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Assessment of relative potential for *Legionella* species or surrogates inhalation exposure from common water uses

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ABSTRACT

The *Legionella* species have been identified as important waterborne pathogens in terms of disease morbidity and mortality. Microbial exposure assessment is a tool that can be utilized to assess the potential of *Legionella* species inhalation exposure from common water uses. The screening-level exposure assessment presented in this paper developed emission factors to model aerosolization, quantitatively assessed inhalation exposures of aerosolized *Legionella* species or *Legionella* species surrogates while evaluating two generalized levels of assumed water concentrations, and developed a relative ranking of six common in-home uses of water for potential *Legionella* species inhalation exposure. Considerable variability in the calculated exposure dose was identified between the six identified exposure pathways, with the doses differing by over five orders of magnitude in each of the evaluated exposure scenarios. The assessment of exposure pathways that have been epidemiologically associated with legionellosis transmission (ultrasonic and cool mist humidifiers) produced higher estimated inhalation exposure doses than pathways where epidemiological evidence of transmission has been less strong (faucet and shower) or absent (toilets and therapy pool). With consideration of the large uncertainties inherent in the exposure assessment process used, a relative ranking of exposure pathways from highest to lowest exposure doses was produced using culture-based measurement data and the assumption of constant water concentration across exposure pathways. In this ranking, the ultrasonic and cool mist humidifier exposure pathways were estimated to produce the highest exposure doses, followed by the shower and faucet exposure pathways, and then the toilet and therapy pool exposure pathways.

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1. Introduction

1.1. Legionellosis transmission

The disease legionellosis and the causative organism *Legionella pneumophila* were named for the 1976 Convention of the American Legion meeting where the disease made its first identified appearance during a fatal pneumonia outbreak (U.S. Environmental Protection Agency, 1999). In addition to *L. pneumophila*, 24 *Legionella* species have been described as human pathogens as of 2012 (Buse et al., 2012). Legionellosis, defined by the medical diagnosis of Legionnaires' disease or Pontiac fever, is a waterborne disease transmitted by inhalation of respirable water particles or aspiration of water contaminated with *Legionella* species. *Legionella* species have been identified as important waterborne pathogens in terms of disease morbidity and mortality (Neil and Berkelman, 2008). Legionnaires' disease is a significant cause of community-acquired pneumonia, when the pneumonia is not caused by a communicable disease outbreak (Ng et al., 2008a).

Historically, most reported legionellosis cases were associated with transmission from health care facilities, with potential sources identified as drinking water supplies, air conditioning units, and cooling towers (U.S. Environmental Protection Agency, 1999). Less than 20% of all legionellosis cases are currently associated with defined disease outbreaks (Neil and Berkelman, 2008) and most cases occur sporadically (U.S. Environmental Protection Agency, 1999). Transmission from the community setting (i.e., not from health care facilities) is thought to be primarily responsible for disease incidence (U.S. Environmental Protection Agency, 1999). The most common reservoirs for potential transmission of community-acquired legionellosis include heat-rejection equipment (e.g., cooling towers), plumbing systems and associated devices, nebulizers, humidifiers, whirlpool spas, and public fountains (U.S. Environmental Protection Agency, 1999). *Legionella* species can be especially problematic from a water system disinfection perspective. Residual chlorine may not be maintained in sufficient concentration to control the pathogen and prevent disease transmission due to issues of water flow (e.g., stagnation in pipes) or potential reservoirs that shelter *Legionella* species (e.g., biofilms, amoebae, pipe sediment) (Buse et al., 2012).

Early legionellosis research efforts identified epidemiological associations by documenting the occurrence of the same disease strain in individual(s) with legionellosis and likely environmental sources. However, there are a number of possible transmission sources with potential to produce *Legionella* species aerosols from contaminated potable water. Epidemiological studies may have difficulty distinguishing the relative importance of individual transmission sources when there is the potential for multiple and co-occurring exposure points (e.g., faucet, shower) from a common originating source (e.g., contaminated water). The potential for multiple sources as well as multiple modes of transmission operating in the same exposure setting has been identified for legionellosis (Muder et al., 1986). Microbial exposure assessment may provide unique capabilities to evaluate the relative contribution of identified exposure sources.

Model-based exposure assessments have been conducted previously for two sources associated with legionellosis transmission: shower (Schoen and Ashbolt, 2011) and whirlpool spa (Armstrong and Haas, 2007b). The evaluations were not directly comparable due to differing exposure assumptions, water concentration, aerosolization estimates, and other assessment elements. While potential aerosolization exposure pathways for *Legionella* species have been identified, a systematic comparison of the relative potential for *Legionella* species exposure from common in-home water uses has not been conducted.

1.2. Objectives

The main objectives of this paper were to evaluate the use of microbial exposure assessment to assess *Legionella* species inhalation exposure from common in-home water uses, to determine if a relative ranking of exposure pathways could identify pathways with a greater potential for *Legionella* species exposure when assuming consistent water concentrations, and to assess the uncertainty and variability associated with the calculated exposure doses. Additional actions with potential to limit *Legionella* species exposure and data gaps that affected the confidence in the calculated exposure doses were also identified.

2. Methods

A screening-level exposure assessment was conducted to evaluate the inhalation exposure doses resulting from aerosolization of *Legionella* species from water at the point of household use. Screening-level assessments are conducted when data are limited and there are high levels of uncertainty in the assessment (U.S. Environmental Protection Agency, 2004). The assessment outputs provide high-end or bounding-type estimates and identify pathways where more refined inputs may be appropriate to pursue.

2.1. Literature search

A targeted literature search was conducted to develop the conceptual model, including identification of exposure pathways and input values for the exposure assessment. Exposure pathways from in-home use of potable water that were associated with reported transmission of legionellosis or aerosolization of waterborne bacterial pathogens were identified and evaluated. If *Legionella* species data were unavailable from the published literature and respirable aerosol generation was documented, data for bacterial surrogates were also considered.

2.2. Equation to calculate exposure dose

Exposure doses were calculated using Eq. (1). The equation was derived from a generic equation for chemical intake (U.S. Environmental Protection Agency, 1989), with modifications to remove exposure frequency, averaging time, and body weight parameters. Exposure frequency and averaging time terms were removed because the unit of exposure was one 24-h day. Events were assumed to occur one time per day only