Chapter 6
Control of Foodborne Viruses at Retail

Jason Tetro

6.1 Introduction

Unlike bacteria, there are only a handful of viruses associated with foodborne outbreaks (Table 6.1). However, over the last decade, the role of viruses in outbreaks associated with foodborne illness has increased such that together, they represent a significant threat to global public health (FAO/WHO 2008). Moreover, there continues to be an ever growing list of emerging viral pathogens that could threaten the food supply. These include such well-known agents as the severe acute respiratory syndrome (SARS), foot and mouth disease virus (FMDV) and avian influenza, as well as the lesser known Aichi and Nipah viruses.

Estimating the necessity for control of viruses in retail can be difficult for several reasons. Most foodborne illnesses are either underreported or not reported at all leaving many gaps in our understanding of the impact of viruses in food (Fischer Walker et al. 2010; Mead et al. 1999; Newell et al. 2010). A large percentage of documented viral foodborne outbreaks are not associated with retail, but rather through away from home establishments (Matthews et al. 2012) such as restaurants, cruise ships, and healthcare facilities. Of those that do occur at home, outbreaks may be due not to the nature of the food at purchase, but as a result of contamination of the food source after the product has been purchased (Fein et al. 2011; Henley et al. 2012; Hoelzl et al. 2013). These factors in food safety suggest the current methods of microbiological control, which mainly are based on coliform bacterial identification and enumeration to assess fecal contamination, may not be sufficient.

Compiled information suggests that there is a need for better control of viruses in foods destined for the retail and RTE markets. A recent survey of foodborne out-

J. Tetro, B.Sc. (✉)
University of Guelph, 130 Rosedale Valley Road, Suite 103, Toronto, ON, Canada M4W 1P9
e-mail: jtetro@misciconsulting.com

J. Farber et al. (eds.), *Retail Food Safety*, Food Microbiology and Food Safety,
DOI 10.1007/978-1-4939-1550-7_6

Table 6.1 Known foodborne viruses and association with retail products

Virus	Mode of transmission	Incubation period (days)	Duration of illness (days)	Recorded retail foodborne outbreaks?	Current pathogen of concern at retail?
Adenovirus	Fecal–oral, contaminated water	3–10	10	Yes	Yes
Aichi virus	Fecal–oral, contaminated water	3–7	3–10	Yes	Yes
Astrovirus	Fecal–oral, contaminated water	2–3	3–4	Yes	Yes
Avian influenza	Fecal–oral, droplet, close contact with infected animals and birds	2–17	5–21 with proper treatment	Yes (live animal markets)	Yes
Caliciviruses	Fecal–oral, contaminated water	0.5–3	1–3	Yes	Yes
Coronavirus (SARS)	Fecal–oral, airborne	2–5	7–21	No	Yes
Coxsackievirus	Fecal–oral, contaminated water	3–10	3–7	Yes	No
Echovirus	Fecal–oral, contaminated water	3–10	3–7	Yes	No
Hepatitis A virus	Fecal–oral, contaminated water	5–10	14–21	Yes	Yes
Hepatitis E virus	Fecal–oral, contaminated water, infected animal meat	15–45	100–150	No	Yes
Nipah virus	Infected animals, contaminated fruit sap	4–18	5–30	Yes (infected date sap)	Yes
Parvovirus	Fecal–oral, contaminated water	1–2	5–10	No	No
Rotavirus	Fecal–oral, contaminated water	1–3	4–8	Yes	Yes
Tick borne encephalitis	Milk from infected animals	7–14	10–14	No	No

breaks in the USA revealed that regardless of the means of spread, over 40 % of the recorded outbreaks were due to virus infection (Centers for Disease Control and Prevention 2013). Globally, estimates suggest that viruses may account for between 8 and 68 % of the total number of foodborne infections (FAO/WHO 2008). A significant proportion of these cases are due to the continuing increase in food importation (Centers for Disease Control and Prevention 2013; FAO Trade and Markets Division 2012). Many of these countries do not have the capacity to incorporate food safety practices including hazard analysis and critical control point (HACCP), good hygiene practices (GHP), and adherence to the standards of the Codex

Alimentarius, in particular, Guidelines for the Validation of Food Safety Control Measures (Codex Alimentarius 2008). Yet, imported foods are actively sought by an increasing exotic appetite in the developed world. Without proper surveillance activity, many viral agents can move freely across borders without detection (Buisson et al. 2008; Jebara 2004).

6.2 Viruses in Food

The diverse nature of the viruses listed in Table 6.1 suggests that each possesses unique physical characteristics, causes a diverse array of symptoms, persists in the host and environment, and has a number of routes for spread. However, they all share common properties that are indicative of the necessary means for control:

1. They are abundant in nature.
2. They are common to several or all areas of the world.
3. They can easily be transferred either through contaminated water or through the fecal–oral route.

Adenoviruses: The adenoviruses are a group of double-stranded DNA viruses that are known pathogens of humans. Most documented cases are respiratory in nature, however, two particular strains, Ad40 and Ad41 have been implicated in gastroenteritis and foodborne transmission in many areas of the globe (Ahluwalia et al. 1994; Aminu et al. 2007; Brown 1990; Bryden et al. 1997; Dey et al. 2009; Grimwood et al. 1995; Herrmann et al. 1988; Johansson et al. 1994; Saderi et al. 2002; Shinozaki et al. 1991a; Tiemessen et al. 1989) particularly in children under 2 years of age (Shinozaki et al. 1991b; Uhnoo et al. 1984). The main source of these viruses is unsafe water, which can either contaminate fish or produce through irrigation. For example, Hansman et al. (2008) identified that 52 % of 33 packages of clams collected from Japanese markets were positive for adenoviruses. Similarly, Cheong et al. (2009) found the presence of adenoviruses on spinach, lettuce, and chicory; a result of irrigation with unsafe water. Based on laboratory studies of the persistence of these viruses on foods, there was no significant loss of infectivity after 1 week (Verhaelen et al. 2012). A similar study by Diez-Valcarce et al. (2012) showed that 36 % of the mussels sampled from three European countries had the presence of the gastrointestinal adenoviruses.

Aichi virus: First discovered in 1989 (Yamashita et al. 1991), this virus is a member of the Picornaviridae family in the Kobuvirus genus. Over the last two decades, the aichi viruses have demonstrated their significance as a foodborne pathogen worldwide (Goyer et al. 2008; Jonsson et al. 2012; Kaikkonen et al. 2010; Oh et al. 2006; Reuter et al. 2009; Ribes et al. 2010; Sdiri-Loulizi et al. 2009; Verma et al. 2011; Yang et al. 2009). The main sources of the virus are unsafe water and sewage (Alcala et al. 2010; Di Martino et al. 2013; Kitajima et al. 2011; Sdiri-Loulizi et al. 2010) and production of foods with such waters results in the potential for infection at the consumer level. The virus has been implicated in an outbreak associated with the consumption of oysters (Le Guyader et al. 2008) and has been linked to other incidences of gastroenteritis (Oh et al. 2006), although the food source was not determined. The virus is stable on produce (Fino and Kniel 2008a) and in shellfish (Sdiri-Loulizi et al. 2010).

Astroviruses: This group of viruses found in the Astroviridae family was first described in 1975 by Madeley and Cosgrove (1975). These viruses are significant pathogens of both humans and animals (Kurtz and Lee 1987) and have been identified in human outbreaks associated with foods (Le Guyader et al. 2008; Mead et al. 1999). The predominant route of infection is water (Abad et al. 1997) and the virus can persist on fomites for several days (Abad et al. 2001), suggesting that foodborne infections are due to improper food handling. Yet, there has also been evidence that astroviruses can contaminate shellfish (Hansman et al. 2008), suggesting a possible foodborne route at the retail level.

Hepatitis A virus: Also a member of the Picornaviridae family, HAV is a well-recognized cause of foodborne disease (Fiore 2004; Sanchez et al. 2007). The virus is abundant worldwide and present in many regions of the world including developed countries such as Italy (Campagna et al. 2012) and The Netherlands (Whelan et al. 2013). Studies in the laboratory have shown that HAV is highly stable in the environment (Siegl et al. 1984) and can easily be found in shellfish growing in contaminated waters (Diez-Valcarce et al. 2012). In agricultural settings, the virus can be internalized into produce such as spinach (Hirneisen and Kniel 2013), tomatoes (Carvalho et al. 2012), and strawberries (Niu et al. 1992). While there is ample evidence to suggest that the virus can easily be involved in retail as a result of improper food processing (Wang et al. 2013), there is also significant evidence showing that the virus can also be transferred through food handling (Tricco et al. 2006). The virus can transfer easily through environmental surfaces, known as fomites (Abad et al. 1994) including knives and graters (Wang et al. 2013), and can remain infective for several hours in acidic conditions (Scholz et al. 1989).

Hepatitis E virus: Initially described as a picornavirus in 1983 (Balayan et al. 1983), HEV has been found to represent a novel genus, Herpesvirus (Berke and Matson 2000). Since its discovery, the virus has grown to be a major cause of hepatitis in the developing world and its prevalence is growing in the developed world (Miyamura 2011). Transmission is generally mediated through water, however, foodborne outbreaks have occurred, primarily through the ingestion of improperly cooked meat products including swine, boar, poultry, venison, ovine, and beef products (Meng 2011). HEV has also been found in shellfish (Koizumi et al. 2004; Song et al. 2010), in pig livers (Berto et al. 2012; Bouwknegt et al. 2007), and in agricultural produce (Ceylan et al. 2003), but the risk associated with these two routes is significantly smaller than that of livestock and game meats.

Caliciviruses: The caliciviruses are a group of small viruses that are very stable in the environment and pose a significant threat for foodborne infection. The two major groups of caliciviruses known to cause foodborne infection are the sapoviruses and the noroviruses. While sapoviruses have been associated with foodborne outbreaks (Gallimore et al. 2005; Kobayashi et al. 2012; Usuku et al. 2008), noroviruses are the leading cause of gastroenteritis worldwide (Koo et al. 2010). The viruses were first discovered in 1972 (Kapikian et al. 1972) in an isolated case of pediatric diarrhea. Over the three decades that followed, the noroviruses were found to be globally abundant and identified as the cause of winter vomiting disease, stomach flu, and cruise ship illness. There have been over 900 documented cases of norovirus foodborne outbreaks (Matthews et al. 2012), many of which were determined to be due to retail and RTE purchases.

Rotaviruses: These viruses are part of the Reoviridae family. Studies to identify the presence of the virus in the food supply have revealed its presence in almost every aspect of the food continuum from shellfish (Benabbes et al. 2013; Bigoraj et al. 2012; Boxman 2010; Hansman et al. 2008; Woods and Burkhardt 2010) to livestock (Dalton et al. 2004; Mattison et al. 2007) to produce (Baert et al. 2011; Berger et al. 2010; Mattison et al. 2010; Serracca et al. 2012; Tuan et al. 2010) and fruits (Berger et al. 2010; Le Guyader et al. 2004; Martin-Latil et al. 2012; Strawn et al. 2011; Verhaelen et al. 2012). They have been recognized as a major cause of gastroenteritis, particularly in children (Parashar et al. 2003). There are five groups of rotavirus but only three are infectious to humans, Groups A–C. They are known to be highly stable in water, can survive for months in the environment (Fu et al. 1989), and for several hours in the air (Ijaz et al. 1985) and on human hands (Ansari et al. 1991). The majority of cases of infection are due to ingestion of contaminated water, however up to 1 % of foodborne infections are attributable to these viruses (Mead et al. 1999).

Emerging foodborne viruses: There have been several viruses that have caused concern with respect to foodborne illness due to the potential for infection from live or dead animals, a process known as zoonotic transmission. These include avian influenza, the Nipah viruses, and the coronaviruses, of which SARS is a member. In all three cases, they cause significant clinical infection and have high mortality rates. In addition, for all three viruses, interaction with live animals or foods associated with these animals at the market has led to human infection. In the case of Nipah virus, infection at retail has come from the sharing of raw date sap (Luby et al. 2006; Rahman et al. 2012), however the prevalence of these cases is low and isolated to areas where bats are common, such as Bangladesh (Luby and Gurley 2012).

6.3 Controlling Viruses in Food

The means to control viruses in retail foods in theory should not differ significantly from the methods used to control bacterial infections in these same products. However, there are several unique properties of many foodborne viruses that need to be viewed separately from bacteria. Therefore, no bacterial control studies can be extrapolated to the majority of these viruses.

Structurally, viruses are characterized into two major categories, enveloped and nonenveloped. Enveloped viruses possess an external layer made of both proteins and lipids. The lipids in the envelope can easily be broken down, particularly by soaps, rendering the virus unable to infect, a process known as inactivation (Klein 2004). In contrast, nonenveloped viruses have an external protein shell that can resist environmental stressors and many disinfectants (Maillard and Russell 1997; Sattar et al. 1989). In the context of foodborne viruses, the major contributors to infection, i.e., the astroviruses, Aichi virus, caliciviruses, HAV, and HEV, are all small and nonenveloped. The adenoviruses are also nonenveloped although somewhat larger in size, meaning controlling them may be somewhat easier (Maillard and Russell 1997). Only the rotaviruses and the emerging viruses, avian influenza, SARS, and Nipah are enveloped.

The survival and persistence of enveloped viruses in the food processing environment is fairly poor. Studies on rotaviruses showed that while the viruses have the ability to sustain infectivity over days in both raw and treated drinking water (Raphael et al. 1985; Sattar et al. 1984), the virus was rapidly reduced on fomites and hands in a matter of hours (Ansari et al. 1988). These data correlate well with the fact that foodborne infections due to rotavirus are limited to shellfish and raw produce irrigated with water from unsafe sources (Brassard et al. 2012; Le Guyader et al. 2008; Mattison et al. 2010; Vilarino et al. 2009). In contrast, the nonenveloped viruses can survive and spread throughout the entire food continuum from processing (Baert et al. 2008; Van Boxstael et al. 2013) to storage (Brandsma et al. 2012; Butot et al. 2008; Shieh et al. 2009; Sun et al. 2012; Verhaelen et al. 2012). Moreover, these viruses are well adapted to survive on hands (Greig et al. 2007; Richards 2001; Todd et al. 2009), increasing the potential for contamination both in processing as well as in preparation (Mokhtari and Jaykus 2009).

In determining risk factors associated with virus infections, the European Food Safety Authority (EFSA) published a risk assessment taking into account the survivability and transmissibility of viruses (EFSA Panel on Biological Hazards 2011). The breadth of the risks reveals that in order to properly control these viruses, there needs to be a wide-reaching set of control measures implemented in food processing and handling to ensure virus infections are reduced.

6.4 Viruses and Current Regulatory Mechanisms

Hazard analysis and critical control points (HACCP) and good hygiene practices (GHP) have been incorporated in many food industries and are generally known to be important in reducing the microbial risk to the consumer (FAO 1995; Panisello et al. 2000). These practices have been adopted in other environments, including retail, although there has yet to be one specific set of standards or guidelines to prevent retail virus infections (Little et al. 2003; Mortlock et al. 1999). The EFSA suggested (EFSA Panel on Biological Hazards 2011) that the use of HACCP to control viruses may not be sufficient to overcome the stability of viruses as well as their spread. In response, a 2008 joint meeting of the FAO and WHO (FAO/WHO 2008) suggested that regulation be focused on five high impact areas of concern involving specific combinations of viruses.

The virus–food combinations were determined based on (1) the number of documented cases and/or concerns of high impact public health threats; and (2) laboratory information focusing on virus survival in these food types. They are:

1. Noroviruses and HAV in bivalve molluscan shellfish, including oysters, clams, cockles, and mussels.
2. Noroviruses and HAV in fresh produce.
3. Noroviruses and HAV in prepared foods.
4. Rotaviruses in water used for food preparation.
5. Emerging viruses and their associated commodities including avian influenza, HEV, Nipah and others, as they are indicated.

In each case, there are subcategories that best characterize the potential for risk, as well as priority areas needed for a proper regulatory framework. They include (1) test development to identify these viruses throughout the food continuum; (2) in-depth assessment of exposure to these viruses not only at the consumer level but also at the worker and handler levels; and (3) an analysis of dose–response relationships.

While the EFSA developed these suggestions in 2008, there has been little progress made, due in part to hurdles occurring in the development of tests to identify viruses. While diagnostic tests continue to improve, there continues to be a large variation in testing results. The reasons for this have been excellently reviewed by Stals et al. (2012). In addition, while the detection of viruses in different food sources continues to improve, the applicability of these diagnostic tests has been less than favorable. All the viruses identified in these priority areas have relatively low dose responses and thus require a very low detection limit. This requires highly sensitive methods such as the diagnostic tool, polymerase chain reaction (PCR), which identifies the genetic material of a virus, and the more recently developed lab on a chip, in which not only the genetic material but other pieces of the virus including proteins can be detected (Yoon and Kim 2012). However, these are hindered by the requirement for a large sample size to best assess a food source. This challenge has yet to be overcome.

Another significant hurdle deals with the linking of quantitative analysis with qualitative risk assessment. Though genetic material may be found in a food source, there may be no actual link to a viable organism able to cause illness; the virus might already be dead. Thus, any current diagnostic test based on genetic material only gives you an indication of the potential risk associated with exposure to a food.

The determination of these five virus-food combinations has increased the understanding of virus transmission in the food continuum and provided keys to improvements in regulation. Using both data collected from the field as well as controlled experimental data using surrogates, such as the murine norovirus (MNV) and vaccine-strain poliovirus and/or bacteriophage MS2 for HAV (Deboosere et al.

2012; Richards 2012), a more comprehensive look at how these viruses spread by water, food users, and handlers as well as animals, follows.

Water contamination: The introduction of sewage, manure, and other biosolids into the watershed can contaminate water sources used in food production. Several studies have shown the capability of viruses to survive in sewage (Ehlers et al. 2005; Kokkinos et al. 2011b; Muniesa et al. 2009; Sattar and Westwood 1976, 1977, 1979; Wei et al. 2010) even after treatment (Myrmel et al. 2006; van den Berg et al. 2005; Villar et al. 2007) and the association with a risk for foodborne illness (Alcala et al. 2010; Ceballos et al. 2003; Ceylan et al. 2003; Cheong et al. 2009; Fiona Barker et al. 2013; Kokkinos et al. 2011a; Mathijs et al. 2012; Meng 2013; Steele and Odumeru 2004; Tierney et al. 1977; Ueki et al. 2005). The incorporation of management strategies to focus on the use of safe water has thus been identified as a necessary step in improving food safety (Godfree and Farrell 2005; Keraita et al. 2008; Westrell et al. 2004). Yet in many areas of the world, maintaining a safe supply of water can be difficult (Alcala et al. 2010; Ehlers et al. 2005; Kokkinos et al. 2011a), leaving regulatory officials facing a conundrum between the need for production and the maintenance of safety.

Food workers and handlers: Food workers and handlers are an important part of bringing foods to retail; however, these individuals also post a threat to the food, particularly when they themselves are infected with a foodborne virus. One study revealed that norovirus can reach as high as 10^{10} virus particles per gram of fecal matter (Atmar et al. 2008) while symptoms are being experienced. Lower levels can be found even before symptoms have begun (Gaulin et al. 1999) and for several weeks after symptoms have subsided (Gallimore et al. 2004). With the infectious dose of this particular virus being less than 100 particles (Teunis et al. 2008), the chance for contamination leading to infection is particularly high. Yet the most likely chance for contamination in this case occurs at the foodhandling stage, which is the last step before food products are provided to the consumer. As Michaels et al. (2004) and Mokhtari and Jaykus (2009) have both shown, food handlers represent the most likely reservoir leading to high levels of viral contamination and subsequent infections to the consumer.

Zoonotic transmission: While the most recent concerns with zoonotic transmission of pathogens such as avian influenza, SARS, and Nipah (Chmielewski and Swayne 2011; Guan et al. 2003; Smith et al. 2011) are due to close contact with live animals, the impact of animals on the contamination of the food supply cannot be understated. For example, the increase in HEV infections has been directly attributed to the zoonotic potential of the virus from swine (Banks et al. 2010; Berto et al. 2012; Bouwknegt et al. 2007; Casas et al. 2011; Di Bartolo et al. 2008; Fu et al. 2010; Leblanc et al. 2010; Pavio et al. 2010; Scobie and Dalton 2013). The presence of the virus not only in the liver of swine, but also their feces, suggests that this particular virus could cause infection either through the traditional fecal–oral route or through the bloodborne route during processing. In contrast, within the context of the viruses identified by the FAO/WHO, there is little evidence to demonstrate the likelihood of

HAV or rotavirus infection through a zoonotic route. Additionally, the noroviruses have shown potential, albeit no confirmed zoonotic route has been documented. Surveillance for noroviruses in animals has revealed that they can harbor human noroviruses (Mathijs et al. 2012; Mattison et al. 2007) and that without proper handling of animals could lead to transmission of the virus to humans, particularly farmers and food workers. Interestingly, Summa et al. (2012) have suggested that pet dogs may also serve as a route for infection. While this may not pose a risk for food processing, at the food handling level, where pets may be a part of a food service complement, a potential risk could be implied.

6.5 Control Measures

The achievements of HACCP and GHP implementation have aided in the increase of food safety but as seen earlier, there are gaps associated with these regulatory protocols in terms of preventing virus contamination of foods and subsequent foodborne infection. There have been a number of methods tested to inactivate viruses in the food continuum with an emphasis on retail. While each has demonstrated its potential to prevent infection of the consumer, there are still specific obstacles that need to be addressed. Moreover, in certain cases, there is little current feasibility for the incorporation of the methods at the retail stage; they are best used during prior steps of the food continuum.

Hand hygiene: The most effective and simplest means of controlling virus transmission is proper hand hygiene. In the context of food safety, the most effective means involves the use of soap for a minimum of 20 s followed by rinsing with water (Todd et al. 2010b). The use of other hand hygiene products, such as alcohol-based handrubs, may be effective against the majority of foodborne bacterial pathogens but the active ingredient, ethanol, is known to be ineffective against HAV and has limited efficacy against the noroviruses (Liu et al. 2010; Park et al. 2010; Sattar et al. 2011). While there is validity to the incorporation of alcohol-based handrubs in any food safety environment as a supplement to handwashing, these products cannot supplant regular handwashing.

The use of hand hygiene practices in the food continuum has been investigated (Michaels et al. 2004; Todd et al. 2010a, b) and there is an incorporation of hand hygiene in HACCP and GHP guidelines. Yet the use of hand hygiene measures at all stages of the food continuum continues to be an issue, particularly with compliance (Hoelzl et al. 2013; Strohbehn et al. 2004; Todd et al. 2010a). In 2008, for example, Strohbehn et al. (2008) conducted an assessment of foodservice workers in restaurants, childcare institutions, and facilities providing assisted living for the elderly and schools. In comparison to the Food Code requirements of handwashing, which ranged from 7 to 29 handwashing moments per hour, the results were disappointing. In the context of providing RTE foods, this result suggests that there is a significant risk posed to the consumer. Similar results have been seen in other retail markets such as butcheries, supermarkets, and delis (Tebbutt 2007).

In 1999, Armstrong (1999) developed an integrated hygiene program into food safety management called hygieomics. The program not only dealt with the implementation of hand hygiene into food production and processing practices, but also described means to cope with the problems associated with behaviour, which is a common concern in both the healthcare and food services sectors (Ferguson 2009; Gilling et al. 2001; Huis et al. 2012; Vindigni et al. 2011; Whitby et al. 2007). The process involved rules and compliance enforcement similar to HACCP, but also demanded an individual commitment to action and the development of a community that is engaged in safeguarding the food supply to achieve both personal and organizational confidence. Such efforts have been used in the health care field with significant success (Huis et al. 2012).

Another means to increase hand hygiene compliance in food workers and handlers is the use of appropriate and consistent training regimens. Hand hygiene training has been used extensively in the health care sector and results have been promising (Pincock et al. 2012). In food safety, training has been used but the results have been meager to disappointing (Averett et al. 2011; Chapman et al. 2010; Lillquist et al. 2005; York et al. 2009). Reasons for these poor results have been investigated (Green et al. 2005, 2006, 2007; Pragle et al. 2007) and a combination of factors including high workload, inappropriate staffing, lack of managerial support, and personal beliefs have been identified. The clear conclusion, therefore, is that a lack of adherence to hand hygiene is based on behavior, not lack of information.

The issues faced in the food industry are no different from those in the health care field where compliance rates for hand hygiene have never reached 100 %. While there has been no meaningful way to reach that goal, there has been a change in the direction of health care toward a 'patient-centric' viewpoint (Landers et al. 2012), whereby hand hygiene is a means to keep patient satisfaction high. This may be a very reasonable way to improve hand hygiene rates in the food industry as focusing on the satisfaction of those who are purchasing foods at retail will help maintain a high reputation and continued returns.

Washing and scrubbing: Vega et al. (2008) have demonstrated that viruses have the ability to attach to produce through electrostatic forces. Based on their analysis, the use of nonionic detergents as well as high levels of salt was sufficient to remove viruses from the surfaces of lettuce. This suggests that a salt solution of 1 N NaCl and agitation may be sufficient to remove the majority of viruses from fresh produce. Similarly, Wang et al. (2013) have shown that the simple action of scrubbing and peeling is sufficient to reduce up to 99 % of virus from the surfaces of produce. However, the likelihood of cross-contamination without proper hot water treatment in between items increases significantly. This potential for fomite transmission has been demonstrated for other food preparation activities such as cutting and grating (Wang et al. 2013).

Temperature: The use of temperature and pasteurization is an effective means to kill bacteria, however, viruses are significantly more resistant to such temperatures. Bozkurt et al. (2013) have shown that MNV is very temperature resistant, requiring over 10 min in some cases for a reduction of 1 log at 50 °C. Barnaud et al. (2012) found a similar requirement for inactivation of HEV in meat products. An internal temperature of 71 °C for 20 min was required to completely inactivate the virus. In a more comprehensive study, Tuladhar et al. (2012) investigated the thermal stability of viruses by measuring the time required to inactivate by 1 $\log_{10}$ (90 %). The results showed that 53 °C is inadequate to attain proper food safety for adenovirus, poliovirus, MNV, and adenovirus; the time required was well over 5 min and as long as 15 min for MNV-1. The results were significantly improved at 73 °C, with the required reduction being achieved in less than 2 min. Bertrand et al. (2012) reviewed the available literature and found similar observations for HAV and astroviruses. The data clearly show that higher temperatures than those used for bacteria are required to attain proper inactivation of viruses. Unfortunately, the use of temperatures above 73 °C in the food continuum can pose a problem in terms of maintaining the aesthetic and organoleptic properties of these foods.

Disinfection: The use of liquid chemical microbicides, more commonly referred to as disinfectants, in the food continuum can be used within a HACCP program including at retail. However, the actual application of these chemicals on food can be problematic due to potential changes in food quality, as well as the potential for improper rinsing leading to residues. Studies investigating the use of nonresidual disinfectants have been undertaken to reduce the levels of viruses on the surfaces of foods and also in waters used in the food continuum. Kahler et al. (2011) investigated the inactivation of viruses in the presence of monochloramine and found that there is a sufficient reduction of adenoviruses, coxsackieviruses, and MNV for use in food production and processing. In a similar manner, Su and D'Souza (2011) investigated the use of water containing 5 % trisodium phosphate (which has a similar activity to hypochlorite) on produce. They found the solution was sufficient to inactivate over 7 $\log_{10}$ of MNV after rinsing for 30 s. Fraisse et al. (2011) investigated the use of peroxyacetic acid against MNV and HAV and found that 100 ppm could reduce MNV on lettuce by 1 log with simple washing. An extended exposure of 2 min reduced the levels of MNV by over 99 %, whereas the reduction of HAV was only 0.7 $\log_{10}$.

Pressure: The use of high hydrostatic pressure (HPP) may be used in the processing and packaging stages of the food continuum to help prevent spread at retail. HPP has the ability to reduce the viral load of foods, including complex matrices, while maintaining food quality (Kingsley et al. 2004, 2013). Kingsley has reviewed the literature on the use of HPP and found that all but the Aichi viruses may be inactivated in 5 min by pressures ranging from 400 to 500 MPa (Kingsley 2013). However, there has yet to be a fully standardized protocol associated with HPP to ensure proper activity against all viruses. Upon finding a harmonized and standard protocol, HPP may see a rise in its use.

UV irradiation: Surface decontamination using ultraviolet (UV) irradiation continues to be investigated, although it has limited use in food processing and preparation. UV light has been known for over a decade to inactivate foodborne viruses (Nuanualsuwan et al. 2002) at levels over 0.1 J/cm^2. Fino and Kniel (2008b) found that UV light at a concentration of 0.24 J/cm^2 was effective at inactivating over 99 % of HAV, Aichi virus, and the human norovirus surrogate feline calicivirus (FCV) on experimentally contaminated lettuce and onions. The use of UV was not, however, applicable to strawberries due to shielding of the virus in the seed pockets as well as the three-dimensional nature of the surface allowing shadowing. Jean et al. (2011) investigated the use of pulsed-UV light to reduce MNV and HAV on inanimate surfaces. When exposed alone, a 2 s burst consisting of 1.27 J/cm^2 overall was enough to inactivate over 99 % of virus. However, when a complex mixture was used (comprising of 5 % fetal bovine serum), that level was reduced significantly. Thus, this method would likely be sufficient when surfaces are cleaned on a regular basis.

Ionizing irradiation: As an alternative to UV light, in some countries gamma irradiation is an accepted means of bacterial control in food processing and preparation. The use of 4 kGy has now been accepted by the FDA in the USA for use in ensuring food safety (U.S. Food and Drug Administration 2009). However, gamma irradiation is far less effective against foodborne viruses. At 4 kGy, Feng et al. (2011) have shown that inactivation of MNV is not sufficient to reduce the virus by more than 3 $\log_{10}$ on the surface of various produce. In a similar experiment, Espinosa et al. (2012) showed that 4 kGy was somewhat effective at reducing the levels of poliovirus by at least 1.5 $\log_{10}$ and satisfactory against rotavirus at levels of 3 $\log_{10}$. While there is significant promise for the use of irradiation, both the cost and the requirement for highly trained personnel suggest that this method is not applicable for retail but may be used in prior steps to ensure food safety.

6.6 Conclusion

Controlling virus infections at retail continues to be a significant challenge due to the fact that viruses can contaminate food at every level of the farm-to-fork continuum. The widespread nature of viruses in water poses a threat during production and their ease of transmission through the fecal–oral route can lead to inadvertent contamination during processing. Moreover, their relative stability and persistence renders many decontamination efforts useless.

There may be a direction to improving the safety of foods, but the path is iterative and highly systematic. There is little doubt that there needs to be a more integrated Food Safety Management System that spans the entire food continuum and harmonizes with the current practices of HACCP, GMP, and GHP. In Europe, the PathogenCombat project (Jakobsen 2010) aims to improve food safety through a combination of quantitative and qualitative risk assessment and subsequent framework development to develop Food Safety Management Systems specific to each food continuum.

PathogenCombat could potentially be effective not only due to the quantitative evaluations of risk, but also the inclusion of qualitative parameters including behavior and practice audits, as well as the ability for workers and handlers to register complaints (Jacxsens et al. 2010). This essentially holds any food production or service company to a higher standard of performance. For example, Sumner et al. (2011) examined the nature of food handlers' habits when suffering from vomiting or diarrheal illness. They found that over 11.9 % of these individuals actually worked during their sickness and did not adhere properly to food safety practices. No matter how effective technology might be to identify and inactivate viruses, the lack of adherence on the part of these workers is a risk to the food supply, including those who would purchase food at retail.

To fully combat foodborne viruses, the focus of food safety has to widen to incorporate a One-Heath approach such that it includes all stakeholders, not only microbiologists and inspectors. Much like what is occurring in the health care sector, there needs to be a full commitment from everyone involved in the food continuum to ensure that virus contamination is minimized. There may never be a means to entirely prevent virus contamination of food, yet a combination of quantitative and qualitative practices from farm to fork may leave not only these stakeholders, but also consumers confident that the food offered at retail is safe.

References

Abad FX, Pinto RM, Bosch A (1994) Survival of enteric viruses on environmental fomites. Appl Environ Microbiol 60:3704–3710

Abad FX, Pinto RM, Villena C et al (1997) Astrovirus survival in drinking water. Appl Environ Microbiol 63:3119–3122

Abad FX, Villena C, Guix S et al (2001) Potential role of fomites in the vehicular transmission of human astroviruses. Appl Environ Microbiol 67:3904–3907

Ahluwalia GS, Scott-Taylor TH, Klisko B et al (1994) Comparison of detection methods for adenovirus from enteric clinical specimens. Diagn Microbiol Infect Dis 18:161–166

Alcala A, Vizzi E, Rodriguez-Diaz J et al (2010) Molecular detection and characterization of Aichi viruses in sewage-polluted waters of Venezuela. Appl Environ Microbiol 76:4113–4115

Aminu M, Ahmad AA, Umoh JU et al (2007) Adenovirus infection in children with diarrhea disease in Northwestern Nigeria. Ann Afr Med 6:168–173

Ansari SA, Sattar SA, Springthorpe VS et al (1988) Rotavirus survival on human hands and transfer of infectious virus to animate and nonporous inanimate surfaces. J Clin Microbiol 26:1513–1518

Ansari SA, Springthorpe VS, Sattar SA (1991) Survival and vehicular spread of human rotaviruses: possible relation to seasonality of outbreaks. Rev Infect Dis 13:448–461

Armstrong GD (1999) Towards integrated hygiene and food safety management systems: the Hygieneomic approach. Int J Food Microbiol 50:19–24

Atmar RL, Opekun AR, Gilger MA et al (2008) Norwalk virus shedding after experimental human infection. Emerg Infect Dis 14:1553–1557

Averett E, Nazir N, Neuberger JS (2011) Evaluation of a local health department's food handler training program. J Environ Health 73:65–69

Baert L, Uyttendaele M, Vermeersch M et al (2008) Survival and transfer of murine norovirus 1, a surrogate for human noroviruses, during the production process of deep-frozen onions and spinach. J Food Prot 71:1590–1597

Baert L, Mattison K, Loisy-Hamon F et al (2011) Review: norovirus prevalence in Belgian, Canadian and French fresh produce: a threat to human health? Int J Food Microbiol 151: 261–269

Balayan MS, Andjaparidze AG, Savinskaya SS et al (1983) Evidence for a virus in non-A, non-B hepatitis transmitted via the fecal–oral route. Intervirology 20:23–31
Banks M, Martelli F, Grierson S et al (2010) Hepatitis E virus in retail pig liver. Vet Rec 166:29
Barnaud E, Rogee S, Garry P et al (2012) Thermal inactivation of infectious hepatitis E virus in experimentally contaminated food. Appl Environ Microbiol 78:5153–5159
Benabbes L, Ollivier J, Schaeffer J et al (2013) Norovirus and other human enteric viruses in Moroccan shellfish. Food Environ Virol 5:35–40
Berger CN, Sodha SV, Shaw RK et al (2010) Fresh fruit and vegetables as vehicles for the transmission of human pathogens. Environ Microbiol 12:2385–2397
Berke T, Matson DO (2000) Reclassification of the Caliciviridae into distinct genera and exclusion of hepatitis E virus from the family on the basis of comparative phylogenetic analysis. Arch Virol 145:1421–1436
Berto A, Martelli F, Grierson S et al (2012) Hepatitis e virus in pork food chain, United Kingdom, 2009–2010. Emerg Infect Dis 18:1358–1360
Bertrand I, Schijven JF, Sanchez G et al (2012) The impact of temperature on the inactivation of enteric viruses in food and water: a review. J Appl Microbiol 112:1059–1074
Bigoraj E, Chrobocińska M, Kwit E (2012) Norovirus contamination of bivalve molluscs as a cause of gastroenteritis. Med Weter 68:210–213
Bouwknegt M, Lodder-Verschoor F, van der Poel WH et al (2007) Hepatitis E virus RNA in commercial porcine livers in The Netherlands. J Food Prot 70:2889–2895
Boxman ILA (2010) Human enteric viruses occurrence in shellfish from european markets. Food Environ Virol 2:156–166
Bozkurt H, D'Souza DH, Davidson PM (2013) Determination of the thermal inactivation kinetics of the human norovirus surrogates, murine norovirus and feline calicivirus. J Food Prot 76: 79–84
Brandsma SR, Muehlhauser V, Jones TH (2012) Survival of murine norovirus and F-RNA coliphage MS2 on pork during storage and retail display. Int J Food Microbiol 159:193–197
Brassard J, Gagne MJ, Genereux M et al (2012) Detection of human food-borne and zoonotic viruses on irrigated, field-grown strawberries. Appl Environ Microbiol 78:3763–3766
Brown M (1990) Laboratory identification of adenoviruses associated with gastroenteritis in Canada from 1983 to 1986. J Clin Microbiol 28:1525–1529
Bryden AS, Curry A, Cotterill H et al (1997) Adenovirus-associated gastro-enteritis in the north-west of England: 1991–1994. Br J Biomed Sci 54:273–277
Buisson Y, Marie JL, Davoust B (2008) Ces maladies infectieuses importées par les aliments. Bull Soc Pathol Exot 101:343–347
Butot S, Putallaz T, Sanchez G (2008) Effects of sanitation, freezing and frozen storage on enteric viruses in berries and herbs. Int J Food Microbiol 126:30–35
Campagna M, Siddu A, Meloni A et al (2012) Changing pattern of hepatitis a virus epidemiology in an area of high endemicity. Hepat Mon 12:382–385
Carvalho C, Thomas H, Balogun K et al (2012) A possible outbreak of hepatitis A associated with semi-dried tomatoes, England, July–November 2011. Euro Surveill 17:6
Casas M, Cortés R, Pina S et al (2011) Longitudinal study of hepatitis E virus infection in Spanish farrow-to-finish swine herds. Vet Microbiol 148:27–34
Ceballos BS, Soares NE, Moraes MR et al (2003) Microbiological aspects of an urban river used for unrestricted irrigation in the semi-arid region of north-east Brazil. Water Sci Technol 47: 51–57
Centers for Disease Control and Prevention (2013) Surveillance for foodborne disease outbreaks—United States, 2009–2010. MMWR Morb Mortal Wkly Rep 62:41–47
Ceylan A, Ertem M, Ilcin E et al (2003) A special risk group for hepatitis E infection: Turkish agricultural workers who use untreated waste water for irrigation. Epidemiol Infect 131: 753–756
Chapman B, Eversley T, Fillion K et al (2010) Assessment of food safety practices of food service food handlers (risk assessment data): testing a communication intervention (evaluation of tools). J Food Prot 73:1101–1107

Cheong S, Lee C, Song SW et al (2009) Enteric viruses in raw vegetables and groundwater used for irrigation in South Korea. Appl Environ Microbiol 75:7745–7751

Chmielewski R, Swayne DE (2011) Avian influenza: public health and food safety concerns. Annu Rev Food Sci Technol 2:37–57

Codex Alimentarius (2008) Guideline for the validation of food safety control measures (CAC/GL 69-2008). Codex Alimentarius Commission, Rome

Dalton CB, Gregory J, Kirk MD et al (2004) Foodborne disease outbreaks in Australia, 1995 to 2000. Commun Dis Intell Q Rep 28:211–224

Deboosere N, Pinon A, Caudrelier Y et al (2012) Adhesion of human pathogenic enteric viruses and surrogate viruses to inert and vegetal food surfaces. Food Microbiol 32:48–56

Dey SK, Shimizu H, Phan TG et al (2009) Molecular epidemiology of adenovirus infection among infants and children with acute gastroenteritis in Dhaka City, Bangladesh. Infect Genet Evol 9:518–522

Di Bartolo I, Martelli F, Inglese N et al (2008) Widespread diffusion of genotype 3 hepatitis E virus among farming swine in Northern Italy. Vet Microbiol 132:47–55

Di Martino B, Di Progio F, Ceci C et al (2013) Molecular detection of Aichi virus in raw sewage in Italy. Arch Virol 158:2001–2005

Diez-Valcarce M, Kokkinos P, Söderberg K et al (2012) Occurrence of human enteric viruses in commercial mussels at retail level in three European countries. Food Environ Virol 4:73–80

EFSA Panel on Biological Hazards (2011) Scientific opinion on an update on the present knowledge on the occurrence and control of foodborne viruses. EFSA J 9:2190

Ehlers MM, Grabow WO, Pavlov DN (2005) Detection of enteroviruses in untreated and treated drinking water supplies in South Africa. Water Res 39:2253–2258

Espinosa AC, Jesudhasan P, Arredondo R et al (2012) Quantifying the reduction in potential health risks by determining the sensitivity of poliovirus type 1 chat strain and rotavirus SA-11 to electron beam irradiation of iceberg lettuce and spinach. Appl Environ Microbiol 78:988–993

FAO (1995) Report of the FAO expert technical meeting on the use of Hazard Analysis Critical Control Point (HACCP) principles in food control. FAO Food Nutr Pap 58:1–13

FAO Trade and Markets Division (2012) Food outlook: global market analysis. Food and Agriculture Organization of the United Nations, Rome

FAO/WHO (2008) Viruses in food: scientific advice to support risk management activities. World Health Organization, Geneva

Fein SB, Lando AM, Levy AS et al (2011) Trends in U.S. consumers' safe handling and consumption of food and their risk perceptions, 1988 through 2010. J Food Prot 74:1513–1523

Feng K, Divers E, Ma Y et al (2011) Inactivation of a human norovirus surrogate, human norovirus virus-like particles, and vesicular stomatitis virus by gamma irradiation. Appl Environ Microbiol 77:3507–3517

Ferguson JK (2009) Preventing healthcare-associated infection: risks, healthcare systems and behaviour. Intern Med J 39:574–581

Fino VR, Kniel KE (2008a) Comparative recovery of foodborne viruses from fresh produce. Foodborne Pathog Dis 5:819–825

Fino VR, Kniel KE (2008b) UV light inactivation of hepatitis A virus, Aichi virus, and feline calicivirus on strawberries, green onions, and lettuce. J Food Prot 71:908–913

Fiona Barker S, O'Toole J, Sinclair MI et al (2013) A probabilistic model of norovirus disease burden associated with greywater irrigation of home-produced lettuce in Melbourne, Australia. Water Res 47:1421–1432

Fiore AE (2004) Hepatitis A transmitted by food. Clin Infect Dis 38:705–715

Fischer Walker CL, Sack D, Black RE (2010) Etiology of diarrhea in older children, adolescents and adults: a systematic review. PLoS Negl Trop Dis 4:e768. doi:10.1371/journal.pntd.0000768

Fraisse A, Temmam S, Deboosere N et al (2011) Comparison of chlorine and peroxyacetic-based disinfectant to inactivate Feline calicivirus, Murine norovirus and Hepatitis A virus on lettuce. Int J Food Microbiol 151:98–104

Fu ZF, Hampson DJ, Blackmore DK (1989) Detection and survival of group A rotavirus in a piggery. Vet Rec 125:576–578

Fu H, Li L, Zhu Y et al (2010) Hepatitis E virus infection among animals and humans in Xinjiang, China: possibility of swine to human transmission of sporadic hepatitis E in an endemic area. Am J Trop Med Hyg 82:961–966

Gallimore CI, Cubitt D, du Plessis N et al (2004) Asymptomatic and symptomatic excretion of noroviruses during a hospital outbreak of gastroenteritis. J Clin Microbiol 42:2271–2274

Gallimore CI, Pipkin C, Shrimpton H et al (2005) Detection of multiple enteric virus strains within a foodborne outbreak of gastroenteritis: an indication of the source of contamination. Epidemiol Infect 133:41–47

Gaulin C, Frigon M, Poirier D et al (1999) Transmission of calicivirus by a foodhandler in the pre-symptomatic phase of illness. Epidemiol Infect 123:475–478

Gilling SJ, Taylor EA, Kane K et al (2001) Successful hazard analysis critical control point implementation in the United Kingdom: understanding the barriers through the use of a behavioral adherence model. J Food Prot 64:710–715

Godfree A, Farrell J (2005) Processes for managing pathogens. J Environ Qual 34:105–113

Goyer M, Aho LS, Bour JB et al (2008) Seroprevalence distribution of Aichi virus among a French population in 2006–2007. Arch Virol 153:1171–1174

Green L, Selman C, Banerjee A et al (2005) Food service workers' self-reported food preparation practices: an EHS-Net study. Int J Hyg Environ Health 208:27–35

Green LR, Selman CA, Radke V et al (2006) Food worker hand washing practices: an observation study. J Food Prot 69:2417–2423

Green LR, Radke V, Mason R et al (2007) Factors related to food worker hand hygiene practices. J Food Prot 70:661–666

Greig JD, Todd ECD, Bartleson CA et al (2007) Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 1. Description of the problem, methods, and agents involved. J Food Prot 70:1752–1761

Grimwood K, Carzino R, Barnes GL et al (1995) Patients with enteric adenovirus gastroenteritis admitted to an Australian pediatric teaching hospital from 1981 to 1992. J Clin Microbiol 33:131–136

Guan Y, Zheng BJ, He YQ et al (2003) Isolation and characterization of viruses related to the SARS coronavirus from animals in Southern China. Science 302:276–278

Hansman GS, Oka T, Li TC et al (2008) Detection of human enteric viruses in Japanese clams. J Food Prot 71:1689–1695

Henley SC, Stein SE, Quinlan JJ (2012) Identification of unique food handling practices that could represent food safety risks for minority consumers. J Food Prot 75:2050–2054

Herrmann JE, Blacklow NR, Perron-Henry DM et al (1988) Incidence of enteric adenoviruses among children in Thailand and the significance of these viruses in gastroenteritis. J Clin Microbiol 26:1783–1786

Hirneisen KA, Kniel KE (2013) Comparative uptake of enteric viruses into spinach and green onions. Food Environ Virol 5:24–34

Hoelzl C, Mayerhofer U, Steininger M et al (2013) Observational trial of safe food handling behavior during food preparation using the example of Campylobacter spp. J Food Prot 76: 482–489

Huis A, van Achterberg T, de Bruin M et al (2012) A systematic review of hand hygiene improvement strategies: a behavioural approach. Implement Sci 7:92. doi:10.1186/1748-5908-7-92

Ijaz MK, Sattar SA, Johnson-Lussenburg CM et al (1985) Comparison of the airborne survival of calf rotavirus and poliovirus type 1 (Sabin) aerosolized as a mixture. Appl Environ Microbiol 49:289–293

Jacxsens L, Uyttendaele M, Devlieghere F et al (2010) Food safety performance indicators to benchmark food safety output of food safety management systems. Int J Food Microbiol 141:S180–S187

Jakobsen M (2010) Introduction to supplement issue PathogenCombat: reducing food borne disease in Europe—control and prevention of emerging pathogens at cellular and molecular level throughout the food chain. Int J Food Microbiol 141:S1–S3

Jean J, Morales-Rayas R, Anoman MN et al (2011) Inactivation of hepatitis A virus and norovirus surrogate in suspension and on food-contact surfaces using pulsed UV light (pulsed light inactivation of food-borne viruses). Food Microbiol 28:568–572

Jebara KB (2004) Surveillance, detection and response: managing emerging diseases at national and international levels. Rev Sci Tech 23:709–715

Johansson ME, Andersson MA, Thorner PA (1994) Adenoviruses isolated in the Stockholm area during 1987–1992: restriction endonuclease analysis and molecular epidemiology. Arch Virol 137:101–115

Jonsson N, Wahlstrom K, Svensson L et al (2012) Aichi virus infection in elderly people in Sweden. Arch Virol 157:1365–1369

Kahler AM, Cromeans TL, Roberts JM et al (2011) Source water quality effects on monochloramine inactivation of adenovirus, coxsackievirus, echovirus, and murine norovirus. Water Res 45:1745–1751

Kaikkonen S, Rasanen S, Ramet M et al (2010) Aichi virus infection in children with acute gastroenteritis in Finland. Epidemiol Infect 138:1166–1171

Kapikian AZ, Wyatt RG, Dolin R et al (1972) Visualization by immune electron microscopy of a 27-nm particle associated with acute infectious nonbacterial gastroenteritis. J Virol 10: 1075–1081

Keraita B, Drechsel P, Konradsen F (2008) Using on-farm sedimentation ponds to improve microbial quality of irrigation water in urban vegetable farming in Ghana. Water Sci Technol 57: 519–525

Kingsley DH (2013) High pressure processing and its application to the challenge of virus-contaminated foods. Food Environ Virol 5:1–12

Kingsley DH, Chen H, Hoover DG (2004) Inactivation of selected picornaviruses by high hydrostatic pressure. Virus Res 102:221–224

Kitajima M, Haramoto E, Phanuwan C et al (2011) Prevalence and genetic diversity of Aichi viruses in wastewater and river water in Japan. Appl Environ Microbiol 77:2184–2187

Klein G (2004) Verbreitung von Viren uber die Lebensmittelkette. Dtsch Tierarztl Wochenschr 111:312–314

Kobayashi S, Fujiwara N, Yasui Y et al (2012) A foodborne outbreak of sapovirus linked to catered box lunches in Japan. Arch Virol 157:1995–1997

Koizumi Y, Isoda N, Sato Y et al (2004) Infection of a Japanese patient by genotype 4 hepatitis e virus while traveling in Vietnam. J Clin Microbiol 42:3883–3885

Kokkinos P, Ziros P, Meri D et al (2011a) Environmental surveillance. An additional/alternative approach for virological surveillance in Greece? Int J Environ Res Public Health 8: 1914–1922

Kokkinos PA, Ziros PG, Mpalasopoulou A et al (2011b) Molecular detection of multiple viral targets in untreated urban sewage from Greece. Virol J 8:195

Koo HL, Ajami N, Atmar RL et al (2010) Noroviruses: the leading cause of gastroenteritis worldwide. Discov Med 10:61–70

Kurtz JB, Lee TW (1987) Astroviruses: human and animal. Ciba Found Symp 128:92–107

Landers T, Abusalem S, Coty MB et al (2012) Patient-centered hand hygiene: the next step in infection prevention. Am J Infect Control 40:S11–S17

Le Guyader FS, Mittelholzer C, Haugarreau L et al (2004) Detection of noroviruses in raspberries associated with a gastroenteritis outbreak. Int J Food Microbiol 97:179–186

Le Guyader FS, Le Saux JC, Ambert-Balay K et al (2008) Aichi virus, norovirus, astrovirus, enterovirus, and rotavirus involved in clinical cases from a French oyster-related gastroenteritis outbreak. J Clin Microbiol 46:4011–4017

Leblanc D, Poitras E, Gagne MJ et al (2010) Hepatitis E virus load in swine organs and tissues at slaughterhouse determined by real-time RT-PCR. Int J Food Microbiol 139:206–209

Lillquist DR, McCabe ML, Church KH (2005) A comparison of traditional handwashing training with active handwashing training in the food handler industry. J Environ Health 67:13–16

Little CL, Lock D, Barnes J et al (2003) Microbiological quality of food in relation to hazard analysis systems and food hygiene training in UK catering and retail premises. Commun Dis Public Health 6:250–258

Liu P, Yuen Y, Hsiao HM et al (2010) Effectiveness of liquid soap and hand sanitizer against Norwalk virus on contaminated hands. Appl Environ Microbiol 76:394–399
Luby SP, Gurley ES (2012) Epidemiology of henipavirus disease in humans. Curr Top Microbiol Immunol 359:25–40
Luby SP, Rahman M, Hossain MJ et al (2006) Foodborne transmission of Nipah virus, Bangladesh. Emerg Infect Dis 12:1888–1894
Madeley CR, Cosgrove BP (1975) Editorial: virus of infantile gastroenteritis. Br Med J 3: 555–556
Maillard JY, Russell AD (1997) Viricidal activity and mechanisms of action of biocides. Sci Prog 80:287–315
Martin-Latil S, Hennechart-Collette C, Guillier L et al (2012) Comparison of two extraction methods for the detection of hepatitis A virus in semi-dried tomatoes and murine norovirus as a process control by duplex RT-qPCR. Food Microbiol 31:246–253
Mathijs E, Stals A, Baert L et al (2012) A review of known and hypothetical transmission routes for noroviruses. Food Environ Virol 4:131–152
Matthews JE, Dickey BW, Miller RD et al (2012) The epidemiology of published norovirus outbreaks: a review of risk factors associated with attack rate and genogroup. Epidemiol Infect 140:1161–1172
Mattison K, Shukla A, Cook A et al (2007) Human noroviruses in swine and cattle. Emerg Infect Dis 13:1184–1188
Mattison K, Harlow J, Morton V et al (2010) Enteric viruses in ready-to-eat packaged leafy greens. Emerg Infect Dis 16:1815–1817
Mead PS, Slutsker L, Dietz V et al (1999) Food-related illness and death in the United States. Emerg Infect Dis 5:607–625
Meng XJ (2011) From barnyard to food table: the omnipresence of hepatitis E virus and risk for zoonotic infection and food safety. Virus Res 161:23–30
Meng XJ (2013) Zoonotic and foodborne transmission of hepatitis e virus. Semin Liver Dis 33: 41–49
Michaels BS, Keller C, Blevins M et al (2004) Prevention of food worker transmission of foodborne pathogens: risk assessment and evaluation of effective hygiene intervention strategies. Food Serv Technol 4:31–49
Miyamura T (2011) Hepatitis E virus infection in developed countries. Virus Res 161:40–46
Mokhtari A, Jaykus LA (2009) Quantitative exposure model for the transmission of norovirus in retail food preparation. Int J Food Microbiol 133:38–47
Mortlock MP, Peters AC, Griffith CJ (1999) Food hygiene and hazard analysis critical control point in the United Kingdom food industry: practices, perceptions, and attitudes. J Food Prot 62: 786–792
Muniesa M, Payan A, Moce-Llivina L et al (2009) Differential persistence of F-specific RNA phage subgroups hinders their use as single tracers for faecal source tracking in surface water. Water Res 43:1559–1564
Myrmel M, Berg EM, Grinde B et al (2006) Enteric viruses in inlet and outlet samples from sewage treatment plants. J Water Health 4:197–209
Newell DG, Koopmans M, Verhoef L et al (2010) Food-borne diseases—the challenges of 20 years ago still persist while new ones continue to emerge. Int J Food Microbiol 139:S3–S15
Niu MT, Polish LB, Robertson BH et al (1992) Multistate outbreak of hepatitis A associated with frozen strawberries. J Infect Dis 166:518–524
Nuanualsuwan S, Mariam T, Himathongkham S et al (2002) Ultraviolet inactivation of feline calicivirus, human enteric viruses and coliphages. Photochem Photobiol 76:406–410
Oh DY, Silva PA, Hauroeder B et al (2006) Molecular characterization of the first Aichi viruses isolated in Europe and in South America. Arch Virol 151:1199–1206
Panisello PJ, Rooney R, Quantick PC et al (2000) Application of foodborne disease outbreak data in the development and maintenance of HACCP systems. Int J Food Microbiol 59:221–234
Parashar UD, Hummelman EG, Bresee JS et al (2003) Global illness and deaths caused by rotavirus disease in children. Emerg Infect Dis 9:565–572

Park GW, Barclay L, Macinga D et al (2010) Comparative efficacy of seven hand sanitizers against murine norovirus, feline calicivirus, and GII.4 norovirus. J Food Prot 73:2232–2238

Pavio N, Meng XJ, Renou C (2010) Zoonotic hepatitis E: animal reservoirs and emerging risks. Vet Res 41:46

Pincock T, Bernstein P, Warthman S et al (2012) Bundling hand hygiene interventions and measurement to decrease health care-associated infections. Am J Infect Control 40:S18–S27

Pragle AS, Harding AK, Mack JC (2007) Food workers' perspectives on handwashing behaviors and barriers in the restaurant environment. J Environ Health 69:27–32

Rahman MA, Hossain MJ, Sultana S et al (2012) Date palm sap linked to Nipah virus outbreak in Bangladesh, 2008. Vector Borne Zoonotic Dis 12:65–72

Raphael RA, Sattar SA, Springthorpe VS (1985) Long-term survival of human rotavirus in raw and treated river water. Can J Microbiol 31:124–128

Reuter G, Boldizsar A, Papp G et al (2009) Detection of Aichi virus shedding in a child with enteric and extraintestinal symptoms in Hungary. Arch Virol 154:1529–1532

Ribes JM, Montava R, Tellez-Castillo CJ et al (2010) Seroprevalence of Aichi virus in a Spanish population from 2007 to 2008. Clin Vaccine Immunol 17:545–549

Richards GP (2001) Enteric virus contamination of foods through industrial practices: a primer on intervention strategies. J Ind Microbiol Biotechnol 27:117–125

Richards GP (2012) Critical review of norovirus surrogates in food safety research: rationale for considering volunteer studies. Food Environ Virol 4:6–13

Saderi H, Roustai MH, Sabahi F et al (2002) Incidence of enteric adenovirus gastroenteritis in Iranian children. J Clin Virol 24:1–5

Sanchez G, Bosch A, Pinto RM (2007) Hepatitis A virus detection in food: current and future prospects. Lett Appl Microbiol 45:1–5

Sattar SA, Westwood JC (1976) Comparison of four eluents in the recovery of indigenous viruses from raw sludge. Can J Microbiol 22:1586–1589

Sattar SA, Westwood JC (1977) Isolation of apparently wild strains of poliovirus type 1 from sewage in the Ottawa area. Can Med Assoc J 116:25–27

Sattar SA, Westwood JC (1979) Recovery of viruses from field samples of raw, digested, and lagoon-dried sludges. Bull World Health Organ 57:105–108

Sattar SA, Raphael RA, Springthorpe VS (1984) Rotavirus survival in conventionally treated drinking water. Can J Microbiol 30:653–656

Sattar SA, Springthorpe VS, Karim Y et al (1989) Chemical disinfection of non-porous inanimate surfaces experimentally contaminated with four human pathogenic viruses. Epidemiol Infect 102:493–505

Sattar SA, Ali M, Tetro JA (2011) In vivo comparison of two human norovirus surrogates for testing ethanol-based handrubs: the mouse chasing the cat! PLoS One 6:e17340. doi:10.1371/journal.pone.0017340

Scholz E, Heinricy U, Flehmig B (1989) Acid stability of hepatitis A virus. J Gen Virol 70:2481–2485

Scobie L, Dalton HR (2013) Hepatitis E: Source and route of infection, clinical manifestations and new developments. J Viral Hepat 20:1–11

Sdiri-Loulizi K, Hassine M, Gharbi-Khelifi H et al (2009) Detection and genomic characterization of Aichi viruses in stool samples from children in Monastir, Tunisia. J Clin Microbiol 47:2275–2278

Sdiri-Loulizi K, Hassine M, Aouni Z et al (2010) First molecular detection of Aichi virus in sewage and shellfish samples in the Monastir region of Tunisia. Arch Virol 155:1509–1513

Serracca L, Rossini I, Battistini R et al (2012) Potential risk of norovirus infection due to the consumption of "ready to eat" food. Food Environ Virol 4:89–92

Shieh YC, Stewart DS, Laird DT (2009) Survival of hepatitis A virus in spinach during low temperature storage. J Food Prot 72:2390–2393

Shinozaki T, Araki K, Fujita Y et al (1991a) Epidemiology of enteric adenoviruses 40 and 41 in acute gastroenteritis in infants and young children in the Tokyo area. Scand J Infect Dis 23:543–547

Shinozaki T, Fujita Y, Araki K et al (1991b) Clinical features of enteric adenovirus infection in infants. Acta Paediatr Jpn 33:623–627
Siegl G, Weitz M, Kronauer G (1984) Stability of hepatitis A virus. Intervirology 22:218–226
Smith TC, Harper AL, Nair R et al (2011) Emerging swine zoonoses. Vector Borne Zoonotic Dis 11:1225–1234
Song YJ, Jeong H, Kim YJ et al (2010) Analysis of complete genome sequences of swine hepatitis E virus and possible risk factors for transmission of HEV to humans in Korea. J Med Virol 82:583–591
Stals A, Baert L, Van CE (2012) Extraction of food-borne viruses from food samples: a review. Int J Food Microbiol 153:1–9
Steele M, Odumeru J (2004) Irrigation water as source of foodborne pathogens on fruit and vegetables. J Food Prot 67:2839–2849
Strawn LK, Schneider KR, Danyluk MD (2011) Microbial safety of tropical fruits. Crit Rev Food Sci Nutr 51:132–145
Strohbehn CH, Gilmore SA, Sneed J (2004) Food safety practices and HACCP implementation: perceptions of registered dietitians and dietary managers. J Am Diet Assoc 104:1692–1699
Strohbehn C, Sneed J, Paez P et al (2008) Hand washing frequencies and procedures used in retail food services. J Food Prot 71:1641–1650
Su X, D'Souza DH (2011) Trisodium phosphate for foodborne virus reduction on produce. Foodborne Pathog Dis 8:713–717
Summa M, von Bonsdorff CH, Maunula L (2012) Pet dogs—a transmission route for human noroviruses? J Clin Virol 53:244–247
Sumner S, Brown LG, Frick R et al (2011) Factors associated with food workers working while experiencing vomiting or diarrhea. J Food Prot 74:215–220
Sun Y, Laird DT, Shieh YC (2012) Temperature-dependent survival of hepatitis A virus during storage of contaminated onions. Appl Environ Microbiol 78:4976–4983
Tebbutt GM (2007) Does microbiological testing of foods and the food environment have a role in the control of foodborne disease in England and Wales? J Appl Microbiol 102:883–891
Teunis PF, Moe CL, Liu P et al (2008) Norwalk virus: how infectious is it? J Med Virol 80: 1468–1476
Tiemessen CT, Wegerhoff FO, Erasmus MJ et al (1989) Infection by enteric adenoviruses, rotaviruses, and other agents in a rural African environment. J Med Virol 28:176–182
Tierney JT, Sullivan R, Larkin EP (1977) Persistence of poliovirus 1 in soil and on vegetables grown in soil previously flooded with inoculated sewage sludge or effluent. Appl Environ Microbiol 33:109–113
Todd EC, Greig JD, Bartleson CA et al (2009) Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 6. Transmission and survival of pathogens in the food processing and preparation environment. J Food Prot 72:202–219
Todd EC, Greig JD, Michaels BS et al (2010a) Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 11. Use of antiseptics and sanitizers in community settings and issues of hand hygiene compliance in health care and food industries. J Food Prot 73:2306–2320
Todd EC, Michaels BS, Holah J et al (2010b) Outbreaks where food workers have been implicated in the spread of foodborne disease. Part 10. Alcohol-based antiseptics for hand disinfection and a comparison of their effectiveness with soaps. J Food Prot 73:2128–2140
Tricco AC, Pham B, Duval B et al (2006) A review of interventions triggered by hepatitis A infected food-handlers in Canada. BMC Health Serv Res 6:157
Tuan ZC, Hidayah MS, Chai LC et al (2010) The scenario of norovirus contamination in food and food handlers. J Microbiol Biotechnol 20:229–237
Tuladhar E, Bouwknegt M, Zwietering MH et al (2012) Thermal stability of structurally different viruses with proven or potential relevance to food safety. J Appl Microbiol 112:1050–1057
U.S. Food and Drug Administration (2009) Ionizing radiation for the treatment of food. Fed Reg 21:455–456

Ueki Y, Sano D, Watanabe T et al (2005) Norovirus pathway in water environment estimated by genetic analysis of strains from patients of gastroenteritis, sewage, treated wastewater, river water and oysters. Water Res 39:4271–4280
Uhnoo I, Wadell G, Svensson L et al (1984) Importance of enteric adenoviruses 40 and 41 in acute gastroenteritis in infants and young children. J Clin Microbiol 20:365–372
Usuku S, Kumazaki M, Kitamura K et al (2008) An outbreak of food-borne gastroenteritis due to sapovirus among junior high school students. Jpn J Infect Dis 61:438–441
Van Boxstael S, Habib I, Jacxsens L et al (2013) Food safety issues in fresh produce: bacterial pathogens, viruses and pesticide residues indicated as major concerns by stakeholders in the fresh produce chain. Food Control 32:190–197
van den Berg H, Lodder W, van der Poel W et al (2005) Genetic diversity of noroviruses in raw and treated sewage water. Res Microbiol 156:532–540
Vega E, Garland J, Pillai SD (2008) Electrostatic forces control nonspecific virus attachment to lettuce. J Food Prot 71:522–529
Verhaelen K, Bouwknegt M, Lodder-Verschoor F et al (2012) Persistence of human norovirus GII.4 and GI.4, murine norovirus, and human adenovirus on soft berries as compared with PBS at commonly applied storage conditions. Int J Food Microbiol 160:137–144
Verma H, Chitambar SD, Gopalkrishna V (2011) Circulation of Aichi virus genotype B strains in children with acute gastroenteritis in India. Epidemiol Infect 139:1687–1691
Vilarino ML, Le Guyader FS, Polo D et al (2009) Assessment of human enteric viruses in cultured and wild bivalve molluscs. Int Microbiol 12:145–151
Villar LM, de Paula VS, Diniz-Mendes L et al (2007) Molecular detection of hepatitis A virus in urban sewage in Rio de Janeiro, Brazil. Lett Appl Microbiol 45:168–173
Vindigni SM, Riley PL, Jhung M (2011) Systematic review: handwashing behaviour in low- to middle-income countries: outcome measures and behaviour maintenance. Trop Med Int Health 16:466–477
Wang Q, Erickson M, Ortega YR et al (2013) The fate of murine norovirus and hepatitis a virus during preparation of fresh produce by cutting and grating. Food Environ Virol 5:52–60
Wei J, Jin Y, Sims T et al (2010) Survival of murine norovirus and hepatitis A virus in different types of manure and biosolids. Foodborne Pathog Dis 7:901–906
Westrell T, Schonning C, Stenstrom TA et al (2004) QMRA (quantitative microbial risk assessment) and HACCP (hazard analysis and critical control points) for management of pathogens in wastewater and sewage sludge treatment and reuse. Water Sci Technol 50:23–30
Whelan J, Sonder G, van den Hoek A (2013) Declining incidence of hepatitis A in Amsterdam (The Netherlands), 1996–2011: second generation migrants still an important risk group for virus importation. Vaccine 31:1806–1811
Whitby M, Pessoa-Silva CL, McLaws ML et al (2007) Behavioural considerations for hand hygiene practices: the basic building blocks. J Hosp Infect 65:1–8
Woods JW, Burkhardt W III (2010) Occurrence of norovirus and hepatitis a virus in U.S. Oysters. Food Environ Virol 2:176–182
Yamashita T, Kobayashi S, Sakae K et al (1991) Isolation of cytopathic small round viruses with BS-C-1 cells from patients with gastroenteritis. J Infect Dis 164:954–957
Yang S, Zhang W, Shen Q et al (2009) Aichi virus strains in children with gastroenteritis, China. Emerg Infect Dis 15:1703–1705
Yoon JY, Kim B (2012) Lab-on-a-chip pathogen sensors for food safety. Sensors (Basel) 12:10713–10741
York VK, Brannon LA, Shanklin CW et al (2009) Foodservice employees benefit from interventions targeting barriers to food safety. J Am Diet Assoc 109:1576–1581