Available online at www.sciencedirect.com

ScienceDirect

Current Opinion in Virology

Viral pathogens in water: occurrence, public health impact, and available control strategies

Kristen E Gibson

The public health impact of the transmission of viruses in water is significant worldwide. Waterborne viruses can be introduced into our recreational and finished drinking water sources through a variety of pathways ultimately resulting in the onset of illness in a portion of the exposed population. Although there have been advances in both drinking water treatment technologies and source water protection strategies, waterborne disease outbreaks (WBDOs) due to viral pathogens still occur each year worldwide. By highlighting the prevalence of viral pathogens in water as well as (1) the dominant viruses of concern, (2) WBDOs due to viruses, and (3) available water treatment technologies, the goal of this review is to provide insight into the public health impact of viruses in water.

Addresses
University of Arkansas, Department of Food Science, 2650 North Young Avenue, Fayetteville, AR 72704, United States

Corresponding author: Gibson, Kristen E (keg005@uark.edu)

Current Opinion in Virology 2013, **4**:50–57

This review comes from a themed issue on **Environmental virology**

Edited by **Lee-Ann Jaykus** and **John Scott Meschke**

1879-6257X/$ – see front matter, Published by Elsevier B.V.

http://dx.doi.org/10.1016/j.coviro.2013.12.005

Introduction

Waterborne viruses are frequently implicated as the cause of water-related gastrointestinal illness. Waterborne disease outbreaks (WBDOs) are reported each year and are associated with recreational water (RW), treated drinking water (DW), and ground water (treated and untreated). Depending on the water source, the actual source of contamination can vary; however, the two common threads are (1) the introduction of fecal material into the water source and (2) inadequate or interrupted treatment of water intended for drinking [1–4]. In 2003, the World Health Organization estimated that worldwide 3.4 million deaths each year can be attributed to the water-related (water, sanitation, hygiene) transmission of pathogens (all pathogens, not just enteric viruses) [5]. For the European Union (EU), the European Environment and Health Information System estimated the annual burden of disease due to water-related pathogens at 13,548 deaths for children 0–14 years old. For the United States, Reynolds (2008) estimated 7 million illnesses and more than 1000 deaths each year were due to waterborne pathogens though these are based on model simulations and not actual values. Unfortunately, the number of illnesses and deaths due specifically to waterborne viruses is difficult to determine and thus basically unknown.

The current review (Figure 1) focuses on (1) the occurrence of viral pathogens of primary concern in various water sources; (2) virus-related WBDOS by water type reported worldwide over the past decade (from approximately 2000 to 2012); and (3) DW treatment options for the inactivation or removal of viruses. Finally, this review briefly discusses how we may better understand the public health impact of waterborne viruses as well as potential measures that can be taken to reduce the impact of viral pathogens in water.

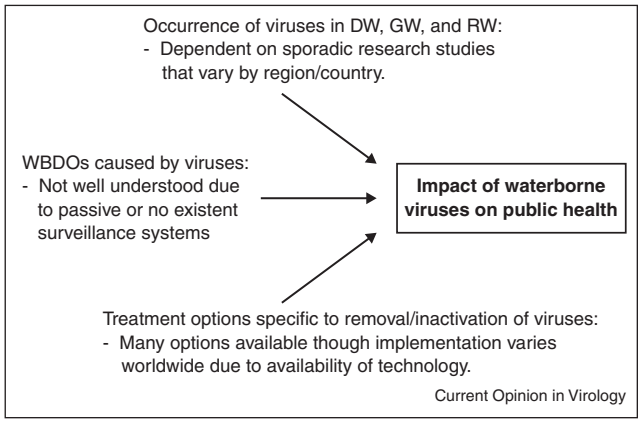
Waterborne viruses of primary concern

Viruses most often implicated in WBDOs include (but are not restricted to) noroviruses (NoV), Hepatitis A virus (HAV), Hepatitis E virus (HEV), adenovirus (AdV), astrovirus, enteroviruses (EV), and rotavirus (RV) (Table 1). Although viruses implicated in WBDOs are capable of causing a variety of acute illnesses (Table 1), acute gastrointestinal illness (AGI) is most commonly reported. Enteric viruses are host-specific (i.e. in this instance, specific to humans) and are not capable of replicating in the environment outside of its host. In addition, enteric viruses have a presumed low infectious dose (i.e. <10–10^3 virus particles) [6–9]; prolonged (3–4 weeks), asymptomatic periods of shedding; and enhanced environmental stability due to their non-enveloped capsid structure [10]. These characteristics allow enteric viruses to play a significant role in water-related outbreaks. Noroviruses have been the largest cause of virus-related WBDOs in the U.S. since 2003, and data indicate a similar trend in selected countries (France, Japan, Sweden, Switzerland, The Netherlands, UK) [11•,12,13]. Aside from NoVs, HAV, HEV, and RV are still of significant concern in low-income countries without adequate water and sanitation. Additional viruses of lesser epidemiologic importance though still capable of waterborne transmission include human reovirus, parvovirus, parechovirus, polyomavirus, coronavirus, and torovirus [14,15].

Occurrence of viral pathogens in water

Human enteric viruses may be introduced into the water environment through various routes. One obvious route of transmission is through the discharge of sewage-contaminated water into RW and/or DW sources. Viruses may also

Figure 1



Summary of key factors effecting the impact of waterborne viruses on public health. DW: drinking water; RW: recreational water; GW: groundwater; WBDO: waterborne disease outbreak.

be introduced by land application of municipal biosolids [16,17]; groundwater impacted by surface water or in proximity to faulty septic systems and leaking sewers [18–21]; and discharge of untreated wastewater [22] or inadequately treated wastewater effluent [23,24•,25]. The occurrence of human enteric viruses in water remains largely unknown unless an outbreak is reported and samples are collected since water sources are not routinely tested for viruses. Moreover, there are challenges related to sampling studies to determine virus presence due to both differences and limitations in recovery and concentration methods for the detection of viruses in water [26•]. Regardless of these challenges, a snapshot of the occurrence of enteric viruses in water sources over the past decade is provided below.

Treated drinking water

In this section, there is a specific focus on DW derived from treated surface water as opposed to treated ground water that is used as DW. Keswick *et al.* (1984) — one of the seminal publications on the prevalence of viruses in DW in the U.S. — reported 83% of the samples to be positive for either RV or EVs [27]. Shortly thereafter, Bitton *et al.* (1986) followed up with a review on viruses in DW both in the U.S. and internationally [28]. Aside from these earlier studies, few studies on virus occurrence in DW in the U.S. have been reported since, and of those, such as Gibson and Schwab (2011), no viruses were detected [29]. This paucity of available data for viruses in DW can most likely be attributed to the need for very large volumes (>100 to 6000 L) of water to be concentrated followed by subsequent recovery and detection of virus targets — a process that is challenging often

Table 1

Viruses of primary concern for waterborne disease outbreaks.

Family	Virus group	Properties	Associated illnesses	Public health impact
Adenoviridae	Adenoviruses	90–100 nm, dsDNA	Conjunctivitis, gastroenteritis, respiratory disease	Outbreaks not common in the U.S. though sporadic illnesses do occur; respiratory disease most common
Astroviridae	Astroviruses	28–30 nm, ssRNA	Gastroenteritis	Predominantly impacts children ≤2 years of age; possibly higher prevalence in settings outside of U.S. (i.e. China, India, Egypt)
Picornaviridae	Enteroviruses[a]	24–30 nm, ssRNA	Gastroenteritis, HFMD, encephalitis, meningitis, conjunctivitis	10–15 million infections in the U.S. each year (all routes of transmission, not just water)[b]
Picornaviridae	HAV	25-30 nm, ssRNA	Hepatitis	17,000 new cases in the U.S. in 2010 (person-to-person, food and water)[c]; in developing countries nearly all children are infect with HAV by 9 years of age[d]
Picornaviridae	HEV	25–30 nm, ssRNA	Acute viral hepatitis	Rare in the U.S. though it is very common in many parts of the world due to inadequate sanitation; 20 million cases globally each year[e]
Caliciviridae	Noroviruses	27–38 nm, ssRNA	Gastroenteritis	Leading cause of reported outbreaks of gastroenteritis in the U.S. and primary cause of viral gastroenteritis and foodborne outbreaks worldwide
Reoviridae	Rotaviruses	70–75 nm, dsRNA	Gastroenteritis	Before introduction of vaccine in 2006, resulted in hospitalization 55,000 children each year in the U.S. and caused 527,000 deaths in children each year worldwide[f]

ds: double stranded; ss: single stranded; HFMD: hand, foot, and mouth disease.
[a] Non-polio enteroviruses: Coxsackievirus A and B, Echoviruses.
[b] CDC: http://www.cdc.gov/non-polio-enterovirus/about/overview.html.
[c] CDC: http://www.cdc.gov/hepatitis/Resources/Professionals/PDFs/ABCTable_BW.pdf.
[d] WHO: http://www.who.int/csr/disease/hepatitis/HepatitisA_whocdscsredc2000_7.pdf.
[e] WHO: http://www.who.int/mediacentre/factsheets/fs280/en/.
[f] CDC: http://www.cdc.gov/rotavirus/clinical.html.