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Growth of *Legionella* during COVID-19 lockdown stagnation

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While "avoiding stagnation" has been the mantra of many building water quality experts, the foundational support for how this terminology is used in peer-reviewed publications and building water management guidelines is not overly convincing. With COVID-19 lockdowns and subsequent reopening, the concern that extended stagnation will trigger increased incidence (or even an epidemic) of legionellosis has been widely raised in the news and social media. Here, we provide a perspective on four simple questions to a complex topic, with hope that it encourages a broader dialogue and more critical assessment of assumptions and communication strategies surrounding stagnation and *Legionella* growth.

Water impact

The decades-old dogma that "stagnation causes *Legionella* growth" has been widely disseminated after COVID-19 lockdowns became prevalent. We argue this "fact" has been over-simplified to a singular concept and is not unilaterally supported in peer-reviewed literature. This review highlights nuances surrounding stagnation in buildings and suggests criteria to carefully consider how results are communicated to practitioners for forthcoming post-COVID-19 building water quality studies being conducted worldwide.

Introduction

It is a widely accepted "fact" that water stagnation in buildings leads to *Legionella* growth.[1–7] This has been amplified considerably following the COVID-19 building shutdowns worldwide, with calls for some intensive actions to be undertaken by building managers (flushing protocols[3,8,9]) being translated to warnings of potentially severe health risks.[10–13] Optimizing hydraulic design and thus maintaining target controls within building networks is clearly beneficial to controlling microbial water quality.[14,15] However, the available scientific evidence regarding the impact of stagnation on *Legionella* growth is more complicated and less convincing than what is frequently conveyed in peer-reviewed literature, *Legionella* control guidelines, news media, and social media. Here, we provide opinion on four fundamental questions related to the impact of stagnation during the COVID-19 lockdown through an assessment of some of the influential literature in the field and identify criteria to be addressed when conducting and reporting on post-COVID-19 *Legionella* studies. A more careful approach in documenting the impacts of stagnation on legionellosis (Legionnaires' disease and the more under-studied and under-reported Pontiac fever) is needed to put health risks of *Legionella* occurrence into context with other problems that can develop during stagnation, or unintended consequences (*e.g.*, improper flushing causing release of contaminants).

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(1) What is stagnation?

Stagnation of water in building plumbing systems coincides with physiochemical water quality changes that alter the trajectory of microbial dynamics in water systems. These changes include water temperatures trending towards and remaining at ambient temperature, decay of disinfection residual (where applicable), destabilization of corrosion scales[16] and biofilms,[17] release of metals such as copper and lead,[18] and changes in the composition and concentration of bio-available nutrients.[19,20] However, part of the confusion and potential for miscommunication regarding the effects of stagnation on water quality is how stagnation is defined. In the context of controlling *Legionella* growth, the term stagnation has been used to describe complete stagnation (no water exchange or flow) in unused water storage tanks[1] or outlets,[21] intermittent demand at individual outlets,[1] existence of dead-end pipes,[22] generally elevated water age due to low demand and/or over-sized components,[23] and no water exchange in the presence of continuous water movement due to water recirculation.[21] The duration of stagnation studied also changes considerably in context of the system, encompassing periods of one night,[17] days,[24] weeks,[21] months,[25] more than a year,[1] and undefined durations.[2] These differences in system components (tanks *vs.* primary branches *vs.* outlets), type of stagnation (complete *vs.* intermittent), and duration (days *vs.* months), undoubtably alter the microbiological response. Unfortunately, "stagnation" is frequently used as an all-encompassing term to describe different aspects of water use in building plumbing systems, which has led to propagation of information that lacks critical nuance. We assert that "stagnation" as currently referred to in literature cannot be viewed a singular concept. Rather, defining the frequency and duration of stagnation that raise concerns should be system specific. Such a definition requires an engineering system assessment on a site-by-site basis that considers that location's prior experiences with stagnation, water quality, and incidence of disease. Moreover, stagnation should be defined and communicated for each building water system (and relevant sub-systems) individually, and novel findings of future studies should be framed in the context of carefully evaluated supporting literature that reports the impact of similar facets of stagnation (components, types, and durations) as the location being studied, where applicable.

(2) Does stagnation cause *Legionella* growth?

Many publications that suggest stagnation supports *Legionella* growth can be traced back to Ciesielski and colleagues (1984),[1] which stated "Conditions known to be favorable for the multiplication of *L. pneumophila* include stagnating warm water" without attribution. Their work demonstrated that reducing stagnation in severely contaminated hot water storage tanks quickly decreased *L. pneumophila* levels, but did not strongly support the conclusion that stagnation increased growth. In fact, they observed diverging trends in the two completely stagnant storage tanks monitored. Their conclusion that stagnation supports *Legionella* growth may have alternatively stemmed from the fact that showers and faucets with aerators in their study were heavily colonized despite negative culture results in the water storage tanks serving them.[26–28] However, differences in biofilm/water sample collection strategies and not treating or replacing the showerheads and faucets aerators prior to the monitoring period severely complicates sound comparisons and conclusions. In addition, the hot water temperature in the online tanks was frequently within *Legionella's* ideal growth range. This suggests intermittent use and the associated fluctuations in temperature, nutrients, and hydraulic conditions cannot be wholly separated from the effects of stagnation alone.

Hoge and Breiman (1991)[4] reviewed a number of earlier publications and concluded that "Sites from which *Legionella* has been cultured include water heaters, shower heads, faucets, and blind loops of plumbing where water can stagnate." Notably, they did not include any direct attribution for this statement, thus suggesting the anecdotal evidence for a link between stagnation and *Legionella* occurrence was well established by at least 1991. A survey of nine buildings by Völker and colleagues (2016)[2] provides somewhat more compelling evidence linking *Legionella* growth with stagnant conditions. In 807 samples analyzed, they observed a correlation between *L. pneumophila* occurrence and temperature, pipe length measures, and stagnation. However, stagnation in this study, as in many studies, was only qualitatively defined and again appeared to be linked to pipes with low/intermittent water use, rather than absolute stagnation. Nonetheless, the seemingly preconceived notion that stagnation always supports *Legionella* growth has been adopted in many control guidelines and standards internationally.[29]

After observing a case where by eliminating dead-legs (thus eliminating points of stagnation) had no impact on *Legionella* colonization,[22] the conventional wisdom that stagnation supported *Legionella* growth was first experimentally challenged by Liu and colleagues (2006).[21] In this study, completely stagnant conditions had the lowest numbers of biofilm-associated *Legionella* spp. relative to turbulent and laminar flow conditions in a 5 week pilot-scale experiment. However, there was very little water exchange (5%) in the flowing conditions, and the experiments were conducted at ambient temperature with no residual disinfectant. These latter two factors are important for *Legionella* growth and typically vary substantially between systems with flowing and non-flowing stagnant conditions (*e.g.*, recirculating hot water systems *vs.* cold). The lack of *Legionella* growth during stagnation was further documented by Bédard and colleagues (2015)[24] in a well-controlled field study where no increase in *L. pneumophila* gene copy numbers was observed in repeat sampling events at outlets of a contaminated building that were completely stagnated for up to 10 days, suggesting that stagnation was not a driving factor for growth in this building.

Highlighting the complexity and challenges with respect to *Legionella* growth and stagnation, Rhoads and colleagues (2015)[30] demonstrated that continuous flow and intermittent stagnation can both support and limit increases in *L. pneumophila* gene copy numbers depending on the water heater setpoint and frequency of exposure. Thus, we assert that there is currently not detailed consensus on the various dimensions of "stagnation" that encompass water quality changes that coincide with stagnation as well as different environmental conditions (*e.g.*, materials used) on the occurrence, and specifically growth, of *Legionella*. We recognize that the literature above is not exhaustive, but we believe that it captures the lack of clarity and contradicting research on the topic. Hence, we identify a clear need for more carefully designed experiments that places novel findings into context with, and which builds upon, relevant prior literature to improve our understanding of the biological processes occurring while water is not being exchange or flowing.

(3) Are legionellosis cases linked to extended stagnation?

In keeping with the conventional wisdom, we would expect well-documented case studies definitively linking extended stagnation to legionellosis cases and outbreaks. Extended stagnation conditions are not altogether uncommon – schools and universities have summer holiday for six to eight weeks; seasonal resorts and sporting facilities annually have months-long periods of substantially lower water demand – making it more curious that there is not more literature on this topic. Early reports of legionellosis cases and outbreak investigations were focused on identifying patient susceptibility factors and these reports do not provide detailed, useful information regarding the actual conditions present.[31,32] Similarly, later legionellosis case reports are also epidemiologic in nature and provide only limited documentation regarding the design, operation, or function of the plumbing mechanical systems, which is essential understanding how stagnation may have contributed to the root-cause of disease and properly identifying and resolving issues.[33] There is a body of work linking construction activities, which includes the associated water system stagnation, with legionellosis.[34] However, in this literature it is difficult to separate the impact of the stagnation relative to the other physical disturbance and pressure fluctuations that tend to occur with construction activities.

Some work does suggest that extended stagnation is more likely to be associated with *Legionella* colonization, but these studies are in the absence of identified legionellosis cases, which is somewhat complicated by the seasonality in legionellosis incidence. For instance, Mouchtouri and colleagues (2007)[25] demonstrated that seasonal operation of hotels was the principal predicting factor for *L. pneumophila* colonization as determined by culture analysis of 1086 samples from 385 hotels in Greece. However, the authors note that hotels in smaller towns were more likely to operate seasonally than large towns or cities, implying that there may be other factors to consider such as awareness and resources available for proper system management. Rakić and colleagues (2011)[35] demonstrated similar findings in 11 seasonally operated hotels in Croatia. But again, the specific conditions of stagnation are not summarized in these or similar surveys.

Even considering the difficulty in conducting legionellosis case investigations due to their time- and health-sensitive nature, the limited information linking extended stagnation directly with legionellosis is perplexing. We assert that this gap exists partially because of the historic focus on the epidemiological aspects of investigations. This gap may be filled by future detailed legionellosis case studies that include better summaries and analysis of engineering, plumbing, and mechanical aspects of the system, designed experimental monitoring of seasonally operated facilities, and potentially retrospective analysis of available case studies that have occurred surrounding well-known periods of extended stagnation (*i.e.*, seasonality).

(4) Have COVID-19 lockdowns increased legionellosis cases?

The end of lockdown and subsequent recommissioning has been ongoing worldwide for months. Yet, not much data has been forthcoming to support suggestions of an emerging public health crisis, either in the form of water analysis data or a spike in legionellosis cases. In the reports we have seen of *Legionella* contamination of stagnant buildings,[36] there is unfortunately no historical data reported or other data to conclude that COVID-19-related stagnation associated with shutdowns caused or exacerbated contamination issues. There have been very few reports legionellosis that may be related to COVID-19. For example, one Legionnaires' disease case was reported in an employee of a school in June 2020, but this school had a fatal Legionnaires' disease cases in April 2019, suggesting there were potentially unresolved issues at the facility prior to COVID-19 lockdown.[37] In a peer-reviewed investigation, Palazzolo and colleagues (2020)[38] speculated on the link between a positive case of legionellosis in Italy following COVID-19 lockdown. Though the title of the study is quite enticing ("*Legionella* pneumonia: increased risk after COVID-19 lockdown?"), Rota and colleagues (2020)[39] point out the authors did not produce supporting evidence that COVID-19-related stagnation had contributed to case and consequently did not provide a clear answer to the poignant question posed in their title. In fact, Palazzolo and colleagues remarked that incidence of legionellosis was 74% lower than historical norms in the Rome health district where the case occurred.

We recognize that it may still be too early for detailed case studies better supporting the causal link between COVID-19 stagnation and legionellosis to have been conducted and disseminated; yet, we remain surprised more case information is not readily available if there is an ongoing or impending public health crisis. Timely, accurate, and contextualized communications are needed to prevent practices that may not be fully effective (*e.g.*, not managing the system after interventions), unintentionally increase risks (*e.g.*, incorrect flushing),[40] or unduly burdensome communities (*e.g.*, being told to test for and respond to *Legionella* health warnings by experts without having adequate decision-making resources).[41] An in-depth retrospective analysis of reporting data will be needed to assess trends in legionellosis and reopening patterns relative to trends in historical incidence data.

Criteria to consider for COVID-19 *Legionella* publications

Given the heightened publicity to the topic, we expect a number of studies dealing with COVID-19 stagnation and *Legionella* occurrence during the following months. In this regard, we pose several questions that should be considered when making such information available, noting that the mere detection of *Legionella* after lockdown is by itself not evidence of growth during lockdown or evidence of increased risk of contracting legionellosis.

(1) Does the study adequately demonstrate COVID-19 stagnation caused the occurrence/growth of *Legionella* by providing appropriate baseline data? Data collected prior to the start of lockdown is ideal. Tracking performance of a building during recommissioning is an alternative, but does not necessarily indicate pandemic-related issues. Single time-point snap shot data of just one building is not meaningful, while snap shot data of many buildings should be placed into context with past surveys indicating wide-spread colonization of *Legionella*.[42–44]

(2) Does the study adequately describe background water demand during lockdown relative to historical norms in addition to the specific stagnation period for outlets tested (*i.e.*, complete stagnation *vs.* low occupancy)? Quantitatively assessing overall water demand and use patterns within the building is ideal. Building occupancy (or surrogates for occupancy[45]) may be helpful.

(3) Were any intensive flushing actions or other interventions taken during stagnation or prior to reopening? Various recommendations exist, and we expect a wide variety of preventative and remedial flushing and/or treatment practices to have occurred in response to COVID-19 lockdowns. Samples collected before and after flushing is clearly important, but inform on the efficacy of flushing, and not necessarily the impact of stagnation. These distinctions must be clearly handled in forthcoming publications and communications.

(4) Does the study adequately characterize plumbing, mechanical, and engineering aspects of the building? For example, the basic plumbing design (circulating systems *vs.* trunk and branch *vs.* manifold), number of outlets, water demand patterns, boiler system design (*e.g.*, volume, heat source, use of master mixing valves), materials, history of construction, and other pertinent building details help readers interpret the results and evaluate how the cause(s) of identified issues may relate to other examples. Often, detailed water quality and engineering aspects of building systems are not reported in peer-reviewed literature.

(5) Is the sampling strategy sensible and clearly described, and done in the context of the plumbing aspects described above? For example, are completely stagnating first draw samples compared to flushed samples, and hot water samples compared to cold water samples? Are data presented in context with the operational settings of the plumbing system (profiles of hot and cold water quality throughout the building)? For instance, Bédard and colleagues (2015)[24] present a sound approach to evaluating temperature; Rhoads and colleagues (2014)[23] present examples for evaluating residual disinfectant levels. Ambient building temperatures and HVAC operation also will likely play an important (and potentially unappreciated) role in microbial growth during stagnation.

(6) How does the study link or correlate *Legionella* occurrence to other relevant physical and chemical water quality data? Measuring temperature, chorine, inorganics, or other variables in samples collected sequentially with flushing, instead of splitting the volume of one sample for all analyses, can lead to misinterpretation of data.

(7) Does the study use culture methods to assess potential risk? Molecular methods are not typically used for risk assessments without long-term trends of detection. If molecular methods are used, does the study differentiate the genetic material of pathogenic species of *Legionella* (*e.g.*, *L. pneumophila*) or only at the genus level that may also contain non-pathogenic species of *Legionella*?

(8) Are culture results put into context with levels of concern? For non-healthcare buildings water systems that do not have high numbers of susceptible occupants, the recent National Academies of Science, Engineering, and Medicine suggest 50 000 CFU L^{-1} as an "action level" warranting serious concern and triggering remediation.[7] Many international standards use 1000 CFU L^{-1}.[46]

We recognize that many COVID-19-related experimental studies were started with limited time for detailed planning, and carried out under very challenging working conditions. Nonetheless, we argue that the more of these criteria can be considered and communicated, the easier it will be to draw sensible and universal conclusions from the results.

Conclusions

Water stagnation in building plumbing is complex. Investigation of legionellosis cases or *Legionella* occurrence requires detailed investigations that benefit from involving multiple disciplines. We recognize that stagnation clearly causes issues in some circumstances, but conclude that the highly variable conditions that can be observed during "stagnation" requires a more detailed definition and accounting of these conditions. Given the costs associated with reducing water system stagnation in buildings, a better understanding of these variables is needed to guide recommended practices. In the current COVID-19 situation, we urge a careful and considered communication approach, both in peer-reviewed publications and in communications with the broader public through news and social media. It is important that well-substantiated facts drive the dissemination of knowledge in this period. For the future, we strongly advocate for properly controlled studies and closer scrutiny of past literature to better understand *Legionella* colonization and growth during stagnation.

Conflicts of interest

There are no conflicts to declare.

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