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Legionnaires' Disease Contracted from Patient Homes: The Coming of the Third Plague?

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Introduction

In biblical times, 10 plagues were inflicted on Egypt, causing fear and consternation. The plagues included locusts, frogs, hail, and, ultimately, the deaths of the first-born sons of Egypt [1]. Similarly, Legionnaires' disease swept into our medical consciousness like a plague, causing fear and consternation. The first plague was discovered as an outbreak of severe pneumonia during an American Legion convention at a Philadelphia hotel in 1976. The abruptness of the outbreak, the high mortality despite antibiotics and modern ICU care, and the unknown cause contributed to its notoriety, which has endured today. The general public and the lay media retain their fascination with Legionnaires' disease. Even the name of the disease and the microorganism were derived from the victims of the 1976 hotel outbreak.

The second plague was the discovery of outbreak-related pneumonia in the hospital setting in 1978. This plague occurred when, over a course of 4 years, hospital-acquired Legionnaires' disease was diagnosed in over 300 patients in U.S. Veterans Hospitals in Los Angeles, CA, Pittsburgh, PA, and Togus, ME [2, 3]. The mortality was high (50%). The patients tended to have chronic lung disease, to have received a renal transplant, or to have undergone surgery requiring general anesthesia with endotracheal intubation. Cigarette smoking and receipt of immunosuppressive medications were the most common risk factors. These outbreaks were, in retrospect, endemic cases of hospital-acquired Legionnaires' disease. Panic and consternation occurred among patients and hospital employees and was fueled by media coverage. The third plague is the emerging recognition that sporadic community-acquired legionellosis can be contracted from drinking water in patient homes.

The first plague led to one triumph: discovery of the cause – a fastidious bacterium [4]. With that discovery, an antibiotic cure was soon found [5]. The second plague led to a second triumph: discovery that the hospital water supply harbored the bacterium and was the source of infection [2, 6]. And, it was soon discovered that endemic Legionnaires' disease existed in numerous community hospitals in the USA as well as in other countries.

Attention initially focused on cooling towers and air conditioners, which became convenient lightning rods that could defuse panic because these sources could be easily confronted and disinfected. However, in the era of molecular epidemiology with case-control studies and DNA fingerprinting, it soon became clear that potable water was the primary source [7]. Air conditioners have never been scientifically linked to an outbreak of Legionnaires' disease, and its role now approaches mythical folklore. Nevertheless, cooling towers and air conditioners continue to be identified by health departments as sources, especially in Europe and Australia; none of these sources are ever validated by subsequent case-control studies and molecular epidemiology, and results are rarely, if ever, published in peer-reviewed journals.

Legionnaire's disease has an image of being a plague with high patient mortality. It must be remembered that the original cases were skewed toward those with severe disease who did not receive appropriate antibiotics. In this millennium, mortality has plummeted with the increased index of suspicion by physicians and the advent of rapid laboratory diagnostic tests followed by earlier administration of more potent antibiotics. The report from Alcoy, Spain, in this issue of the *European Journal of Clinical Microbiology & Infectious Diseases* confirms these observations. With administration of appropriate antibiotics

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Table 1 Risk factors for *Legionella* environmental colonization in homes

City, country [reference no.]	No. of homes	Percent colonization	*Legionella* serogroup	Risk factors for colonization		
				Temperature HWT	Electric heater	Other
Pittsburgh, USA [15]	55	10.9 (6/55)	Lp1	low	yes	city area
Quebec, Canada [16]	211	32.7 (69/21)	Lp4 (24.8%), Lp2 (21%)	low	yes	low temp. faucet, old heater, old district
Pittsburgh, USA [14]	218	6.4 (14/218)	Lp1 (85%)	low	no[a]	city area, iron level, low temp. faucet
Germany, Netherlands, Austria [33]	65	8 (5/65)	Lp[b]	NA	NA	copper plumbing, low water use

HWT, hot water tank; Lp, *Legionella pneumophila*; temp., temperature

[a] Only 5% of homes had electric heaters
[b] Serogroup not provided

(clarithromycin) and rapid diagnosis, only 8.4% of cases of Legionnaires' disease required admission to the intensive care unit, and the mortality was only 6.2% [8].

Given the fact that, for the majority of cases, the source has been linked to drinking water supplies, prevention can be successfully enacted by water system disinfection. Unfortunately, a strong bureaucratic tendency to publicly avoid consideration of drinking water as the source soon appeared among public health authorities, given the panic and irrational action that often followed such a discovery. Although the use of environmental cultures in hospitals has successfully led to cost-effective preventive measures, this approach has not been accepted by many public health authorities and hospital administrators. The reason is that discovery of *Legionella* in the drinking water of a hospital implies (incorrectly) negligence and an image of uncleanliness. The media and lay public are not aware that *Legionella* is a common colonizer of water distribution systems (similar to many other pathogenic bacteria and fungi).

In this issue of the *European Journal of Clinical Microbiology & Infectious Diseases* comes an impressive collection of five studies on the clinical and microbiological epidemiology of Legionnaire's disease: the aforementioned report of clinical features of community-acquired Legionnaires' disease in Spain [8], a report from the European Working Group on *Legionella* Infection (EWGLI) on standardization of a molecular fingerprinting technique that can identify the source [9], a pan-European study of serotype/serogroup distribution of *Legionella pneumophila* in patients [10], a survey of *Legionella* colonization of homes in Catalonia, Spain [11], and a case of Legionnaires' disease in Taiwan contracted from a home water source [12]. The intense media coverage and panic generated by the first two plagues indicates that public health authorities should brace themselves for the public's reaction to news that Legionnaires' disease can be acquired from the drinking water in their own homes. In this editorial, we will review the current state of knowledge about Legionnaires' disease contracted from homes and recommend future approaches for clinical investigators, public health officials, and patients. The studies come in three forms: environmental surveys of *Legionella* in homes, anecdotal reports of community-acquired Legionnaires' disease linked to home water sources, and prospective studies of community-acquired Legionnaires' disease linked to home water sources.

Environmental Surveys

We reviewed four environmental surveys that specifically addressed *Legionella* colonization of water plumbing systems in homes defined as single or two-family dwellings (duplexes) (Table 1). (A survey of homes in Vermont was omitted because selective media for environmental cultures was not used, which would severely underestimate the true prevalence of *Legionella* positivity [13]. In that survey, *Legionella* was found in 0 of 68 water samples and in only 2 of 93 hot water tank heaters.) The number of homes studied ranged from 55 to 218 in two Pittsburgh surveys [14, 15] (Table 1). The prevalence of *Legionella pneumophila* colonization in homes varied by geography, not only from country to country and state to state, but also within a single city. The prevalence ranged from 6.4% in Pittsburgh to 32.7% in Quebec [14, 16]. But, one area of Pittsburgh had a significantly higher number of colonized homes than four other areas of Pittsburgh [17]. Iron concentration was significantly higher in the one area with the highest prevalence.

Anecdotal Reports of Community-Acquired Legionnaires' Disease Linked to Homes

Legionnaires' disease linked to drinking water in patient homes was first reported in 1987 [18]. Since then, numerous anecdotal cases of Legionnaires' disease epidemiologically linked to homes or apartments colonized by *Legionella pneumophila* have been published, including the Taiwan study in this issue of the *European Journal of Clinical Microbiology & Infectious Diseases* (Table 2) [12, 18, 19, 20, 21, 22, 23, 24, 25]. The report by

Table 2 Demographics of 13 cases of Legionnaires' disease acquired from home water supplies

Country	Reference no.	Year published	Age/sex	Cigarette smoker	Chronic lung disease	Immuno-suppression	Outcome	Source	Molecular typing method
USA	[18]	1987	65 M	no	no	CLL	lived	home	none
			55 M	yes	COPD	none	lived	home	MAB
USA	[20, 37]	1987	56 M	no	no	transplant	lived	home	MAB
Italy	[19]	1988	20 M	NA	no	none	lived	home	none
USA	[17]	1992	45 M	yes	no	none	lived	apartment	REA, MAB
			75 F	no	no	diabetes	lived	apartment	REA, MAB
			56 F	no	no	transplant	lived	home	REA, MAB
UK	[21]	1994	52 F	no	no	none	died	home	REA
Netherlands	[22]	1996	50 M	no	no	CLL	lived	apartment	PFGE
UK	[23]	2001	46 M	no	no	transplant	died	home	AFLP
USA	[24]	2001	76 F	yes	no	none	died	apartment	PFGE
Switzerland	[25]	2002	58 F	no	no	transplant	lived	home	PFGE AFLP
Taiwan	[12]	2002	69 M	no	no	Sweet syndrome, myelodysplasia	died	home	PFGE

AFLP, amplified fragment polymorphism; CLL, chronic lymphocytic leukemia; COPD, chronic obstructive pulmonary disease; MAB, monoclonal antibody; NA, not available; PFGE, pulsed-field gel electrophoresis; REA, restriction endonuclease analysis

Castellani-Pastoris et al. [19] is interesting in that three cases occurred within one family: one case of Legionnaires' disease and two other cases of presumed Pontiac fever, a flu-like syndrome with no respiratory symptoms.

Prospective Studies of Community-Acquired Legionnaires' Disease Linked to Homes

Four reports using different study designs have assessed epidemiologic links of Legionnaires' disease to patient homes. First, Pittsburgh investigators prospectively studied 20 consecutive patients with sporadic community-acquired Legionnaires' disease that was confirmed by culture. They then cultured the water supply of the workplace and home of each patient [17]. Secondly, the Ohio Legionnaires' disease group and the Catalonia investigators identified patients with community-acquired Legionnaires' disease and then cultured the homes of both patients and concomitant controls [11, 26]. Thirdly, German investigators found high-level *Legionella* contamination (>1,000 cfu/l) in an apartment complex with a central hot water system. *Legionella* antibody titers were determined and *Legionella* urinary antigen tests performed on the 53 individuals residing in the apartment complex, and the results were compared with those obtained for 92 controls who lived in single-dwelling homes in which only 3% of homes had *Legionella* counts of >1,000 cfu/l [27].

Legionella Serogroups and Species in Patients

In the studies reviewed, 20 patients contracted Legionnaires' disease from their home water supply as assessed by molecular epidemiology methods in anecdotal cases (10 patients), the Pittsburgh prospective study (3 patients) [14], and the Ohio Legionnaires' disease study (7 patients) [26]. Of these, *Legionella pneumophila* serogroup 1 was found in 70% (16/20), *Legionella pneumophila* serogroup 3 in 10% (2/20), and *Legionella pneumophila* serogroup 6 in 10% (2/20). This rank order was nearly identical to that of the pan-European survey of *Legionella pneumophila* serogroups [10].

Legionella Serogroups and Species in Homes

In the environmental surveys, *Legionella pneumophila* serogroup 1 was the predominant species/serotype isolated (85%) in the Pittsburgh home survey [14]. *Legionella pneumophila* serogroup 4 (24.8%) and serogroup 2 (21%) were the most common in Quebec; *Legionella pneumophila* serogroup 1 was found in only 9.5% of homes [16]. Non-*Legionella pneumophila* species were rare: *Legionella bozemanii*/*Legionella jordanis* (*n*=3 isolates), *Legionella longbeachae* (*n*=3 isolates), and *Legionella micdadei* (*n*=2 isolates) were found in homes in both the Catalonia and the Quebec studies [11, 16]. *Legionella pneumophila* serogroup 1 was the predominant member of the *Legionellaceae* found in the water supply from homes of infected patients, supporting previous findings that serogroup 1 of *Legionella pneumophila* is the serogroup most commonly linked to human disease [10, 28]: 100% of isolates (3/3) in the Pittsburgh prospective study [17], 86% (6/7) in the Ohio study, and 70% (7/10) in the anecdotal reports belonged to serogroup 1.

Legionella in Home Drinking Water Sites

In the Quebec survey, positive cultures were found exclusively in the hot water tank in 52.2% (36/69), exclusively at a distal site (faucet or showerhead) in 43.5% (30/69), and in both the hot water tank and distal sites in 4.3% (3/69), thus documenting that multiple sites in a patient's home must be cultured for maximal sensitivity.

Table 3 Water temperature and *Legionella* colonization in patient homes. Water temperature was lower in homes colonized by *Legionella*

Reference no.	No. of homes sampled	Source	Mean temperature (°C)		*P* value
			Legionella positive	*Legionella* negative	
[15]	55	HWT	40.5 (range, 35–48)	50.4 (range, 32–66)	0.05
[14]	218	HWT	41	47.4	0.01
		distal[a]	48	54	
[16]	211	HWT	55±0.6	57.3±0.1	0.01
		distal[a]	54.3±0.8	57±0.4	0.01
[26]	422	HWT	41.9±9.5	47.4±8.8	0.03
		distal[a]	51.6±9.2	54.8±11.0	0.15

HWT, hot water tank
[a] Showerheads, faucets

In a Wisconsin, USA, study implicating a cooling tower, homes were dismissed as a source because one culture from a home hot water tank was negative [29]. Evidence subsequently uncovered during a litigation trial raised strong doubts about the cooling tower as the source (R. Muder, personal communication, 1994).

Hot Water Temperature

In the surveys from Pittsburgh [14, 15] and Quebec [16], the hot water temperature at both the distal site and the hot water tank was significantly lower in *Legionella*-positive homes than in *Legionella*-negative homes (Table 3). Studies in hospitals have also consistently documented an association between *Legionella* colonization and lower hot water temperature [30, 31, 32]. In a small European study of 63 homes, *Legionella* positivity in five homes tended to occur with copper plumbing (as opposed to galvanized steel or PE-X piping), low daily water consumption, and lack of a hot water recirculation system [33]. Points where the cold water systems were subjected to warming or where the hot water was cooled by addition of cold water to prevent scalding were found to favor *Legionella* growth.

Electric Heaters

Legionella pneumophila colonization occurred significantly more often in homes in which the hot water tank was heated by electricity rather than by gas or oil. In the Quebec survey, none (0%) of the houses with gas heaters were colonized as compared to 39% of those with electric heaters [16]. Since the water temperature at the bottom of electrically heated tanks tends to be lower given the placement of heating coils (several centimeters above the bottom of the tank), it might be hypothesized that the association between electric heaters and *Legionella* colonization may be indirect. However, in the Quebec survey, when the analysis was stratified by water temperature, the association with the presence of electric water heaters remained significant [16]. In the prospective Ohio study, patients with Legionnaires' disease were more likely to reside in homes with electric water heaters than in homes with gas water heaters; however, the authors were careful to point out the possibility of confounding factors.

Demographic Data of Patients

Demographic data was available for 13 patients in nine reports: 10 from anecdotal case reports [12, 18, 19, 20, 21, 22, 23, 24, 25] and 3 from the Pittsburgh prospective study [17]. Unpublished demographic data on patients from two Pittsburgh reports was obtained from our files [17, 24]. Demographic data was not available from the prospective studies in Catalonia and Ohio [11, 26]. Overall, 62% (8/13) of the patients were male. The median age was 56 years (range, 20–76 years), and 23% (3/13) were cigarette smokers. Only one patient had chronic lung disease [18]. Fifty-four percent (7/13) were considered immunosuppressed (Table 2). Mortality was 31% (4/13).

Fifteen cases (including 3 from the Ohio study) were confirmed by culture of respiratory tract or lung specimens [12, 17, 18, 20, 21, 22, 23, 24, 25, 26]. One case was positive by direct fluorescent-antibody (DFA) assay for *Legionella pneumophila* serogroup 1 [19] and four by detection of *Legionella* antigen in urine [26]. *Legionella* selective culture media was not used for either the patient or the water specimen in the Italian study [19]. A positive serologic test was the criterion used for diagnosis of Legionnaires' disease in the German case-control study [27]. Detection of urinary antigen was the primary criterion in the Catalonia study [11].

Risk of Contracting Legionnaires' Disease in Homes

The risk for individuals residing in homes colonized with *Legionella pneumophila* appears to be low, although sample sizes of the prospective studies were small. In the one survey in Pittsburgh (totaling 11 individuals residing in positive homes) [14] and one study in Frankfurt, Germany (totaling 53 individuals residing in an apartment complex with a high level of *Legionella* colonization) [27], no cases of Legionnaires' disease could be documented in residents of these homes. Urinary antigen tests were negative for all individuals in both studies. The incidence of elevated antibody titers to *Legionella* was not significantly different between individuals living in colonized versus uncolonized homes, although the absolute titers were somewhat higher in individuals residing in the colonized apartment complex in the Frankfurt, Germany study.

The Catalonia study was a case-control study that evaluated *Legionella* colonization rates in homes of clinical cases and in homes of control cases without evidence of pneumonia [11]. Surprisingly, *Legionella* colonization occurred more often in homes of controls compared with homes of patients with Legionnaires' disease. However, only 9% (32/354) of the control homes were sampled for *Legionella*.

Cases of sporadic community-acquired Legionnaires' disease were linked to drinking water in the homes in 6.1% (9/146) in the Ohio Legionnaires' study [26] and in 15% (3/20) in the prospective Pittsburgh study [17]. In the Pittsburgh study, the water supply of each patient's home was sampled promptly after the patient's hospital admission [17]. Culturing of the home water supply was often performed months after discovery of the case in the Ohio study; culture positivity was likely to be higher if cultures were taken promptly after hospital admission [26].

There was a significant association between the rate of positivity for *Legionella* colonization of the water distribution system and cases of Legionnaire's disease in the Ohio study [26], but not in the Catalonia study [11]. The Ohio Legionnaires' group used a case-control study design with 146 cases of sporadic community-acquired Legionnaires' disease and two matched controls for each case. Multivariate analyses showed that recent plumbing in the home and services from a nonmunicipal water supply (e.g., a well) were independent risk factors for Legionnaires' disease). Interestingly, in the first two cases of Legionnaires' disease linked to home water supplies [18], both homes were supplied by well water. Isolation of amoebas was found to be equal (81% vs. 79%) for case vs. control homes in the Ohio study.

Epidemiologic Links

Molecular methods such as pulsed-field gel electrophoresis (PFGE), arbitrarily primed PCR (AP-PCR), and amplified fragment length polymorphism (AFLP) typing provide investigators with the ability to link cases of Legionnaires' disease to a specific water reservoir if the isolate from the patient is also available. The implications of making such a link are not inconsequential. If a source is correctly identified and remediation efforts are successful, a public health problem is resolved. If the source is incorrectly implicated, the considerable effort at disinfecting the source may be wasted and the actual source untouched. Therefore, not only should these methods be accurate and reproducible (as shown in the EWGLI study [9]), but the significance of the match must also be thoroughly understood. For example, numerous studies, including the pan-European study, have shown that certain molecular types were more prevalent than other types [10, 34]. If only a few types are represented in a region, the significance of a match is reduced. Thus, molecular analysis must not be used in isolation, but rather in conjunction with clinical epidemiologic data to achieve maximal sensitivity.

Drenning et al. [35] recommended combining both genotypic and phenotypic (monoclonal antibody subtyping) methods for optimal comparison of epidemiologically linked clinical and environmental isolates of *Legionella pneumophila*. The utility of monoclonal typing in determining the distribution of virulent subtypes by disease classification was demonstrated in the pan-European study [10]. The authors recommended using monoclonal antibody typing as a rapid screening tool and a genotypic typing method for further investigation. The suggestion by EWGLI that epidemiologic investigations might proceed based on results obtained from geographically distinct laboratories using a universal typing scheme is technically sound, but the proof of causation is in the interpretation of these results, which may be far more difficult than standardizing the methods.

Multiple subtyping methods were used to link patient isolates to isolates from home water distribution systems, including monoclonal antibody subtyping [17, 26, 36, 37], AFLP [23], PFGE [12, 22, 25], restriction-endonuclease analyses [17, 21], and AP-PCR [26]. In the Pittsburgh prospective study, two patients lived in apartments and one lived in a single-family home. Monoclonal antibody subtyping and restriction endonuclease analysis confirmed that the *Legionella* isolates from the three residences and three patients were identical. In the Ohio study, *Legionella* was isolated from the homes of nine patients. In seven cases (78%), the isolate from the home was identical to the patient isolate by monoclonal antibody subtyping and AP-PCR.

Recommendations

The pan-European study showed that 45% of the cases of culture-proven Legionnaires' disease were community-acquired [10]. Although no attempt was made to determine the source of these infections, a proportion of these cases undoubtedly occurred from exposure to a water source within the home. Thus, continuing investigation into the risks of contracting *Legionella* infection from patient homes is indicated. We recommend some caveats for future investigations. A standardized method of culturing would allow comparison of results of studies in different geographic locales [38]. Faucet aerators should be removed. Swabs should be used for distal sites by rotating the swab four times while moving the swab upward into the opening. If water is taken, the water should be concentrated by filtration. The samples should be acid-treated for 3 min and inoculated on buffered charcoal yeast extract medical and selective media containing dyes, glycine, vancomycin, and polymyxin B (DGVP) [38]. In one report of an anecdotal case, glycine selective media was not used and *Legionella* was not isolated from the home, although a DFA assay of the home water was positive for *Legionella pneumophila* serogroup 1 [19].

For case investigations, hot water samples (100–200 ml) should be collected from the distal site outlet immediately and then followed by the collection of swab samples. Multiple sites within the home water distribution system should be sampled to maximize the yield. The Quebec and Pittsburgh surveys found that culturing of both the distal site fixtures and the hot water tanks gave the highest yield [14, 15, 16]. The Catalonia study [11] and the European study [33] did not specify the number of distal sites sampled. For maximal yield, culture of the putative water source should be done as soon as possible after a case of community-acquired Legionnaires' disease has been discovered.

In both the Ohio and the Catalonia case-control studies, risk factors for *Legionella* colonization were assessed statistically [11, 26]. The Ohio Legionnaires' group compared culture-positive homes with culture-negative homes, independent of case-control status – a logical approach. In contrast, the Catalonia investigation evaluated risk factors for *Legionella* colonization by comparing homes where patients with Legionnaires' disease resided vs. homes where control subjects resided (regardless of whether the homes were culture positive or culture negative) and, not surprisingly, found no correlation with any parameters studied. The glaring weakness of this comparison is that not all patients may have contracted Legionnaires' disease from their homes.

The mode of transmission in sporadic cases of community-acquired Legionnaires' disease may be by aspiration (from contaminated water or transient oropharyngeal colonization) or intense aerosolization via a humidifier or whirlpool spa. Showering is not a major disseminator of *Legionella* [7]. Drinking water history was not given in any of the reports reviewed. A case-control study of water and ice usage by the patients would be ideal for future studies.

The details of the Alcoy investigation were not given, but since the "outbreak" lasted at least 1 year (1999–2000) and two cooling towers were ultimately implicated, detection bias was likely [8]. Namely, cooling towers and air conditioners were cultured, but home water supplies were overlooked. Two of the three genotypes of *Legionella pneumophila* detected by molecular subtyping were found in some patients and in two cooling towers; the third genotype apparently arose from another unidentified source, and no further mention is made of this discrepancy. We point out that the two genotypes in the cooling towers were almost certainly present in drinking water sources, since the water in the cooling towers emanates from the same source that supplies drinking water to hotels, hospitals, and homes. A well-publicized hospital outbreak in Rhode Island, USA, was initially attributed to adjacent cooling towers because molecular fingerprinting of cooling tower isolates matched that of the patients [39]. The drinking water of the hospital was correctly identified as the source years later when the outbreak recurred despite successful disinfection of the cooling tower [40] and the *Legionella pneumophila* isolate from the hospital drinking water was found to be identical to the cooling tower and patient isolates [39]. Finally, the investigators of the Alcoy outbreak noted that cases resolved despite "a late recurrence" when legislation mandating cleaning and maintenance of cooling towers was approved. This is insufficient evidence, since outbreaks typically occur in a cyclical pattern. A decrease in cases may not be the result of a specific intervention but may merely reflect the natural history of the epidemic (Farr's Law of Epidemics). This is especially pertinent since the Alcoy, Spain, outbreak occurred during 1999–2000, and the short follow-up period to 2002 is too limited to draw conclusions.

It is only logical that outbreak investigations of Legionnaires' disease must include the source water to which the patients have maximal exposure, and that is usually the water in the patient's home! On the basis of the information in this editorial, outbreak investigations implicating cooling towers and air conditioners are conspicuously incomplete if the home water supply and other drinking water sources are overlooked during environmental surveillance.

What action can the homeowner take if *Legionella* is in the water supply? Single-family dwellings are much easier to disinfect than large buildings. Superheating and flushing followed by elevation of the thermostat temperature or installation of a modular ultraviolet system is effective, although long-term efficacy is unknown [18, 41]. For our patients who are immunosuppressed or have chronic lung disease, we recommend that they boil and store water to be used for drinking, as is currently done in many developing countries. This recommendation is not a radical one. In some American cities, HIV patients are advised to boil their drinking water as a precaution against waterborne parasites.

In summary, each of the first two plagues of Legionnaires' disease led to scientific triumphs. Rigorous research approaches for studying the third plague should also lead to a third triumph yet to be discovered and implemented.

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References

1. The Holy Bible, King James version (1951) Exodus, Chapters 7–12. American Bible Society, New York
2. Stout JE, Yu VL, Vickers RM, et al (1982) Ubiquitousness of *Legionella pneumophila* in the water supply of a hospital with endemic Legionnaires' disease. N Engl J Med 36:466–468
3. Kirby BD, Snyder KM, Meyer RD, et al (1978) Legionnaires' disease: clinical features of 24 cases. Ann Intern Med 89:297–309
4. McDade J, Shepard C, Fraser D, et al (1977) Legionnaires' disease: isolation of a bacterium and demonstration of its role in other respiratory disease. N Engl J Med 297:1197–1203
5. Fraser DW, Wachsmuth IK, Bopp C, Feeley JC, Tsai TF (1978) Antibiotic treatment of guinea-pigs infected with agent of Legionnaires' disease. Lancet i:175–178
6. Tobin JO (1980) Legionnaires' disease in a transplant unit: isolation of the causative agent from shower baths. Lancet ii:118–121
7. Sabria M, Yu VL (2002) Hospital-acquired legionellosis: solutions for a preventable infection. Lancet Infectious Diseases 2:368–373

8. Fernández JA, López P, Orozco D, Merino J (2002) Clinical study of an outbreak of Legionnaires' disease in Alcoy, Southeastern Spain. Eur J Clin Microbiol Infect Dis DOI 10.1007/s10096-002-0819-9
9. Fry NK, Bangsborg JM, Bergmans A, Bernander S, Etienne J, Franzin L, Gaia V, Hasenberger P, Baladrón Jiménez B, Jonas D, Lindsay D, Mentula S, Papoutsi A, Struelens M, Uldum SA, Visca P, Wannet W, Harrison TG (2002) Designation of the European Working Group on *Legionella* Infection (EWGLI) amplified fragment length polymorphism types of *Legionella pneumophila* serogroup 1 and results of intercentre proficiency testing using a standard protocol. Eur J Clin Microbiol Infect Dis DOI 10.1007/s10096-002-0790-5
10. Helbig JH, Bernander S, Castellani-Pastoris M, Etienne J, Gaia V, Lauwers S, Lindsay D, Lück PG, Marques T, Mentula S, Peeters MF, Pelaz C, Struelens M, Uldum SA, Wewalka G, Harrison TG (2002) Pan-European study on culture-proven Legionnaires' disease: distribution of *Legionella pneumophila* serogroups and monoclonal subgroups. Eur J Clin Microbiol Infect Dis DOI 10.1007/s10096-002-0820-3
11. Codony F, Álvarez J, Oliva JM, Ciurana B, Company M, Camps N, Torres J, Miguell S, Jove N, Cireva E, Admetilla T, Abós R, Escofet A, Predrol A, Grau R, Badosa I, Vila G (2002) Factors promoting colonization by legionellae in residential water distribution systems: an environmental case-control survey. Eur J Clin Microbiol Infect Dis DOI 10.1007/s10096-002-0789-y
12. Chen YS, Lin W-R, Liu Y-C, Chang C-L, Gan V-L, Huang W-K, Huang T-S, Wann S-R, Lin H-H, Lee SS-J, Huang C-K, Chin C, Lin Y-SE, Yen M-Y (2002) Residential water supply as a likely cause of community-acquired Legionnaires' disease in an immunocompromised host. Eur J Clin Microbiol Infect Dis DOI 10.1007/s10096-002-0815-0
13. Witherell LE, Duncan RW, Stone KM, Stratton LJ, Orciari O, Kappel S, Jillson DA (1988) Investigation of *L. pneumophila* in drinking water. J Am Water Works Assoc 80:87–93
14. Stout JE, Yu VL, Yee YC, Vaccarello S, Diven W, Lee TC (1992) *Legionella pneumophila* in residential water supplies: environmental surveillance with clinical assessment for Legionnaires' disease. Epidemiol Infect 190:49–57
15. Lee TC, Stout JE, Yu VL (1988) Factors predisposing to *L. pneumophila* colonization in residential water systems. Appl Environ Health 43:59–62
16. Alary M, Joly JR (1991) Risk factors for contamination of domestic hot water systems by *Legionella*. Appl Environ Microbiol 57:2360–2367
17. Stout JE, Yu VL, Muraca P, Joly J, Troup N, Tompkins LS (1992) Potable water as the cause of sporadic cases of community-acquired Legionnaires' disease. New Engl J Med 326:151–154
18. Stout JE, Yu VL, Muraca P (1987) Legionnaires' disease acquired within the homes of two patients. Link to the home water supply. JAMA 257:1215–1217
19. Castellani-Pastoris M, Vigano EF, Passi C (1988) A family cluster of *Legionella pneumophila* infections. Scand J Infect Dis 20:489–493
20. Phillips SJ, Zeff RH, Gervick D (1987) Legionnaires' disease. Ann Thorac Surg 44:564
21. Hood J, Hay J, Gillespie T, Seal DV (1994) A fatal case of community-acquired Legionnaires' disease acquired from potable water. J Infect 22:231–233
22. Leverstein-vanHall M, Verbon A, Huisman MV, Kuijper EJ, Dankert J (1994) Reinfection with *Legionella pneumophila* documented by pulsed-field electrophoresis. Clin Infect Dis 19:1147–1149
23. Turner DPJ, Boswell TC, Lee JV, Slack RCB, Burden RP (1999) Community-acquired Legionnaires' disease in an immunocompromised patient masquerading as a hospital-acquired infection. J Hosp Infect 47:76–77
24. Lin YE, Vidic RD, Stout JE, Yu VL (2000) Legionnaires' disease in an apartment building: disinfection methods and recommendations. In: Program of the 1st World Water Congress of the International Water Association, Paris, July 3–6 2000, Poster A, no. 47
25. Sax H, Dharan S, Pittet D (2002) Legionnaires' disease in a renal transplant recipient: nosocomial or home grown? Transplantation 74:75–56
26. Straus WL, Plouffe JF, File TM Jr, Lipman HG, Salstrom SJ, Benson RF, Breiman RF (1996) Risk factors for domestic acquisition of Legionnaires' disease. Arch Intern Med 156:1685–1692
27. Heudorf U, Hentschel W, Hoffmann M, Luck C, Schubert R (2001) *Legionella* in domestic warm water – effects on health of residents. Gesundheitswesen 63:326–334
28. Yu VL, Plouffe JF, Castellani Pastoris M, Stout JE, Schousboe M, Widmer A, Summersgill J, File T, Heath CM, Paterson DL, Chereshsky A (2002) Distribution of *Legionella* species and serogroups isolated by culture in patients with sporadic community-acquired legionellosis: an international collaborative survey. J Infect Dis 186:127–128
29. Addiss DG, Davis JP, Wand PJ, McKinney RM, Gradus MS, Martins RR (1989) Two cases of community-acquired Legionnaires' disease: evidence for association with a cooling tower. J Infect Dis 159:572–575
30. Vickers RM, Yu VL, Hanna SS, Muraca P, Diven W, Carmen N, Taylor FB (1987) Determinants of *Legionella pneumophila* contamination of water distribution systems: 15-hospital prospective study. Infect Control 8:357–363
31. Plouffe JF, Webster LR, Hackman B (1983) Relationship between colonization of hospital buildings with *Legionella pneumophila* and hot water temperatures. Appl Environ Microbiol 46:769–770
32. Colbourne JS, Dennis PJ, Trew R, Berry C, Vesey G (1988) *Legionella* and public water supplies. Water Sci Technol 20:5–10
33. Tiefenbrunner F, Arnold A, Dierich P, Emde K (1993) Occurrence and distribution of *L. pneumophila* in water systems of Central European private homes. In: Barbaree JM, Breiman RF, Dufour AP (eds) Current status and emerging perspectives, 1993. American Society for Microbiology, Washington, DC, pp 235–238
34. Lawrence C, Reyrolle M, Dubrou S, Forey F, Decludt B, Goulvestre C, Matsiota-Bernard P, Etienne J, Nauciel C (1999) Single clonal origin of a high proportion of *Legionella pneumophila* serogroup 1 isolates from patients and the environment in the area of Paris, France, over a 10-year period. J Clin Microbiol 37:2652–2655
35. Drenning SD, Stout JE, Joly JR, Yu VL (2001) Unexpected similarity of pulsed-field gel electrophoresis patterns of unrelated clinical isolates of *Legionella pneumophila*, serogroup 1. J Infect Dis 183:628–632
36. Woo AH, Yu VL, Goetz A (1986) Potential in-hospital mode of transmission for *Legionella pneumophila*: demonstration experiments for dissemination by showers, humidifiers, and rinsing of ventilation bag apparatus. Amer J Med 80:567–573
37. Woo AH, Goetz A, Yu VL (1992) Transmission of *Legionella* by respiratory equipment aerosol generating devices. Chest 102:1586–1590
38. Ta AC, Stout JE, Yu VL, Wagener MM (1995) Comparison of culture methods for monitoring *Legionella* species in hospital potable water systems and recommendations for standardization of such methods. J Clin Microbiol 33:2118–2123
39. Garbe P, David B, Weisfeld J, et al (1985) Nosocomial Legionnaires' disease – epidemiologic demonstration of cooling towers as a source. JAMA 254:521–524
40. Mermel LA, Josephson SL, Girogio CH, Dempsey J, Parenteau S (1995) Association of Legionnaires' disease with construction: contamination of potable water. Infect Control Hosp Epidemiol 16:76–81
41. Yu VL, Stout JE (1992) Sporadic cases of Legionnaires' disease. New Engl J Med 25:1700–1701