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REVIEW

Contaminated water as a source of *Helicobacter pylori* infection: A review

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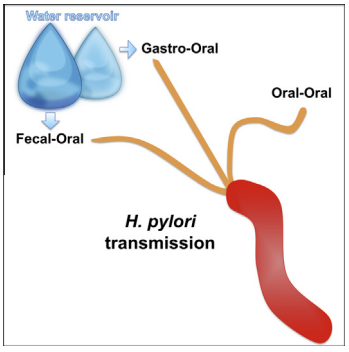
GRAPHICAL ABSTRACT



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ABSTRACT

Over the preceding years and to date, the definitive mode of human infection by *Helicobacter pylori* has remained largely unknown and has thus gained the interest of researchers around the world. Numerous studies investigated possible sources of transmission of this emerging carcinogenic pathogen that colonizes >50% of humans, in many of which contaminated water is mentioned as a major cause. The infection rate is especially higher in developing countries, where contaminated water, combined with social hardships and poor sanitary conditions, plays

Abbreviations: IMS, immunomagnetic separation; PCR, polymerase chain reaction; VBNC, viable-but-non-culturable.

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a key role. Judging from the growing global population and the changing climate, the rate is expected to rise. Here, we sum up the current views of the water transmission hypothesis, and we discuss its implications.

Keywords:
Epidemiology
Infectious diseases
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Water crisis

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Introduction

Water crisis and risk of infectious diseases in the developing world

On July 28, 2010, the General Assembly of the United Nations voted to recognize access to clean water and sanitation as a human right (URL: http://www.un.org/News/Press/docs/2010/ga10967.doc.htm), a long-awaited decision that had been advocated and endorsed by the scientific community [1]. This recent UN resolution came at a time in which water is increasingly becoming at the heart of geopolitical and socioeconomic conflicts, notably in the developing world and in particular as a consequence of climate change [2,3].

In developing countries, many communities lack access to a reliable source of clean water (Fig. 1A) or sanitation services (Fig. 1B) [4]. Instead, those communities find themselves having no other choice but to depend on the surrounding sources of continuously flowing water, such as nearby rivers and streams as their sole everyday water source (Fig. 2A). On the other hand, isolated communities living in low-populated deserted geographical areas, located hundreds of miles away from a nearby river branch or stream, are obliged to rely on municipal water wells as their main supply for drinking and irrigation (Fig. 2B). An alarmingly rising number of those individuals suffer from numerous gastrointestinal tract-related problems [5–8], some of which can be directly linked to *Helicobacter pylori* infection, which can result into chronic infection and even cancer [9,10].

When waterborne diseases are discussed, acute infections related to diarrhea and malnutrition (e.g., infections by *Vibrio cholerae*, *Escherichia coli*, and *Salmonella enterica*) often come to the front scene [3,11], but it is less common to consider chronic diseases, such as those resulting from *H. pylori* infection, as water-related public health threats. Still, the increase in *H. pylori*-associated gastrointestinal conditions could only raise an obvious question of whether contaminated water is a route of transmission of this pathogen, being a common factor among the infected patients [12]. This question gains particular importance given the continuously changing pattern of human demography expected to redraw the global map of *H. pylori* epidemiology [13].

In this article, we briefly introduce *H. pylori* and its epidemiology, we review evidence suggesting contaminated water as a source of infection with emphasis on recent evidence confirming viability of the bacteria isolated from water sources, and we discuss the potential implications of this route of transmission on global health and health policies.

Helicobacter pylori and its transmission

H. pylori, a bacterium initially observed in 1893 ([14] cited in [15]), has not been recognized as an infectious agent until 1982—in the seminal work of Nobel Laureates, Warren and Marshall [16–18]. *H. pylori* colonizes various regions of the upper digestive system, mainly the stomach and duodenum, causing stomach and duodenal ulcers and certain stomach cancers [9,19,20]. The infection is surprisingly common, and the bacteria are believed to colonize more than half of the world's population [21].

H. pylori bacteria grow only under microaerophilic conditions on rich media [22]. An interesting feature of these bacteria is their ability to adapt to harsh conditions. They are

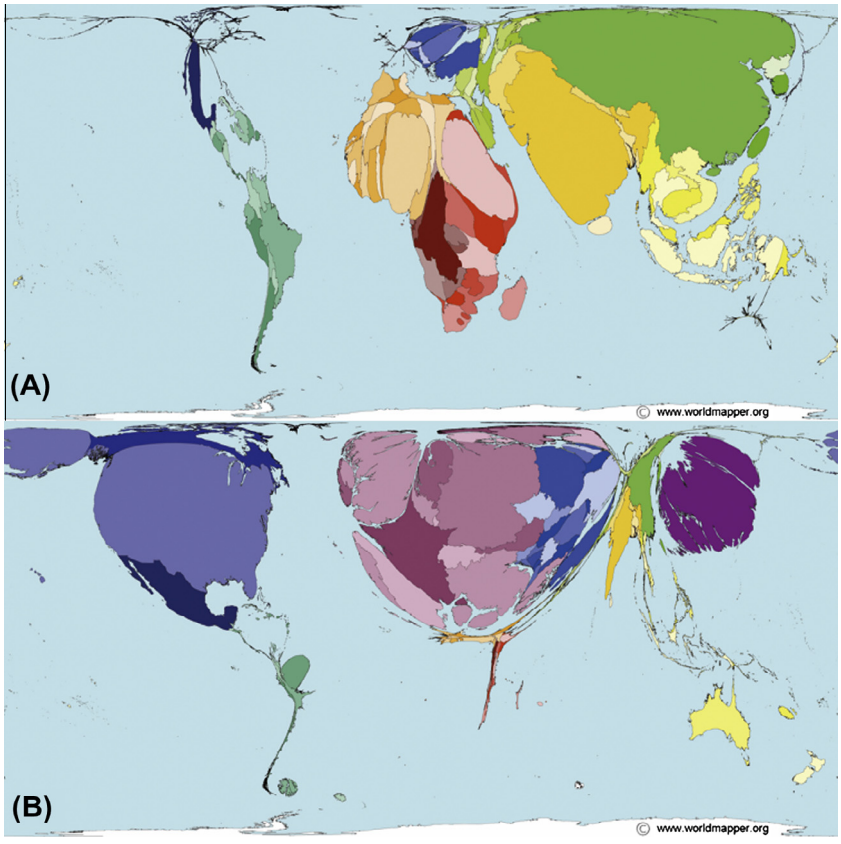

Fig. 1 Global patterns of (A) percent population without sustainable access to an improved water source (B) percent population with access to sanitation. Cartograms or map projections were downloaded from http://www.worldmapper.org (© Copyright SASI Group, University of Sheffield; and Mark Newman, University of Michigan).

capable of becoming virtually metabolically inactive, with minimal synthesis of DNA and RNA through a conversion from spiral into coccoid forms, offering a survival advantage in cases when chances of survival are slim [23] to none [24,25]. The coccoid form has been further classified into three categories, a dying form, a viable culturable form, and a viable-but-non-culturable state (VBNC), found to be metabolically active but not actively growing [26,27].

The nature of *H. pylori* and its infection niche, the human stomach, suggest ingestion as the most likely means of acquisition of this pathogen [28]. Nevertheless, its specific route of transmission has been widely debated among researchers to be oral–oral, gastro–oral, or fecal–oral (recently reviewed in [13] and [29]).

These three routes of transmission, reviewed elsewhere [13,28], are not mutually exclusive and may all be simultaneously involved in the infection process [30,31]. In this article, we focus on the oral ingestion of contaminated water or water-related items. This route of transmission can be fairly argued [12] since water biofilms have been suggested [27] to provide the bacteria with a protective habitat necessary to endure the water handling process. In addition, groundwater supply, being the sole source of water in many geographic areas, ideally fits into the oral–fecal, and perhaps the gastro–oral, models of infection. By time and throughout their life, inhabitants of those geographic areas consume large volumes, which statistically cause their chances of becoming infected to skyrocket.

Water as a source of infection

The hypothesis of water being a route of transmission of *H. pylori* [7,12,32] is supported by epidemiologic studies that have observed a higher prevalence of *H. pylori* infection [33–35] and a more rapid acquisition rate [36,37] in developing countries, which, in most instances, suffer from problems related to the sanitary distribution of water among the population (Fig. 1).

Evidence supporting the water transmission hypothesis comes largely from two groups of studies: (i) epidemiologic studies showing association between prevalence of *H. pylori* and water-related sources (See Table 1 for landmark studies representing this group) and (ii) studies that detected or isolated *H. pylori* from water sources (Table 2).

Water was first suggested as a source of *H. pylori* infection in 1991 by Klein and coworkers, who observed that Peruvian children with an external source of drinking water were more likely to be infected with *H. pylori* than children with an internal source [38]. Subsequently, *H. pylori* cells were detected in the water provided to cities nearby Lima, Peru in 1996 [39] and in municipal water, treated wastewater, and well water in Sweden in 1998 [40]. A few years later, Nurgalieva and coworkers noted that drinking river water was a high risk factor for *H. pylori* infection in Kazakhstan [41]. Accordingly, they stated that transmission of *H. pylori* could be waterborne [41].

Fig. 2 Example of suboptimal water sources in developing countries. (A) A running water source in Giza, Egypt (Photo credit: Radwa Raed Sharaf); (B) An exposed water well in an Al-Bahariya Oasis, Egypt (Photo credit: Mohamed Mahdy Khalifa).

Shahamat and colleagues hypothesized that the VBNC form of *H. pylori* persists in water [42], and in a number of studies [36,38,43,44], untreated municipal water was considered as a main cause of the increased *H. pylori* prevalence in the areas subjected to research. Effectively, in 2001, *H. pylori*'s DNA was detected in a Japanese well, whose consumers were infected [45], while a more recent study from Japan suggested river water-associated incidence [46].

The water transmission possibility was studied in depth in a thesis published in 2005, in which Azevedo strongly argues that drinking water can pose a substantial threat of *H. pylori* infection based on the fulfillment of several essential criteria [32]. These criteria include the ability of *H. pylori* to adhere to different materials and to co-aggregate with other bacteria and form complex structures on pipes or other surfaces in contact with water [32]. The notion about the inability of the bacterium to survive alone in running water, but to develop a symbiotic relationship and form complex structures on contact surfaces [47], makes it rational to assume that groundwater is a reservoir for *H. pylori* due to its stagnant nature.

Surprisingly, it is not uncommon to detect *H. pylori*'s DNA in water [48,49]. In fact, Lu and coworkers went as far as culturing the bacteria from the untreated municipal water using immunomagnetic separation (IMS), which was further confirmed by polymerase chain reaction (PCR) and a set of microbiological tests [44]. However, as Azevedo pointed out [32], the improved handling of water in more developed countries, coupled with sanitary conditions, which mandate proper disinfection, has effectively impeded the transmittance of *H. pylori* over the course of the last 20 years [32]. Nevertheless, *H. pylori* was shown to retain its viability in chlorinated water [50,51].

Furthermore, older findings by West and coworkers show that *H. pylori* is capable of survival in different types of aquatic environments under an array of physical variables [52]. West et al. conclude that the bacterium, unlike other pathogens, is unusually tolerant to pH fluctuations [52]. In support of this finding, a study regarding the occupational health hazards, conducted years later (2008) in India, indicated that the sewage and sanitary workers experience a high risk of *H. pylori* infection [53]. This could only be linked to the constant exposure of these workers to contaminated water in their line of work, in the absence of strict regulations and protocols to ensure their safety. In the same study, the author reported a rising blood level of IgG antibodies, targeted against the bacterium, with increased age [53].

In light of accruing evidence from studies published before 2005, Bellack and colleagues suggested a conceptual model for water's role in *H. pylori* transmission. Their model is based on the assumption that humans and animals can be long-term carriers of the bacteria and that they can transfer it to water, which is a short-term reservoir, via the fecal route [12]. Accordingly, their model suggests the requirement for continuous water contamination by human or animal feces with the high likelihood of fecal–oral transmission to humans consuming contaminated water, in which bacteria survive for limited time. However, Bellack's model stopped short at direct evidence of viable bacteria isolated from water sources. Such evidence has lately been available from different sources, where direct isolation of viable *H. pylori* from water has been reported in developing countries, with less optimal water hygiene, suggesting that bacterial isolation is more likely to be successful when the microbial burden is relatively high. Examples include studies in Pakistan [54,55], Iraq [56], and Iran [57] (see Table 2).

Of note, not all investigators support the water hypothesis, and some have actually designed experiments to debunk it. Janzon and coworkers, for example, reported their failure to detect *H. pylori* DNA in water in spite of using a highly sensitive real-time PCR assay and in spite of adopting a series of controls in their study [58]. Although this conflict has not been resolved, it is possible that these contradictions are related to the variability in bacterial load in water samples. After all, "*absence of evidence is not evidence of absence*" (quote attributed to US astronomer Carl Sagan).

Box 1 Culturing bacteria from water samples.

Entrance of *H. pylori* into the VBNC state allows *H. pylori* to persist in water, but the bacteria remain nonetheless difficult to culture [42]. Other investigators attempted to force the bacteria into entering this state within a laboratory setting [59], and despite the great number of viable cells, the culturability declined sharply to less than 10 colony-forming units per milliliter. This could definitely be a strong indication as to what happens under normal circumstances in a real-life setting [59].

Table 1 Example of landmark epidemiologic studies suggesting possible water transmission.

Year published	Location	# Cases	Design/Methods	Main finding(s) and significance	Refs.
1991	Peru	407 children (< 12 years)	Epidemiologic study using 13C Urea breath test	First report suggesting water as a risk factor for *H. pylori*	[38]
2002	Kazakhstan	288 Unrelated healthy individuals	Cross-sectional seroepidemiologic study between May–August 1999	Statistical and epidemiologic evidence that water and poor sanitation, rather than ethnicity or crowding, are risk factors for *H. pylori* infection: drinking river water is the highest risk	[41]
2008	Japan	224 Children (< 6 years)	Three-year follow-up study	In one district using deep groundwater, the prevalence rate among children was 0%, and these children maintained their uninfected status throughout. Other districts with normal prevalence rate used river water	[46]
2012	Malaysia	161 Subjects (including 82 controls)	Case-control study using gastric histology to detect *H. pylori*	Increased risk of *H. pylori* is associated with unsanitary practices. Also the use of well water and overall poor hygiene were associated with a higher risk of infection (OR = 3.38, 95% CI: 1.76–6.46)	[69]
2013	Six Latin American countries	1859 adults	Urea breath test	The odds of *H. pylori* infection correlated with the lack of indoor plumbing (OR 1.3: 1.0–1.8)	[70]

Cases: Number of human subjects.
OR: Odds ratio.
CI: Confidence interval.
Refs.: References.

Table 2 Key studies detecting *H. pylori* in water samples and confirming the water transmission hypothesis.

Year published	Location	Water source	Detection method	Main finding(s) and significance	Refs.
1993	Maryland, USA	Laboratory microcosms	Autoradiography (to assess viability of VBNC forms)	This study provides evidence for the metabolic activity of VBNC *H. pylori* in water, which supports a possible waterborne route of infection for *H. pylori*.	[42]
2001	Japan	Tap, well, river, and seawater	Membrane filtration followed by polymerase chain reaction	Detection of *H. pylori* DNA in well water	[45]
May 2003	Wisconsin, USA	Any	Culture-based method: development of selective medium for *H. pylori*	A selective HP-agar medium was developed for the isolation of *H. pylori* from mixed microbial population in water that provides faster growth and superior selectivity	[71]
2003	North Carolina, USA	Fresh water	Membrane diffusion chambers followed by plate counts and Live/Dead Baclight assay	*H. pylori* can persist in the VBNC state, which represents a public health hazard.	[59]
January 2004	Portugal and United Kingdom	Various	Different culture media and growth conditions	This work demonstrates the possibility of optimizing culture-based techniques for recovery of *H. pylori* from water	[72]
April 2006	Portugal and United Kingdom	Well	N/A	This study suggests the detection of the pathogen in well water described by other authors can be related to the increased ability of *H. pylori* to integrate into biofilms under conditions of low shear stress. It will also allow a more rational selection of locations to perform molecular or plate culture analysis for the detection of *H. pylori* in drinking water-associated biofilms.	[47]
2011	Basra, Iraq	Treated municipal drinking water	Modified Columbia Urea Agar	Successful cultivation and identification of 14 *H. pylori* samples	[56]
2012	Missouri, USA	N/A	A lanthanum-based concentration method coupled with quantitative real-time PCR	The authors succeeded in developing a detection method for water samples with low concentrations of *H. pylori* and *E. coli*.	[73]
2012	Spain	Wastewater	A combination of culture methods following filtration of the samples and molecular techniques, mostly PCR and fluorescent immunohistochemistry	The authors successfully identified the presence of *H. pylori* in 6 out of 45 wastewater samples.	[74]
2012	Karachi, Pakistan	Drinking tap water samples	Concentration of samples via membrane filtration and PCR on DNA isolated from residue on membranes	The authors obtained a positive result in 4% of samples (2 out of 50 total samples).	[54]
2013	Isfahan, Iran	Various water sources including tap water, bottled mineral water from different brands and samples from publicly available water coolers	Culture on supplemented *Brucella* agar followed by Gram staining and biochemical tests. Positive results confirmed by PCR amplification of *ure*C gene	Culture methods successfully detected *H. pylori* in five out of 200 samples while PCR amplification of *ure*C gene was successful in 14 samples. The authors suggest that PCR-positive, culture-negative samples may have coccoid forms of *H. pylori*; in our opinion, this could be also due to the presence of other *ure*C-carrying bacteria, or other *Helicobacter* species.	[57]

Refs.: References.
N/A.: Not applicable.

What next? From association, detection, and isolation to causation

As noted above, less than a decade ago, the model suggested by Bellack and colleagues for water's role in *H. pylori* transmission [12] seemed quite plausible; yet, there was not enough evidence supporting direct microbial viability. The work of Azevedo [32,47,60] and subsequent published studies on direct microbial isolation (e.g., [56,57]) provided such needed evidence. What remains now is to establish direct causation via well-designed experiments that use water, spiked with *H. pylori*, to cause colonization and/or disease in animal models, fulfilling Koch's postulates for disease etiology [61–63]. One challenge is the choice of appropriate animal model; another is confirming that the initiation of disease is caused by ingested rather than resident *Helicobacter* cells. The latter can be made possible by various methods, ranging from direct labeling to inserting traceable genetic markers in exogenous bacteria by genetic manipulation.

Water-contaminated infection sources

As a corollary to the water transmission hypothesis, if water is a reservoir of *H. pylori*, then any surface exposed to the contaminated water could potentially act as another source of infection. One clear example is harvested raw fruits and vegetables in rural communities. Those crops pose a threat of being a vehicle for the transmission of *H. pylori*, being contaminated by irrigation water and in some cases municipal water, sought by some as a substitute for organic manure.

Goodman and coworkers noted this possibility and included the unsanitary habits of the Columbian Andes population as another contribution to the infection pool [43]. These habits range from the use of the open fields when lacking a toilet facility to the late afternoon swimming—as an escape from the surrounding hot climate—in the flowing streams and rivers, considered to be dumping sites for the excess irrigation water. The authors' results are clear-cut: depending on the source of drinking water, whether from a privately owned well, water pumps, or even tap water—as opposed to a nearby stream or river, the risk of infection fits perfectly into place, which was immensely higher in the latter case.

Possible methods of prevention

Knowing the source of infection is a necessary step toward prevention. Salih reports that in recent years, infection with *H. pylori* in the developing countries has declined owing to the increased awareness of the possible root of the problem and recommends boiling water to prevent infection [64]. Nowadays, it is highly advisable to boil water used for drinking, or even for washing hands and dishes. This simple measure is especially recommended for those who lack a trustworthy water purification system within the community, although compliance is not guaranteed. One can only agree that the process of boiling is an effective combating regimen, since a temperature of merely 30 °C was capable of arresting the growth of various strains of the bacterium as reported by Xia and coworkers [65]. In most cases, such practice was initially promoted by the respective health authorities to fight off more serious forms of infections caused by water-borne microorganisms.

Despite this seemingly obvious assumption, earlier findings of Mitchell and coworkers [36] appear to somewhat contradict the effectiveness of boiling water. Mitchell's study included a section of Southern China's population, who were asked to complete a questionnaire. Results indicated a higher prevalence of infection among rural inhabitants, who drank river water as opposed to well water. Surprisingly, most stated that boiling water is included in their everyday routine [36].

Conclusions

In this Review Article, we focused on water as a possible source of transmission of *H. pylori* and discussed some experimental findings indicating the possibility of detecting viable *H. pylori* in water. We recognize that this hypothesis has been challenged [58] and that even if confirmed as a reservoir for *H. pylori*, water may very well be a secondary route of transmission [18,66]. However, given the accruing evidence, it is still important to seriously consider contaminated water as one of the likely candidate sources and deal with it effectively. Ongoing research aims at providing unequivocal evidence of the suggested route of transmission. As soon as this is achieved, efforts can be directed to prevent further infections and properly treat possible transmission vehicles to cut down the number of new cases.

Outlook

The possibility of *H. pylori* transmission through water has its promises and perils. On the one hand, water transmission is preventable by the implementation of necessary measures of hygiene and water sanitation. On the other hand, availability of drinking water is likely to be a crisis in the following decades, and the burden of this crisis falls unequally on developing countries [4,5,67]. The problem becomes even more serious when considering how the climate change is affecting our planet's demography [1,2,67]. Eventual migrations may worsen the situation of the developing countries not only by increasing their populations, but also by rendering the availability of treated potable water even dearer [4,66,68].

On dealing with waterborne infections, one might give priority to infectious diseases with high mortality such as cholera and other diarrheal diseases [3]. However, *H. pylori* causes cancer especially in elder patients and given that life expectancy has increased, and so has poverty, preventing infection-associated cancers (e.g., *H. pylori* and hepatitis C) should be a priority of health organizations in the decades to come.

Conflict of interest

The authors have declared no conflict of interest.

Compliance with Ethics Requirements

This article does not contain any studies with human or animal subjects.

References

[1] The PLoS Medicine Editors. Clean water should be recognized as a human right. PLoS Med vol. 6; 2009. p. e1000102.
[2] McMichael AJ. Globalization, climate change, and human health. N Engl J Med 2013;368:1335–43.
[3] World Health Organization. Research priorities for the environment, agriculture and infectious diseases of poverty. World Health Organ Tech Rep Ser. vols. i–xiii; 2013. p. 1–125.
[4] World Health Organization, UNESCO. Water for life: making it happen; 2005.
[5] U.S. Environmental Protection Agency EPA. Handbook: ground water – Ground water and contamination, vol. 1. Washington (DC): USEPA, Office of Research and Development; 1990.
[6] Fogarty J, Thornton L, Hayes C, Laffoy M, O'Flanagan D, Devlin J, et al. Illness in a community associated with an episode of water contamination with sewage. Epidemiol Infect 1995;114:289–95.
[7] Engstrand L. *Helicobacter* in water and waterborne routes of transmission. Symp Ser Soc Appl Microbiol 2001:80S–4S.
[8] Khalifa MM. Study on some epidemiological aspects of *Helicobacter pylori* infection and transmission in Egyptian Western Desert. Cairo: Cairo University; 2009, 240 p.
[9] International Agency for Research on Cancer. Infection with *Helicobacter pylori*; 1994. p. 1017–606.
[10] Peter S, Beglinger C. *Helicobacter pylori* and gastric cancer: the causal relationship. Digestion 2007;75:25–35.
[11] Bartram J, Cairncross S. Hygiene, sanitation, and water: forgotten foundations of health. PLoS Med 2010;7:e1000367.
[12] Bellack NR, Koehoorn MW, MacNab YC, Morshed MG. A conceptual model of water's role as a reservoir in *Helicobacter pylori* transmission: a review of the evidence. Epidemiol Infect 2006;134:439–49.
[13] Khalifa MM, Sharaf RR, Aziz RK. *Helicobacter pylori*: a poor man's gut pathogen? Gut pathog 2010;2:2.
[14] Bizzozero G. Ueber die schlauchförmigen Drüsen des Magendarmkanals und die Beziehungen ihres Epithels zu dem Oberflächenepithel der Schleimhaut Dritte Mittheilung. Archiv für Mikroskopische Anatomie 1893;42:82–152.
[15] Figura N, Bianciardi L. Helicobacters were discovered in Italy in 1892: an episode in the scientific life of an eclectic pathologist Giulio Bizzozero. In: Marshall B, editor. *Helicobacter* Pioneers: firsthand accounts from the scientists who discovered Helicobacters 1892–1982. Wiley-Blackwell; 2002. p. 1–13.
[16] Warren JR, Marshall B. Unidentified curved bacilli on gastric epithelium in active chronic gastritis. Lancet 1983;321:1273–5.
[17] Marshall BJ, Warren JR. Unidentified curved bacilli in the stomach of patients with gastritis and peptic ulceration. Lancet 1984;1:1311–5.
[18] Ahmed N. 23 years of the discovery of *Helicobacter pylori*: is the debate over? Ann Clin Microbiol Antimicrob 2005;4:17.
[19] Parsonnet J. Bacterial infection as a cause of cancer. Environ Health Perspect 1995;103(Suppl 8):263–8.
[20] Akhter Y, Ahmed I, Devi SM, Ahmed N. The co-evolved *Helicobacter pylori* and gastric cancer: trinity of bacterial virulence, host susceptibility and lifestyle. Infect Agent Cancer 2007;2:2.
[21] The EUROGAST Study Group. Epidemiology of and risk factors for, *Helicobacter pylori* infection among 3194 asymptomatic subjects in 17 populations. Gut, vol. 34; 1993. p. 1672–6.
[22] Mobley HLT, Mendz GL, Hazell SL. *Helicobacter Pylori*: physiology and genetics. Washington (DC): ASM Press; 2001, 626 p.
[23] Saito N, Konishi K, Sato F, Kato M, Takeda H, Sugiyama T, et al. Plural transformation-processes from spiral to coccoid *Helicobacter pylori* and its viability. J Infect 2003;46:49–55.
[24] Sörberg M, Nilsson M, Hanberger H, Nilsson LE. Morphologic conversion of *Helicobacter pylori* from bacillary to coccoid form. Eur J Clin Microbiol Infect Dis 1996;15:216–9.
[25] Kusters JG, Gerrits MM, Van Strijp JA, Vandenbroucke-Grauls CM. Coccoid forms of *Helicobacter pylori* are the morphologic manifestation of cell death. Infect Immun 1997;65:3672–9.
[26] Azevedo NF, Almeida C, Cerqueira L, Dias S, Keevil CW, Vieira MJ. Coccoid form of *Helicobacter pylori* as a morphological manifestation of cell adaptation to the environment. Appl Environ Microbiol 2007;73:3423–7.
[27] Gião MS, Azevedo NF, Wilks SA, Vieira MJ, Keevil CW. Persistence of *Helicobacter pylori* in heterotrophic drinking-water biofilms. Appl Environ Microbiol 2008;74:5898–904.
[28] Mitchell HM. Epidemiology of infection. In: Mobley HLT, Mendz GL, Hazell SL, editors. *Helicobacter Pylori*: physiology and Genetics. Washington (DC): ASM Press; 2001.
[29] Goh KL, Chan WK, Shiota S, Yamaoka Y. Epidemiology of *Helicobacter pylori* infection and public health implications. *Helicobacter* 2011;16(Suppl 1):1–9.
[30] Mégraud F. Epidemiology of *Helicobacter pylori* infection: where are we in 1995? Eur J Gastroenterol Hepatol 1995;7:292–5.
[31] Goodman KJ, Correa P. The transmission of *Helicobacter pylori*. A critical review of the evidence. Int J Epidemiol 1995;24:875–87.
[32] Azevedo NF. Survival of *Helicobacter pylori* in drinking water and associated biofilms. University of Minho and University of Southhampton; 2005, 137 p.
[33] Graham DY, Adam E, Reddy GT, Agarwal JP, Agarwal R, Evans Jr DJ, et al. Seroepidemiology of *Helicobacter pylori* infection in India. Comparison of developing and developed countries. Dig Dis Sci 1991;36:1084–8.
[34] Hopkins RJ, Vial PA, Ferreccio C, Ovalle J, Prado P, Sotomayor V, et al. Seroprevalence of *Helicobacter pylori* in Chile: vegetables may serve as one route of transmission. J Infect Dis 1993;168:222–6.
[35] Mégraud F. Transmission of *Helicobacter pylori*: faecal–oral versus oral–oral route. Aliment Pharmacol Ther 1995;9(Suppl 2):85–91.
[36] Mitchell HM, Li YY, Hu PJ, Liu Q, Chen M, Du GG, et al. Epidemiology of *Helicobacter pylori* in southern China: identification of early childhood as the critical period for acquisition. J Infect Dis 1992;166:149–53.
[37] Parsonnet J. The incidence of *Helicobacter pylori* infection. Aliment Pharmacol Ther 1995;9(Suppl 2):45–51.
[38] Klein PD, Graham DY, Gaillour A, Opekun AR, Smith EO. Water source as risk factor for *Helicobacter pylori* infection in Peruvian children. Gastrointestinal physiology working group. Lancet 1991;337:1503–6.
[39] Hultén K, Han SW, Enroth H, Klein PD, Opekun AR, Gilman RH, et al. *Helicobacter pylori* in the drinking water in Peru. Gastroenterology 1996;110:1031–5.
[40] Hultén K, Enroth H, Nystrom T, Engstrand L. Presence of *Helicobacter* species DNA in Swedish water. J Appl Microbiol 1998;85:282–6.
[41] Nurgalieva ZZ, Malaty HM, Graham DY, Almuchambetova R, Machmudova A, Kapsultanova D, et al. *Helicobacter pylori* infection in Kazakhstan: effect of water source and household hygiene. Am J Trop Med Hyg 2002;67:201–6.
[42] Shahamat M, Mai U, Paszko-Kolva C, Kessel M, Colwell RR. Use of autoradiography to assess viability of *Helicobacter pylori* in water. Appl Environ Microbiol 1993;59:1231–5.
[43] Goodman KJ, Correa P, Tenganá Aux HJ, Ramírez H, DeLany JP, Guerrero Pepinosa O, et al. *Helicobacter pylori* infection in the Colombian Andes: a population-based study of transmission pathways. Am J Epidemiol 1996;144:290–9.

[44] Lu Y, Redlinger TE, Avitia R, Galindo A, Goodman K. Isolation and genotyping of *Helicobacter pylori* from untreated municipal wastewater. Appl Environ Microbiol 2002;68:1436–9.
[45] Horiuchi T, Ohkusa T, Watanabe M, Kobayashi D, Miwa H, Eishi Y. *Helicobacter pylori* DNA in drinking water in Japan. Microbiol Immunol 2001;45:515–9.
[46] Fujimura S, Kato S, Watanabe A. Water source as a *Helicobacter pylori* transmission route: a 3-year follow-up study of Japanese children living in a unique district. J Med Microbiol 2008;57:909–10.
[47] Azevedo NF, Pinto AR, Reis NM, Vieira MJ, Keevil CW. Shear stress, temperature, and inoculation concentration influence the adhesion of water-stressed *Helicobacter pylori* to stainless steel 304 and polypropylene. Appl Environ Microbiol 2006;72:2936–41.
[48] Hegarty JP, Dowd MT, Baker KH. Occurrence of *Helicobacter pylori* in surface water in the United States. J Appl Microbiol 1999;87:697–701.
[49] Moreno Y, Ferrus MA, Alonso JL, Jimenez A, Hernandez J. Use of fluorescent in situ hybridization to evidence the presence of *Helicobacter pylori* in water. Water Res 2003;37:2251–6.
[50] Moreno Y, Piqueres P, Alonso JL, Jimenez A, Gonzalez A, Ferrus MA. Survival and viability of *Helicobacter pylori* after inoculation into chlorinated drinking water. Water Res 2007;41:3490–6.
[51] Gião MS, Azevedo NF, Wilks SA, Vieira MJ, Keevil CW. Effect of chlorine on incorporation of *Helicobacter pylori* into drinking water biofilms. Appl Environ Microbiol 2010;76:1669–73.
[52] West AP, Millar MR, Tompkins DS. Effect of physical environment on survival of *Helicobacter pylori*. J Clin Pathol 1992;45:228–31.
[53] Tiwari RR. Occupational health hazards in sewage and sanitary workers. Indian J Occup Environ Med 2008;12:112–5.
[54] Khan A, Farooqui A, Kazmi SU. Presence of *Helicobacter pylori* in drinking water of Karachi, Pakistan. J Infect Dev Ctries 2012;6:251–5.
[55] Samra ZQ, Javaid U, Ghafoor S, Batool A, Dar N, Athar MA. PCR assay targeting virulence genes of *Helicobacter pylori* isolated from drinking water and clinical samples in Lahore metropolitan, Pakistan. J Water Health 2011;9:208–16.
[56] Al-Sulami AA, Al-Taee AM, Juma'a MG. Isolation and identification of *Helicobacter pylori* from drinking water in Basra governorate, Iraq. East Mediterr Health J 2011;16:920–5.
[57] Bahrami AR, Rahimi E, Ghasemian Safaei H. Detection of *Helicobacter pylori* in city water, dental units' water, and bottled mineral water in Isfahan, Iran. Scientific World J 2013;2013:280510.
[58] Janzon A, Sjoling A, Lothigius A, Ahmed D, Qadri F, Svennerholm AM. Failure to detect *Helicobacter pylori* DNA in drinking and environmental water in Dhaka, Bangladesh, using highly sensitive real-time PCR assays. Appl Environ Microbiol 2009;75:3039–44.
[59] Adams BL, Bates TC, Oliver JD. Survival of *Helicobacter pylori* in a natural freshwater environment. Appl Environ Microbiol 2003;69:7462–6.
[60] Azevedo NF, Pacheco AP, Keevil CW, Vieira MJ. Adhesion of water stressed *Helicobacter pylori* to abiotic surfaces. J Appl Microbiol 2006;101:718–24.
[61] Hall PA, Lemoine NR. Koch's postulates revisited. J Pathol 1991;164:283–4.
[62] Taylor DN, Blaser MJ. The epidemiology of *Helicobacter pylori* infection. Epidemiol Rev 1991;13:42–59.
[63] Fredericks DN, Relman DA. Sequence-based identification of microbial pathogens: a reconsideration of Koch's postulates. Clin Microbiol Rev 1996;9:18–33.
[64] Salih BA. *Helicobacter pylori* infection in developing countries: the burden for how long? Saudi J Gastroenterol 2009;15:201–7.
[65] Xia HX, Keane CT, O'Morain CA. Determination of the optimal transport system for *Helicobacter pylori* cultures. J Med Microbiol 1993;39:334–7.
[66] Ahmed N, Tenguria S, Nandanwar N. *Helicobacter pylori* – a seasoned pathogen by any other name. Gut Pathog 2009;1:24.
[67] World Health Organization. Safe water, better health; 2008.
[68] Blaser MJ, Blaser MJ. Theodore E Woodward award: global warming and the human stomach: microecology follows macroecology. Trans Am Clin Climatol Assoc 2005;116:65–75 [discussion 75–6].
[69] Lee YY, Ismail AW, Mustaffa N, Musa KI, Majid NA, Choo KE, et al. Sociocultural and dietary practices among Malay subjects in the north-eastern region of Peninsular Malaysia: a region of low prevalence of *Helicobacter pylori* infection. *Helicobacter* 2012;17:54–61.
[70] Porras C, Nodora J, Sexton R, Ferreccio C, Jimenez S, Dominguez RL, et al. Epidemiology of *Helicobacter pylori* infection in six Latin American countries (SWOG Trial S0701). Cancer Causes Control 2013;24:209–15.
[71] Degnan AJ, Sonzogni WC, Standridge JH. Development of a plating medium for selection of *Helicobacter pylori* from water samples. Appl Environ Microbiol 2003;69:2914–8.
[72] Azevedo NF, Pacheco AP, Keevil CW, Vieira MJ. Nutrient shock and incubation atmosphere influence recovery of culturable *Helicobacter pylori* from water. Appl Environ Microbiol 2004;70:490–3.
[73] Zhang Y, Riley LK, Lin M, Hu Z. Determination of low-density Escherichia coli and *Helicobacter pylori* suspensions in water. Water Res 2012;46:2140–8.
[74] Moreno Y, Ferrus MA. Specific detection of cultivable *Helicobacter pylori* cells from wastewater treatment plants. *Helicobacter* 2012;17:327–32.