# Reducing Human Exposure to *Mycobacterium avium*

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## Abstract

In light of the increasing prevalence of *Mycobacterium avium* pulmonary disease and the challenges of treating patients with *M. avium* infection, consideration of measures to reduce exposure is warranted. Because *M. avium* inhabits water and soil, humans are surrounded by that opportunistic pathogen. Because infection has been linked to the presence of *M. avium* in household plumbing, increasing hot water temperature, reducing aerosol (mist) exposures in bathrooms and showers, and installing filters that prevent the passage of mycobacteria will likely reduce *M. avium* exposure. Granular activated carbon (charcoal) filters support the growth of *M. avium* and should be avoided. When gardening, avoid the inhalation of soil dusts by using a mask or wetting the soil because peat-rich potting soils have high numbers of mycobacteria.

**Keywords:** water; aerosols; households; temperature; filters

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*Mycobacterium avium* and other nontuberculous mycobacteria are opportunistic pathogens whose source for human infection is the environment. The objective of this article is to identify the habitats that *M. avium* shares with humans and the characteristics of the pathogen that are determinants of its ecology, epidemiology, and transmission toward the objective of identifying behavioral changes for individuals of increased susceptibility to reduce *M. avium* exposure.

## Host Factors Influencing *M. avium* Infection

The prevalence of *M. avium* and other mycobacterial diseases is approximately 10 to 15 cases per 100,000 individuals and is increasing at a rate of 5 to 8% per year in the United States and Canada (1, 2). The majority of those cases are caused by *M. avium*. An emerging group of patients, who disproportionately contribute to the current increase, are older (> 60 yr), slender (body mass index < 20) women who lack the classic risk factors for mycobacterial disease (3–6) and have a distinct body type (7). Acquisition of *M. avium* pulmonary disease is determined by host and environmental factors. Host factors include heterozygosity for cystic fibrosis mutations (8), $\alpha$-1–antitrypsin deficiency (8), alveolar proteinosis (9), and gastric reflux disease (10). In a Japanese population, the frequency of HLA-DR6 and haplotype A33-B44-DR6 was higher among patients infected with *M. avium* complex than among control subjects (11). It may be the case that any individual with an *M. avium* infection has some predisposing factor, even among the group of older, slender women. As the proportion of the United States population over 60 years continues to grow and the number of individuals with cancer immunosuppressed individuals is anticipated to increase, it is likely that the prevalence of *M. avium* disease will continue to increase. Unfortunately, it is impossible to change genetic factors predisposing individuals to *M. avium* infection. However, because those individuals are susceptible to reinfection (12), it behooves us to determine whether it is possible to reduce their exposure to *M. avium*.

## Sources of *M. avium* Infection

*M. avium* has been recovered from soils (particularly peat-rich soils) (13), natural waters (14), drinking water distribution systems (15, 16), and household plumbing (17) (Table 1). DNA fingerprints of *M. avium* isolates from patients and their household plumbing have been shown to match (18, 19), providing proof that the patients were infected from household plumbing. Evidence that mycobacteria, particularly *M. avium*, were prevalent in showerhead biofilms sampled across the United States (20) suggests that humans are surrounded by *M. avium* and, likely, are continually exposed. The number of *M. avium* cells and their innate virulence would be expected to influence infection.

**Table 1.** *Mycobacterium avium* habitats shared with humans

| |
|---|
| Natural waters |
| Drinking water and distribution systems |
| Household, building, and hospital water systems |
| Humidifiers and humidifiers in HVAC systems |
| Refrigerator water and ice |
| Hot tubs, spas, hydrotherapy pools, and footbaths |
| In-line filters |
| Potting soils rich in peat |

Unfortunately, there is no knowledge of the minimal dose required for infection, and there are few, if any, known virulence markers of *M. avium* and other mycobacteria.

It would follow, and has been shown, that host factors (i.e., a susceptible population) would be a more important factor associated with *M. avium* disease than exposure (21). Because present evidence shows that all individuals are equally exposed to *M. avium* and other mycobacteria through drinking water distribution systems and household and building plumbing, host factors would be expected to distinguish patients from other individuals. However, because it has been shown that *M. avium*–infected patients are susceptible and at risk of repeated mycobacterial infections in spite of prior antimycobacterial therapy (12), reduction of *M. avium* exposure would be expected to reduce the probability of reinfection.

## Why Is *M. avium* in Water and Soil?

Features of *M. avium* that are determinants of its ecology are listed in Table 2. The salient and unique feature of *M. avium* and other mycobacteria is their lipid-rich, impermeable outer membrane (22, 23).

**Table 2.** Determinants of *Mycobacterium avium* ecology

| |
|---|
| Lipid-rich, impermeable outer membrane |
| Disinfectant resistance |
| Surface-adherence and biofilm formation |
| Slow growth |
| Low nutrient requirements (oligotrophic) |
| Heat resistance |

Although this impermeable outer membrane reduces transport of hydrophilic nutrients (24) and results in slow growth, it also makes *M. avium* cells resistant to disinfectants (25) and antibiotics (26). Although *M. avium* is slow growing, it can persist in drinking water distribution systems and in household plumbing without being washed out by flow because it adheres to pipe walls to form biofilms (27). Furthermore, *M. avium* is an oligotroph; it can grow on low concentrations of organics, particularly those present in drinking water distribution systems and household plumbing (28, 29). In fact, *M. avium* numbers increase in drinking water distribution systems as the distance from the treatment plant increases (16). In the absence of microorganisms killed off by disinfection (e.g., gastrointestinal tract pathogens), *M. avium* can grow, albeit slowly, on the available nutrients. Essentially, drinking water systems select for *M. avium*.

Although the basis for the relative heat resistance of *M. avium* is unknown (30), *M. avium* can persist in hot water heaters, particularly in buildings with recirculating hot water systems, such as those found in hospitals, condominiums, apartments, and office buildings. The highest numbers of *M. avium* cells have been measured in buildings with recirculating hot water systems (31). Hot water heater temperature is an important determinant of the presence or absence of *M. avium* in household plumbing. Houses with hot water heater temperatures of 130°F (55°C) or higher seldom had *M. avium*, compared with households with hot water heater temperatures at 120°F (50°C) or below (17). Low oxygen concentrations due to low flow and stagnation in drinking water systems and household plumbing does not restrict *M. avium* growth because it can grow at oxygen concentrations of 6 and 12%, considerably below the oxygen concentration of air (21%).

The presence of high numbers of *M. avium* and other mycobacteria in peat-rich potting soils is due in part to their affinity for growth under acidic (pH 3–5) conditions (32, 33) and growth stimulation by humic and fulvic acids, organic breakdown products of plants that are in high concentration in peat and peat-rich soils (34).

## Transmission of *M. avium* from Environmental Habitats

*M. avium* is not transmitted from person to person; rather, infection occurs through the inhalation of aerosolized droplets containing *M. avium* cells. Aerosolized droplets can be generated from natural waters (35), showerheads and water taps (36), hot tubs and spas, hydrotherapy pools, humidifiers, and humidified air from HVAC systems. *M. avium* cells are enriched in aerosols from water because of their extremely high hydrophobicity; *M. avium* cells prefer to attach to air droplets rising in a water column rather than interacting with the polar groups in water (36). A second water source of infection is likely aspiration via gastric reflux (10). One additional source of infection is dust from handling peat-rich potting soils. *M. avium* numbers are extremely high in peat (approximately 1 million per gram), and *M. avium* can be readily isolated from potting soil dusts. In fact, DNA fingerprints of several patients infected with *M. avium* were shown to match those of *M. avium* isolated from potting soils used by the patients (37).

## Behavioral Changes to Reduce *M. avium* Exposure

Although many of the changes to household plumbing that are listed below require additional expense by patients, that cost must be balanced by the current calculated costs of treatment of *M. avium* infection. Patients infected with *M. avium* are innately susceptible and subject to repeated mycobacterial infection (12) and thereby face the cost of continued antimycobacterial therapy. That cost is estimated to be $321 (Canadian) per month; for a median duration of treatment of 14 months, the total cost would be $4,916 (38). Thus, the cost incurred by raising the hot water heater temperature and more frequently changing filters to possibly reduce reinfection are minor compared with the cost of treating a reinfection.

Inasmuch as it is possible for individuals to alter their behavior to avoid exposure, it is valuable for patients to identify environmental reservoirs of *M. avium*. The suggestions below and presented in Table 3 have not been

**Table 3.** Measures to reduce *Mycobacterium avium* exposure in households

| |
|---|
| Drain and refill the hot water heater every 2 wk. |
| Raise hot water heater temperatures (⩾ 130°F). |
| Remove and clean showerheads (full-strength household bleach for 30 min). |
| Replace showerhead with one that produces streams (holes > 1 mm diameter) and not a fine mist. |
| Reduce aerosol exposures in bathrooms (fan and window). |
| Install shower and tap filters that remove bacteria (⩾ 0.45 μm pore size). |
| Replace granular activated carbon filters every 2 wk. |
| Get rid of any and all humidifiers. |
| Turn off the humidifier in the HVAC system. |
| Boiling for 10 min will kill mycobacteria. |
| Avoid dusts from potting soils (wet potting soil). |

prospectively investigated; they are based on observations of *M. avium* ecology and characteristics. For example, we have not initiated an intervention (e.g., raising hot water heater temperature) and compared *M. avium* numbers in household water and biofilms before and after the change. However, *M. avium* numbers were lower in household plumbing of residences with hot water heater temperatures of 55°C or higher (17).

Keeping in mind that limitation, it appears logical that focusing on a household water system would be a place to start to reduce exposure to *M. avium*–carrying aerosols. Increasing the water heater temperature to 130°F (55°C), disinfecting the showerhead, and draining the hot water heater would be expected to decrease the frequency of water samples yielding *M. avium* and number of cells per sample. Although *M. avium* and other mycobacteria are resistant to the concentrations of chlorine used to disinfect water (i.e., 1 mg/L) (25), they are killed by full-strength household bleach (i.e., 50,000 mg/L) in 10 minutes. Because it takes approximately 2 weeks for an *M. avium* population to recolonize a hot water heater, draining should be performed every 2 weeks. Reducing aerosol exposures in the bathroom could involve *1*) replacing a showerhead with one that produces water streams (holes > 1 mm diameter) and not a fine mist, *2*) replacing a showerhead with one that contains a microbiological filter (i.e., pore size < 0.45 μm diameter) to reduce the proportion of aerosol droplets that can enter the lung (39), *3*) opening a window in the bathroom (if possible), *4*) replacing an inefficient fan with one that exhausts bathroom air rapidly, and *5*) keeping bathroom aerosols to a minimum of time.

Many households have "filters" that contain granular activated carbon (GAC) to improve the taste of drinking water. GAC filters bind and thus remove chlorine and metals that impart a bad taste to water, but the size of the pores in GAC filters is not sufficient to prevent the passage of *M. avium*, and there is evidence that *M. avium* is capable of growing in GAC filters (40). GAC filters simply delay the passage of *M. avium* because the cells must travel a tortuous path to get through; that takes approximately 2 to 3 weeks, long before the recommended schedule for filter replacement based on its chlorine- and metal-binding capacity.

Homes may also have potent aerosol generators. Because household water contains *M. avium* (15–17), free-standing humidifiers and those attached and part of a HVAC system, hot tubs or spas, and tap aerators are potent generators of *M. avium*–laden aerosols. If a humidifier must be used, water should never be left in the reservoir, and it should be regularly (i.e., every 2 wk) scrubbed and cleaned with detergent to get rid of the biofilm and disinfected with household bleach.

For individuals suffering from sinusitis, irrigation with tap water is not recommended (31). Rather, purchase a sterile saline solution at the local pharmacy or boil water for 10 minutes to kill any microorganisms. After cooling, the boiled water can be used for sinus irrigation.

In the garden, back porch, or greenhouse, gardening with peat-rich potting soil can expose one to *M. avium* in dusts (37). Many potting soils are enriched with peat, peat moss, or *Sphagnum* vegetation and contain very high numbers of *M. avium* and other mycobacteria (1 million per gram) (37). If the potting soil or peat moss is dry, transferring the material from the container to the ground or pot will generate a dust that has high numbers of *M. avium* (37). Rather than wearing an uncomfortable mask, simply wet the potting soil or peat moss in the original container and then transfer.

## What Can Water Utilities Do to Reduce *M. avium* Numbers?

The following suggestions to reduce *M. avium* numbers in drinking water by a water utility are based on predictions, not on prospective studies that have measured the effect of an intervention on *M. avium* numbers. *M. avium* and other mycobacteria present in surface drinking water sources enter a treatment plant bound with particulates in soil (16). Therefore, a reduction in the turbidity of water can reduce the total number of *M. avium* and other mycobacteria in the water that leaves the treatment plant (16). The choice of disinfectant may be important in determining if *M. avium* is present. For example, replacement of chlorine with chloramine by one utility in Florida led to a reduction in *Legionella* numbers but led to an increased frequency of recovery of *M. avium* (41). Nutrient levels might also be reduced, with the result that numbers of *M. avium*, *Legionella*, and other water-borne pathogens might be reduced.

## Looking into the Future

The first order of business is to determine whether any of the suggested interventions for reducing exposure is effective. First, we will determine whether raising the hot water heater temperature results in less frequent isolation and reductions in *M. avium* numbers in household plumbing.

The aging of the United States population and the increased proportion of immunosuppressed individuals support the notion that the prevalence of disease caused by *M. avium* and other mycobacteria will continue to rise. The difference values for the prevalence of *M. avium* disease are based on estimates; *M. avium* disease is not reportable. Although we know a good deal about *M. avium* disease, a great deal more could be obtained if the disease was reportable, as was the case for *Legionella pneumophila* disease. Recently, regions in the United States with significantly higher and lower prevalences of *M. avium* disease have been identified (42), but we have no idea why those areas are significantly different from other regions. *M. avium* is a member of the *M. avium* complex (MAC), which consists of four *M. avium* subspecies (i.e., *avium*, *hominissuis*, *silvaticum*, and *paratuberculosis*) (43) and at east another seven related species (*M. intracellulare*, *M. chimaera* [44], *M. colombiense* [45], *M. arosiense* [46], *M. vulneris* [47], *M. marseillense*, *M. timonense*, and *M. bouchedurhonense* [48]). Most are reported as MAC or *M. avium-intracellulare*, which would blur distinctions of ecology, epidemiology, ideal drug therapy, and disease progression. I anticipate, as we retrospectively identify isolates identified as MAC and assign them to their rightful species or subspecies, that we will discover new valuable insights into their ecology and pathogenicity. ■

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