%	15,15	15,16	17,>19
		Vent	50%	4,5	4,5	4,5
			90%	9,11	9,11	9,10
			100%	14,>17	14,>17	16,>17

120 minutes. In a hospital room (1,824 cu ft) that met the CDC-recommended ventilation characteristics for isolation of tuberculosis patients (6 air exchanges per hour, air directly exhausted to the outside, and negative pressure), a portable HEPA filtration unit operating at approximately 400 cfm maximally could clear 90% of >0.3 μm particles within 5 to 8 minutes, as compared to 12 to 16 minutes without supplemental HEPA filtration. Particle clearance by portable filtration units largely will depend on the relative airflow rate of individual units. At 400 cfm, a portable HEPA filtration unit provides approximately 13 air changes per hour in a hospital room with 1,800 cu ft. Using a specially constructed ventilation-filtration unit, Marier and Nelson demonstrated rapid clearance of aerosolized particles or bacteria in a test chamber and of aerosolized particles in a hospital isolation room.²⁰

Healthcare professionals providing direct patient care to infected patients may be protected from inhaling droplet nuclei by use of masks or particulate respirators and by ventilation controls. Although there are no documented failures of surgical masks in providing protection, theoretical problems with surgical masks that have been described include incomplete filtration of droplet nuclei and face-seal leakage.²¹⁻²³ Even the more efficient HEPA filter respirators will not offer complete protection if not properly fitted or worn.^{23,24} The main ventilation control measures to decrease exposure of healthcare professionals are high levels of air change rates and the use of negative pressure rooms. Portable HEPA filtration units may decrease the risk to healthcare professionals by further reducing the concentration of droplet nuclei. Portable HEPA filtration units will be most useful as a supplement in poorly ventilated rooms. However, it should be recognized that no ventilation control measure will reduce the risk of

occupational exposure to infectious droplet nuclei to zero.

Transport of droplet nuclei via recirculated air within the hospital may pose a hazard to patients and staff in remote locations. Use of direct out-exhausted air, HEPA filtration units in exhaust ducts, or UV germicidal lamps in exhaust ducts should provide nearly complete protection. However, use of portable HEPA filtration units in combination with the exhausting of air from the patient's room through high-efficiency filters (90% to 99% efficiency filters for particles 1 to 5 μm), prior to being recirculated, may address potential environmental concerns and result in significant energy savings.

We agree with many of the CDC guidelines regarding the proper use and maintenance of portable HEPA filtration units. The CDC guideline states that portable HEPA filtration units can be used to provide supplemental filtration in rooms that are incapable of providing adequate airflow or where increased effectiveness in room airflow is desired. We believe portable HEPA filtration units may provide an interim solution for hospitals with poor existing ventilation, while upgrades are being made. They also may be useful in small, poorly ventilated rooms used for cough-inducing procedures until proper engineering controls are implemented and rooms meeting CDC guidelines for cough-inducing procedures are available in the facility. In common areas where there is a high frequency of use by patients with unsuspected tuberculosis (eg, waiting areas of pulmonary or infectious disease clinics), portable HEPA filtration units may decrease the risk of person-to-person transmission. Because most operating rooms or labor and delivery rooms were designed to have positive pressure relative to adjacent areas, portable HEPA filtration units may reduce the transmission

risk of infectious droplet nuclei when healthcare workers perform procedures on patients with known or suspected tuberculosis. Our data provide a scientific evaluation of the relative effectiveness of several portable HEPA filtration units. These data may be used to guide institutions in meeting the CDC guidelines.

Concerns with portable filtration units include physical obstruction to movement in the room, air drafts, and noise. Although one manufacturer suggests that portable filtration units should be placed in the center of the room, our data suggest that the location of the unit within the room did not compromise the effectiveness of the units tested. We are in agreement with the CDC guidelines that the healthcare worker should not be positioned between the infectious source and the room exhaust vent or the air intake of a portable filtration unit. Measurements of noise levels suggest that currently available portable filtration units are far below the established noise levels for the 40-hour occupational week (85 dB[A]).²⁵ However, care must be taken in using the portable filtration units in rooms (eg, ICU) in which medical devices have audible alarms to monitor patient or device function. In such cases, the alarm signal may need to be amplified to be heard above the background noise level created by the portable filtration unit.

The portable filtration units will remove other particles, including fungi and allergens such as dust, pollen, mites, etc. Portable filtration units have been used to reduce nosocomial *Aspergillus* infections.^{26,27} They also may be useful for home use for patients with extrinsic allergies. Even the least expensive unit may provide significant aerosol clearance in poorly ventilated rooms. The clinical usefulness of portable filtration units to decrease extrinsic allergic attacks will need to be demonstrated in controlled clinical trials prior to recommendations for their use.

The institution of new engineering control measures should depend on scientifically demonstrated failure of standard measures.^{16,28} Portable HEPA filtration units may be an important supplementary measure to control nosocomial transmission of tuberculosis. However, their use should be dictated by scientific data comparing all ventilation control alternatives and by cost-effectiveness analysis.

REFERENCES

- Centers for Disease Control and Prevention. Emerging infectious diseases: tuberculosis morbidity—United States, 1992. *MMWR* 1993;42:696-697,703.
- Barnes PF, Bloch AB, Davidson PT, Snider DE Jr. Tuberculosis in patients with human immunodeficiency virus infection. *N Engl J Med* 1991;324:1644-1650.
- Dooley SW, Villarino ME, Lawrence M, et al. Nosocomial transmission of tuberculosis in a hospital unit for HIV-infected patients. *JAMA* 1992;267:2632-2635.
- Pierce JR Jr, Sims SL, Holman GH. Transmission of tuberculosis to hospital workers by a patient with AIDS. *Chest* 1992;101:581-582.
- Centers for Disease Control. Nosocomial transmission of multidrug-resistant tuberculosis to health-care workers and HIV-infected patients in an urban hospital—Florida. *MMWR* 1990;32:718-722.
- Centers for Disease Control. Nosocomial transmission of multidrug-resistant tuberculosis among HIV-infected persons—Florida and New York, 1988-1991. *MMWR* 1991;40:585-591.
- Edlin BR, Tokars JL, Grieco MH, et al. An outbreak of multidrug-resistant tuberculosis among hospitalized patients with the acquired immunodeficiency syndrome. *N Engl J Med* 1992;326:1514-1521.
- Pearson ML, Jereb JA, Frieden TR, et al. Nosocomial transmission of multidrug-resistant *Mycobacterium tuberculosis*. *Ann Intern Med* 1992;117:191-196.
- Fischl MA, Uttamchandani RB, Daikos GL, et al. An outbreak of tuberculosis caused by multiple-drug-resistant tubercle bacilli among patients with HIV infection. *Ann Intern Med* 1992;117:177-183.
- Centers for Disease Control. Prevention and control of tuberculosis in migrant farm workers: recommendations of the Advisory Council for the Elimination of Tuberculosis. *MMWR* 1992;41(RR-10):1-15.
- Centers for Disease Control. Prevention and control of tuberculosis in US communities with at-risk minority populations: recommendations of the Advisory Council for the Elimination of Tuberculosis. *MMWR* 1992;41(RR-5):1-11.
- Centers for Disease Control. Prevention and control of tuberculosis among homeless persons: recommendations of the Advisory Council for the Elimination of Tuberculosis. *MMWR* 1992;41(RR-5):13-23.
- Small PM, Schecter GF, Goodman PC, Sande MA, Chaisson RE, Hopewell PC. Treatment of tuberculosis in patients with advanced human immunodeficiency virus infection. *N Engl J Med* 1991;324:289-294.
- Centers for Disease Control and Prevention. Initial therapy for tuberculosis in the era of multidrug resistance: recommendations of the Advisory Council for the Elimination of Tuberculosis. *MMWR* 1993;42(RR-7):1-8.
- Iseman MD. Treatment of multidrug-resistant tuberculosis. *N Engl J Med* 1993;329:784-791.
- Centers for Disease Control. Guidelines for preventing the transmission of tuberculosis in health-care settings, with special focus on HIV-related issues. *MMWR* 1990;39(RR-17):1-29.
- Centers for Disease Control and Prevention. Guidelines for preventing the transmission of tuberculosis in health care facilities, 1994. *Federal Register* 1994;59:54242-54303.
- US Department of Labor. Enforcement policy and procedures for occupational exposure to tuberculosis. Occupational Safety and Health Administration Enforcement Document, October 8, 1993.
- Riley RL, Nardell EA. Controlling transmission of tuberculosis in health care facilities: ventilation, filtration, and ultraviolet air disinfection. In: *Plant Technology and Safety Management Series: Controlling Occupational Exposures to Tuberculosis*. The Joint Commission on Accreditation of Healthcare Organizations 1993;No.1:25-31.
- Marier RL, Nelson T. A ventilation-filtration unit for respiratory isolation. *Infect Control Hosp Epidemiol* 1993;14:700-705.
- Weber A, Willeke K, Marchioni R, et al. Aerosol penetration and leakage characteristics of masks used in the health care industry. *Am J Infect Control* 1993;21:167-173.
- Chen CC, Willeke K. Aerosol penetration through surgical masks. *Am J Infect Control* 1992;20:177-184.
- Chen CC, Willeke K. Characteristics of face seal leakage in filtering facepieces. *Am Ind Hyg Assoc J* 1992;53:533-539.
- Brown V, Bishop C, Rutala WA, Weber DJ. HEPA respirators and tuberculosis in hospitals. *N Engl J Med* 1994;331:1659.
- Moller AR. Noise as a health hazard. In: Last JM, Wallace RB, eds., *Public Health and Preventive Medicine*. 13th ed. Norwalk, CT: Appleton and Lange; 1992:523-531.
- Rhame FS, Streifel AJ, Kersey JH, McGlave PB. Extrinsic risk factors for pneumonia in the patient at high risk of infection. *Am J Med* 1984;76(5A):42-52.
- Opal SM, Asp AA, Cannady PB, Morse PL, Burton LJ, Hammer PG II. Efficacy of infection control measures during a nosocomial outbreak of disseminated *Aspergillus* associated with hospital construction. *J Infect Dis* 1986;153:634-637.
- Garner JS, Simmons BP. CDC guideline for isolation precautions in hospitals. *Infect Control* 1983;4:248-325.