

Recurrence, Microevolution, and Spatiotemporal Dynamics of *Legionella pneumophila* Sequence Type 1905, Portugal, 2014–2022

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We investigated molecular evolution and spatiotemporal dynamics of atypical *Legionella pneumophila* serogroup 1 sequence type 1905 and determined its long-term persistence and linkage to human disease in dispersed locations, far beyond the large 2014 outbreak epicenter in Portugal. Our finding highlights the need for public health interventions to prevent further disease spread.

Legionella, the causative agent of Legionnaires' disease (LD), is a facultative intracellular gram-negative bacterium that is ubiquitous in freshwater environments. *Legionella* bacteria usually thrive in natural and artificial water sources, such as cooling towers, hot water tanks, and plumbing systems. Humans acquire infection by inhaling bacteria-contaminated droplets, usually generated by water systems or devices (1). Although the primary mode of transmission is exposure to contaminated aerosolized water, not all *Legionella* species known to cause disease in humans are exclusively associated with water sources. For example, infection with *L. longbeachae* is associated with exposure to soil and compost-related products (2). Although *Legionella* bacteria typically do not spread from person to person, that transmission route has been reported (3,4).

Incidence of *Legionella* infection in a population is primarily influenced by 3 factors: individual susceptibility, environment, and type of exposure. Outbreaks often occur in healthcare settings (e.g.,

hospitals or long-term care facilities) because of the presence of persons at increased risk for infection and severe disease (5).

One of the world's largest outbreaks of LD (>400 cases and 14 deaths) occurred in the Vila Franca de Xira (VFX) region of Portugal, in 2014 (6,7). The outbreak was associated with the novel sequence type (ST) 1905 of *L. pneumophila* subspecies *fraseri* serogroup 1 strain (PtVFX/2014), which probably originated from a local industrial cooling tower (6,7). In-depth genomic analyses showed that PtVFX/2014 possesses a unique and mosaic genomic backbone marked by specific evolutionary and genetic traits (3), including a recently identified novel effector with nucleotropism (8), that may affect its ability to adapt and persist in diverse environments and cause human disease. The *L. pneumophila* ST1905 strain was also implicated by the strongest evidence to date of person-to-person transmission of LD (3,4). To our knowledge, *L. pneumophila* ST1905 has not been reported in countries other than Portugal. To elucidate the molecular evolution and spatiotemporal dynamics of *L. pneumophila* serogroup 1 ST1905 during 2014–2022, we investigated the phylogenetic relationship of strains isolated during that period at the National Institute of Health, Portugal, in the context of the National Legionnaires' Disease Surveillance Programme.

The Study

Since the large 2014 LD outbreak, the ST1905 genotype has been identified several times in Portugal. For our study, we analyzed all *L. pneumophila* serogroup 1 ST1905 isolates (6 clinical and 6 environmental) obtained from samples collected in 3 interconnected

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municipalities in the Lisbon region (Lisbon, Loures, and VFX) in the context of clinical case investigations (outbreaks or as sporadic cases) (Figures 1, 2; Appendix 1, <https://wwwnc.cdc.gov/EID/article/30/5/23-1383-App1.xlsx>; Appendix 2, <https://wwwnc.cdc.gov/EID/article/30/5/23-1383-App2.pdf>). We also included 2 culture-negative clinical samples genotyped as ST1905 for analysis of the temporal and geographic distribution of this strain after 2014 (Appendices 1, 2).

Single-nucleotide polymorphism (SNP)-based diversity analysis confirmed that all ST1905 isolates were genetically similar to PtVFX/2014, differing by 3–6 SNPs. Overall, the observed microevolution across the 12 isolates was marked by 10 SNPs (9 nonsynonymous and 1 synonymous mutations), 4 insertion/deletions, and 1 small recombination event (Figure 2). The low number of SNPs during the 8-year period supports the notion that *L. pneumophila* evolves at a very slow rate, resulting in substantial temporal and spatial conservation, as previously reported (9,10). When compared with PtVFX/2014, all isolates presented a recombination event in an ≈ 2.5 -kb region (con-

tig 8, PtVFX/2014_08985-08995) belonging to the type IVA secretion system, which is associated with the survival of the bacteria in the environment (11). Of note, Lpn_PT_E259_y2021, isolated from a sporadic LD case, presented mutational events, including 2 deletions and 1 insertion, not found in any other isolates included in this study. The first deletion encompasses a 45,479-bp segment (contig 8, PtVFX/2014_09080-09280) that includes an ≈ 37.5 -Kb genomic island containing an *loh/lor* type IVA secretion system cluster. That cluster was first identified within the *L. pneumophila* species in the PtVFX/2014 strain (PtVFX/2014_09115-09280), possibly because of interspecies transfer from *L. oakridgensis* (3). The second deletion spanned 142 bp and occurred in a CRISPR-associated intergenic region (PtVFX/2014_08935/08940). Moreover, we observed a frameshift 25-bp insertion at the PtVFX/2014_13190 locus, coding for a protein with unknown function. That locus seems to be specific for *L. pneumophila* subsp. *fraseri* and is located within a larger genomic region that contains known Dot/Icm substrates (3). Although we cannot make

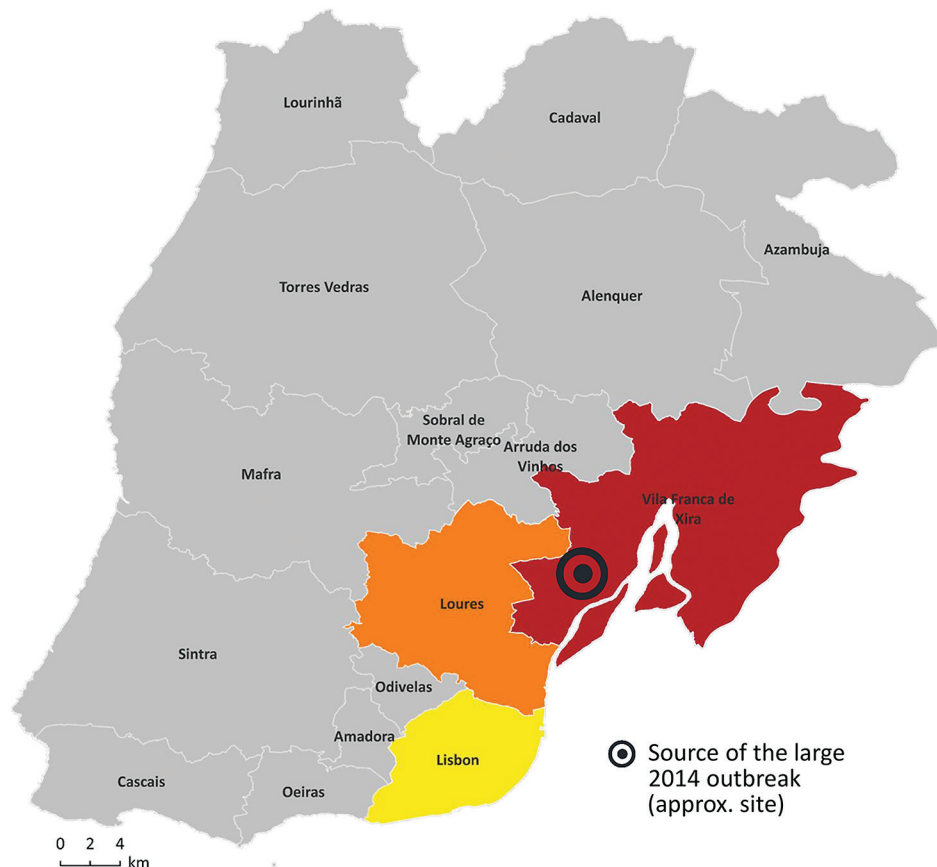


Figure 1. Geographic spread of 12 *Legionella pneumophila* sequence type 1905 isolates by probable municipality of exposure (clinical) or sampling (environmental), Lisbon region, Portugal, 2014–2022. Location of 2014 Legionnaires' disease outbreak is indicated.

health preparedness and control strategies, emphasizing the added value of molecular epidemiology in the surveillance and management of LD.

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We report no potential conflict of interest.

About the Author

Dr. Manageiro is a researcher at the Department of Infectious Diseases, National Institute of Health Doutor Ricardo Jorge, Lisbon, Portugal. Her research focuses on gram-negative pathogen antibiotic resistance, with an emphasis on the roles of resistome and mobilome as linkages between human, animal, and environmental reservoirs. Dr. Borges is a researcher at the Department of Infectious Diseases, National Institute of Health Doutor Ricardo Jorge, Lisbon, Portugal. His research focuses on using genomics and transcriptomics to survey and investigate pathogens with effects on public health.

References

- Iliadi V, Staykova J, Iliadis S, Konstantinidou I, Sivykh P, Romanidou G, et al. *Legionella pneumophila*: the journey from the environment to the blood. *J Clin Med*. 2022;11:6126. <https://doi.org/10.3390/jcm11206126>
- Chambers ST, Slow S, Scott-Thomas A, Murdoch DR. Legionellosis caused by non-*Legionella pneumophila* species, with a focus on *Legionella longbeachae*. *Microorganisms*. 2021;9:291. <https://doi.org/10.3390/microorganisms9020291>
- Borges V, Nunes A, Sampaio DA, Vieira L, Machado J, Simões MJ, et al. *Legionella pneumophila* strain associated with the first evidence of person-to-person transmission of Legionnaires' disease: a unique mosaic genetic backbone. *Sci Rep*. 2016;6:26261. <https://doi.org/10.1038/srep26261>
- Correia AM, Ferreira JS, Borges V, Nunes A, Gomes B, Capucho R, et al. Probable person-to-person transmission of Legionnaires' disease. *N Engl J Med*. 2016;374:497–8. <https://doi.org/10.1056/NEJMc1505356>
- Beauté J, Plachouras D, Sandin S, Giesecke J, Sparén P. Healthcare-associated Legionnaires' disease, Europe, 2008–2017. *Emerg Infect Dis*. 2020;26:2309–18.
- Shivaji T, Sousa Pinto C, San-Bento A, Oliveira Serra LA, Valente J, Machado J, et al. A large community outbreak of Legionnaires disease in Vila Franca de Xira, Portugal, October to November 2014. *Euro Surveill*. 2014;19:20991. <https://doi.org/10.2807/1560-7917.ES2014.19.50.20991>
- George F, Shivaji T, Pinto CS, Serra LAO, Valente J, Albuquerque MJ, et al. A large outbreak of Legionnaires' disease in an industrial town in Portugal. *Rev Port Saude Publica*. 2016;34:199–208. <https://doi.org/10.1016/j.rpsp.2016.10.001>
- Monteiro IP, Sousa S, Borges V, Gonçalves P, Gomes JP, Mota LJ, et al. A search for novel *Legionella pneumophila* effector proteins reveals a strain specific nucleotropic effector. *Front Cell Infect Microbiol*. 2022;12:864626. <https://doi.org/10.3389/fcimb.2022.864626>
- David S, Mentasti M, Lai S, Vaghji L, Ready D, Chalker VJ, et al. Spatial structuring of a *Legionella pneumophila* population within the water system of a large occupational building. *Microb Genom*. 2018;4:e000226. <https://doi.org/10.1099/mgen.0.000226>
- Leenheer D, Moreno AB, Paranjape K, Murray S, Jarraud S, Ginevra C, et al. Rapid adaptations of *Legionella pneumophila* to the human host. *Microb Genom*. 2023;9:mgen000958. <https://doi.org/10.1099/mgen.0.000958>
- Qin T, Zhou H, Ren H, Liu W. Distribution of secretion systems in the genus *Legionella* and its correlation with pathogenicity. *Front Microbiol*. 2017;8:388. <https://doi.org/10.3389/fmicb.2017.00388>
- Oliva G, Sahr T, Buchrieser C. The life cycle of *L. pneumophila*: cellular differentiation is linked to virulence and metabolism. *Front Cell Infect Microbiol*. 2018;8:3. <https://doi.org/10.3389/fcimb.2018.00003>
- David S, Rusniok C, Mentasti M, Gomez-Valero L, Harris SR, Lechat P, et al. Multiple major disease-associated clones of *Legionella pneumophila* have emerged recently and independently. *Genome Res*. 2016;26:1555–64. <https://doi.org/10.1101/gr.209536.116>
- Bédard E, Trigui H, Liang J, Doberva M, Paranjape K, Lalancette C, et al. Local adaptation of *Legionella pneumophila* within a hospital hot water system increases tolerance to copper. *Appl Environ Microbiol*. 2021;87:e00242–21. <https://doi.org/10.1128/AEM.00242-21>
- Russo A, Gouveia CM, Soares PMM, Cardoso RM, Mendes MT, Trigo RM. The unprecedented 2014 Legionnaires' disease outbreak in Portugal: atmospheric driving mechanisms. *Int J Biometeorol*. 2018;62:1167–79. <https://doi.org/10.1007/s00484-018-1520-8>

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Appendix 2

Materials and Methods

Selection of samples and isolates

This study includes all (n = 14) *L. pneumophila* samples and isolates collected after the large outbreak in 2014 that were identified as serogroup 1 and ST1905, in the context of the National Legionnaires' Disease Surveillance Programme, by the National Reference Laboratory for *Legionella*, in Lisbon, Portugal. In detail, it includes: 12 isolates (6 clinical and 6 environmental) and two positive specimens. A representative genome sequence of a ST1905 *L. pneumophila* PtVFX/2014 isolate collected during the 2014 outbreak, which was previously characterized (1), was included in this study as a reference. Details about all studied samples are available at the Appendix 1 Table 1 (<https://wwwnc.cdc.gov/EID/article/30/5/23-1383-App1.xlsx>).

DNA extraction and quantification

Isolation of bacterial DNA from 12 *L. pneumophila* isolates and from 2 *L. pneumophila* PCR-positive culture-negative samples was performed on the EMAG[®] platform (bioMérieux), an automated nucleic acid extraction platform based on magnetic silica technology. DNA was quantified by fluorescence spectroscopy using the Qubit Fluorometer (ThermoFisher Scientific).

L. pneumophila Sequence-Based Typing (SBT) and Whole Genome Sequencing (WGS)

SBT was performed at the National Reference Laboratory for *Legionella* using the DNA retrieved from pure cultures and uncultured clinical samples using the amplification of the 7 loci

in the SBT scheme, following the protocol of the European Working Group for *Legionella* infections (2). Sequencing libraries of DNA obtained from the *L. pneumophila* isolates (n = 12) was prepared using the Nextera XT DNA Sample Preparation Kit (Illumina), following manufacturer's instructions. Whole Genome Sequencing (WGS) was performed using Illumina MiSeq equipment (2x250 bp), as previously described (1).

Phylogeny and microevolutionary analysis

INNUca v4.2.2 (<https://github.com/B-UMMI/INNUca>) was applied to perform quality control of reads, draft de novo assembly and contigs quality assessment, and contamination detection. ReporType (3) (<https://github.com/insapathogenomics/ReporType>) was applied to perform *in silico* prediction of the *L. pneumophila* subspecies and serogroup from the draft assemblies. SBT profile ST1905 was also confirmed *in silico* through BLASTn (also using ReporType) against the SBT allele database available in <https://github.com/tseemann/legsta>. Snippy v4.6.0 (<https://github.com/tseemann/snippy>; settings:–mapqual 20–mincov 10–minfrac 0.51–basequal 20) was applied to the INNUca quality processed reads to perform reference-based mapping and SNP/indel analysis using the *L. pneumophila* PtVFX/2014 draft genome annotation (LORH00000000.1) as reference. Core genome SNP alignments were extracted from the Snippy-derived whole SNP alignment using ReporTree 1.1.2 (4). Whenever a mutation was reported for any of the studied isolates, the mapping files (BAM) of the other isolates were visually inspected in Integrative Genomics Viewer (IGV, <https://igv.org/app/>) to confirm/exclude its presence. Mapping files were also used to search and confirm the presence of indel events. A maximum phylogenetic likelihood tree was then constructed based on the curated core-genome SNP alignment (excluding SNPs found in ~2.5Kb recombination event found in reference contig 8, positions 8985–08995) using the Tamura 3-parameter evolutionary model in MEGA 11 (<https://www.megasoftware.net/>), incorporating 1000 random bootstrap replicates to assess node support within the tree.

References

1. Borges V, Nunes A, Sampaio DA, Vieira L, Machado J, Simões MJ, et al. *Legionella pneumophila* strain associated with the first evidence of person-to-person transmission of Legionnaires' disease: a unique mosaic genetic backbone. Sci Rep. 2016;6:26261. [PubMed](https://doi.org/10.1038/srep26261)
<https://doi.org/10.1038/srep26261>

2. Gaia V, Fry NK, Afshar B, Lück PC, Meugnier H, Etienne J, et al. Consensus sequence-based scheme for epidemiological typing of clinical and environmental isolates of *Legionella pneumophila*. J Clin Microbiol. 2005;43:2047–52. PubMed <https://doi.org/10.1128/JCM.43.5.2047-2052.2005>
3. Cruz H, Pinheiro M, Borges V. ReporType: a flexible bioinformatics tool for targeted loci screening and typing of infectious agents. Int J Mol Sci. 2024;25:3172. <https://doi.org/10.3390/ijms25063172>
4. Mixão V, Pinto M, Sobral D, Di Pasquale A, Gomes JP, Borges V. ReporTree: a surveillance-oriented tool to strengthen the linkage between pathogen genetic clusters and epidemiological data. Genome Med. 2023;15:43. PubMed <https://doi.org/10.1186/s13073-023-01196-1>