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Assessing the risk of Legionnaires' disease: The inhalation exposure model and the estimated risk in residential bathrooms

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ABSTRACT

Legionella are widely found in the built environment. Patients with Legionnaires' disease have been increasing in Japan; however, health risks from *Legionella* bacteria in the environment are not appropriately assessed. We performed a quantitative health risk assessment modeled on residential bathrooms in the Adachi outbreak area and estimated risk levels. The estimated risks in the Adachi outbreak approximately corresponded to the risk levels exponentially extrapolated into lower levels on the basis of infection and mortality rates calculated from actual outbreaks, suggesting that the model of Legionnaires' disease in residential bathrooms was adequate to predict disease risk for the evaluated outbreaks. Based on this model, the infection and mortality risk levels per year in 10 CFU/100 ml (100 CFU/L) of the Japanese water quality guideline value were approximately 10^{-2} and 10^{-5}, respectively. However, acceptable risk levels of infection and mortality from Legionnaires' disease should be adjusted to approximately 10^{-4} and 10^{-7}, respectively, per year. Therefore, a reference value of 0.1 CFU/100 ml (1 CFU/L) as a water quality guideline for *Legionella* bacteria is recommended. This value is occasionally less than the actual detection limit. *Legionella* levels in water system should be maintained as low as reasonably achievable (<1 CFU/L).

1. Introduction

Legionella bacteria are widely found in the built environment. They have also been found in creeks and ponds, hot water taps, hot water tanks, water in cooling towers, and evaporative condensers and whirlpool spas. Legionellosis is an infectious disease caused by bacteria belonging to the genus *Legionella* (WHO, 2007). Over 90% legionellosis cases are caused by *Legionella pneumophila*, a ubiquitous aquatic organism that thrives in warm environments (Diederen, 2008). Legionellosis takes two distinct forms: Legionnaires' disease, which is the more severe form of the infection and causes pneumonia, and Pontiac fever, which causes mild respiratory illness resembling acute influenza (WHO, 2007). Most people contract legionellosis by inhaling mist from a water source contaminated with *Legionella* bacteria. In some cases, the disease may be transmitted in other ways such as by aspiration of contaminated water. There is very little evidence, if any, of human-to-human transmission, and there is no evidence of any animal reservoir with public health relevance for this organism. Outbreaks occur following the exposure of many individuals to a common source of the bacteria in the environment. When a single case occurs, it is extremely difficult to pinpoint a source (US EPA, 1999).

According to surveys by the Ministry of Health, Labour and Welfare (MHLW; NIID, 2012), the number of patients with Legionnaires' disease has rapidly increased in Japan from 56 in 1999 to 518 in 2006, 668 in 2007, 892 in 2008, 717 in 2009, 751 in 2010, and 804 in 2011. In addition, legionellosis cases in the United States of America reportedly increased by 217% annually, from 1110 in 2000 to 3522 in 2009, and the crude national incidence rate increased 192%, from 0.39 per 100,000 persons in 2000 to 1.15 per 100,000 persons in 2009 (CDC, 2011). The reported incidence of Legionnaires' disease in European countries per million of population also increased from 4.3 to 11.8 during 1998–2008 (Joseph et al., 2010). The disease is a major concern for public health professionals and individuals involved in building and maintaining water systems.

Medical, health care, and social welfare facilities as well as specially-designed buildings such as offices, stores, hotels, entertainment facilities, assembly halls, libraries, and museums, whose total floor areas exceed 3000 m^2 and whose schools exceed 8000 m^2, are regulated by the Law for Maintenance of Sanitation in Buildings, which has monitored *Legionella* bacteria under the Legionnaires' Disease Japanese Code of Practice established by

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MHLW (BMEC, 1999). However, the code has not been applied to condominium buildings.

In September 2007, high levels of *Legionella* bacteria exceeding the 10 CFU/100 ml limit specified in the Japanese water quality guidelines were incidentally detected in a circulating hot spring water system in a condominium building in Adachi, Tokyo (Takahashi, 2008). The building had been constructed in July 2005. The Adachi Public Health Center (APHC) performed an inspection to test for *Legionella* bacteria in the circulating hot spring water system because an explosion that damaged equipment in the facility had occurred in a public bathing facility in Shibuya, Tokyo in July 2007 (Takahashi, 2008), leading to the detection of these high levels.

The water in the circulating hot spring water system installed in the condominium building in Adachi was used for the residential bathrooms as well, which was accessed almost daily. These type of condominium buildings have been increasing in number in Japan. Furthermore, the source of infection was determined to be associated with public bathing facilities in many of the legionellosis cases reported in Japan (Kuroki et al., 2009). Therefore, the further spread of *Legionella* bacteria may be of concern.

The Japanese water quality guideline concerning *Legionella* bacteria was established on the basis of the detection limit of *Legionella* bacteria in water and not on the basis of health risk (BMEC, 1999). However, health risk should be properly assessed and appropriate controls implemented in order to decrease the possibility of *Legionella* contamination. In this study, a quantitative health risk assessment using a residential bathroom model is examined and estimated risk levels are suggested. In addition, future water quality guidelines for *Legionella* bacteria in residential bathrooms are recommended.

2. Methods

2.1. The risk assessment model in residential bathrooms

2.1.1. Data on the Adachi outbreak and the water system

Fig. 1 shows a circulating hot spring water system in the Adachi outbreak area (Takahashi, 2008). The water was pumped into each bathtub from a hot water tank and discharged from the bathtub. *Legionella* contamination was found in a system that had been installed in a condominium building, and the levels detected in the water are shown in Table 1 (Takahashi, 2008). The proliferation of *L. pneumophila* occurred in a hot water tank and a circulating hot spring water system. These bacteria increased to greater numbers in the circulating system, and its level was not reduced by additional disinfection after the outbreak. Ohata et al. (2006) clearly demonstrated that *L. pneumophila* increased in the bathing water circulating system in the sequential manner of microbial

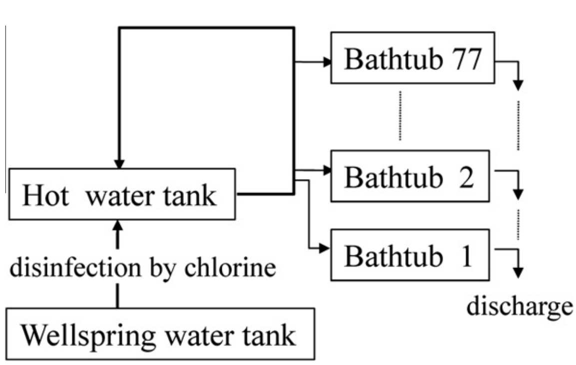

Fig. 1. Circulating hot spring water system in the Adachi outbreak.

Table 1
Legionella pneumophila levels (CFU/L) in hot spring water in the Adachi outbreak.

Sampling point	First survey 2007/09/04	Second survey 2007/09/13	After additional disinfection 2007/11/20
Wellspring water tank	n.d.	–	n.d.
Hot water tank	18,000	8600	2100
Circulating pipe before Bathtub 1	4500	2700	2500
Bathtub 77	–	13,000	–
Range of eight bathtub	–	–	0–46,000

growth. Bacterial cells first increase by utilizing organic matter such as scurf; subsequently, a large number of host amoeba appear, which are predators of the bacteria. *L. pneumophila* then multiplies in the proliferating amoeba, thus increasing in bathing water following the appearance of the host amoeba (Yamaguchi et al., 2011).

2.1.2. Exposure and risk estimation

Quantitative Microbial Risk Assessment (QMRA) utilizes estimates of pathogen density and infectivity information to assess pathogen risk; for example, the risk of infection from inhalation of *Legionella* derived from various engineered water systems (Buse et al., 2012). Armstrong and Haas (2007a,b) developed a QMRA model for Legionnaires' disease. Dose–response relationships for subclinical infection (Muller et al., 1983) and mortality (Baskerville et al., 1981) were developed using available inhalation data for guinea pigs exposed to *L. pneumophila* (Armstrong & Haas, 2007a). The resulting dose–response relationships were used in a subsequent QMRA to assess their applicability (Armstrong & Haas, 2007b). Armstrong and Haas (2008) compared the predicted subclinical infection risk and mortality risk with the documented disease rates in natural hot spring spas contaminated with *Legionella*. As a whole, the documented disease rates and the predicted risks were within an order of magnitude, so this QMRA model was used.

Multiple bathroom amenities such as bathtubs, faucets, toilet flushes, and showers are sources of exposure to *Legionella*-containing aerosols. In Japan, bathtubs are generally installed in residential bathrooms, with the toilets being installed in separate room. Although aerosols produced during faucet and shower use might be a cause of *Legionella* exposure, we did not have information on parameters for adequately estimating exposure from these aerosols, such as the frequency of usage, the shower-head design, and the water flow rate. Thus, aerosols from faucet and shower use were not included in the risk assessment model.

The inhalation exposure dose was estimated on the basis of *Legionella* levels in the water (C_{water}), the bacterial water to air partitioning coefficient, the exposure duration, the inhalation rate, and the respirable aerosol retention rate, which are shown in Eqs. (1 and 2) (Armstrong & Haas, 2007b). The model parameters used for the Monte Carlo simulation are summarized in Table 2. The exposure dose was calculated from a probability distribution using @RISK®5.7 software (Palisade Corp.) for 10000 iterations.

$$C_{air} = C_{water} \times PC_{bwa} \quad (1)$$

where C_{air}, predicted levels in air (CFU/m^3); C_{water}, bacterial levels in water (CFU/L); and PC_{bwa}, bacterial water to air partitioning coefficient (L/m^3).

$$\text{IED(CFU)} = C_{air} \times \text{IR} \times \text{ED} \times \text{RR} \quad (2)$$

where IED, inhalation exposure dose (CFU); IR, inhalation rate (m^3/h); ED, exposure duration (h); and RR, fractional retention rate of aerosol in human alveoli.