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Outbreaks of Food-Borne and Waterborne Viral Gastroenteritis

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INTRODUCTION

A viral etiology for outbreaks of acute infectious nonbacterial gastroenteritis (AING) was confirmed in 1972 (67). Norwalk virus was subsequently shown to be a frequent cause of outbreaks of food-borne and waterborne AING in the United States (20, 40, 69, 76). From 1978 through 1982, the clinical and epidemiologic features of outbreaks of food-borne and waterborne Norwalk virus infection were characterized (4, 43, 44, 47, 48, 70–72, 74, 108, 115); also, during the 1980s, an increasing variety of viral agents were implicated as causing outbreaks of food-borne or waterborne illness (8, 9, 26, 36, 45, 46, 60, 61, 73, 86, 105, 110). The clinical aspects of these illnesses and the epidemiologic aspects of the outbreaks resembled those caused by Norwalk virus. Transmission by food or water has been documented for astroviruses, caliciviruses, rotaviruses, and a group of small round structured viruses (SRSVs) known as Norwalk-like viruses (20).

Laboratory confirmation of viruses as the causes of food-borne and waterborne illness is based on demonstration of virus particles or antigen in stool or demonstration of a rise in specific antibody to the virus. These laboratory methods continue to be developed and refined. However, serologic or antigen testing is not widely available, and laboratory confirmation of the etiology remains the exception in most public health investigations of viral gastroenteritis outbreaks (19, 20). Thus, national surveillance data on food-borne and waterborne illness in the United States and elsewhere underestimate the public health significance of these viruses. The use of epidemiologic criteria to classify outbreaks of food-borne and waterborne illness caused by Norwalk-like viruses was promoted in 1982 but has not been widely adopted by the public health community (5, 68). In the absence of specific laboratory confirmation, epidemiologic classification of these outbreaks may provide a more accurate assessment of their public health significance.

AGENTS OF VIRAL GASTROENTERITIS ASSOCIATED WITH OUTBREAKS OF FOOD-BORNE AND WATERBORNE DISEASE

Several reviews of the clinical and epidemiologic features of viral gastroenteritis have been published recently (7, 20, 21, 29). Outbreaks of food-borne or waterborne illness have primarily been associated with the small RNA viruses such as Norwalk virus (69). Several Norwalk-like viruses have not been well characterized with respect to their nucleic acid type. It is possible that some small viruses, such as Ditchling

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TABLE 1. Instructions for collecting specimens to evaluate outbreaks of viral gastroenteritis[a]

Parameter	Instructions for:	
	Stool	Serum
Source	10 ill persons; 10 controls for comparison (optional)	Same persons from whom stool was collected (controls optional)
Specimen	At least 10 ml/person in clean dry containers	15-ml (adults) and 3-ml (children) blood specimens collected in tubes containing no anticoagulants
Time	Within 48–72 h after onset of illness	Collect acute-phase specimens at same time as stool; collect convalescent-phase specimens 3–4 wk after onset of illness.
Storage and shipping	Immediately refrigerate at 4°C. Place bagged and sealed specimens with frozen refrigerant packs in insulated box. Send by overnight mail. DO NOT FREEZE.	Refrigerate tubes of serum until shipped with frozen refrigerant packs in insulated box. Keep specimens frozen by shipping on dry ice. Send by overnight mail.

[a] Adapted from the CDC (19).

and Cockle agents, may be DNA parvoviruses (11). Small RNA calciviruses and astroviruses and the larger double-stranded RNA rotaviruses are infrequently associated with outbreaks of food-borne or waterborne disease (25, 55, 60).

Classification of the Norwalk-like viruses has been based largely on morphology, mainly because of our inability to cultivate many of these viruses in vitro and the relatively small numbers of virus particles that can be recovered from stool (12, 21, 29). Recently, findings from biochemical and immunologic studies have resulted in a reevaluation of the relationship between Norwalk virus and the caliciviruses (25).

Norwalk virus and Norwalk-like viruses are the most widely recognized agents of outbreaks of food-borne and waterborne viral gastroenteritis (20). Norwalk virus was the first of these viruses to be characterized and serves as the epidemiologic prototype for the group. Norwalk-like viruses are small, round, morphologically similar viruses 25 to 30 nm in diameter (3, 12, 67, 93). Individual viruses (Norwalk, Hawaii, Snow Mountain, and Otofuke viruses) have been named for the locations of outbreaks from which the virus was first isolated. The viruses are visually distinguishable by immune electron microscopy (IEM) (25, 52, 90). These viruses have surface structures that are more amorphous than those of calciviruses and astroviruses and that have been used as the basis for classifying the latter viruses (12). Norwalk virus and several Norwalk-like viruses possess a single major structural polypeptide with molecular weights that range from 59,000 (Norwalk virus) to 63,000 (SRSV-9) (38, 52). Some Norwalk-like viruses exhibit antigenic cross-reactivity, as demonstrated by serologic responses of patients (52, 90).

Caliciviruses are similar in size to Norwalk-like viruses. In addition, cross-reacting antibody responses to infections with Norwalk virus and caliciviruses have been demonstrated by serology (25). However, caliciviruses are distinguishable from Norwalk virus by characteristic cup-shaped depressions on their outer surfaces. Astroviruses are characterized by having star-shaped configurations on smooth outer surfaces (12). These features can be distinguished by electron microscopy (EM).

Rotaviruses are approximately 70 nm in diameter and possess a double-stranded segmented RNA core. Five distinct antigenic groups of rotavirus have been recognized. Group A rotaviruses comprise the primary human pathogens, while groups B through E have been associated primarily with animals (21). Group B and C rotaviruses have been primarily associated with infections in swine, and both have been implicated as causing outbreaks of food-borne or waterborne viral gastroenteritis in humans in China (group B) and Japan (group C) (86, 105). The diversity of rotaviruses is great. In addition to group specificity, a rotavirus can be classified by serotype specificity, subgroup specificity, and strain specificity (21, 116). These markers have potential epidemiologic utility in the investigation of rotavirus outbreaks.

Other viruses that are known or suspected to cause gastroenteritis in humans but have not been implicated as causing outbreaks of food-borne or waterborne illness include adenoviruses, coronaviruses, enteroviruses, pestiviruses, picobirnaviruses, and toroviruses (20). If diagnostic laboratory tests are developed and made available to public health agencies, the significance of transmission of many of these agents by food and water may become apparent.

LABORATORY AND EPIDEMIOLOGIC METHODS USED TO CONFIRM OUTBREAKS OF VIRAL GASTROENTERITIS

Laboratory confirmation of the cause of outbreaks of food-borne and waterborne viral gastroenteritis requires either the detection of virus in stool or demonstration of a rise in specific antibody. Virus can be detected in stool by isolation of the virus in cell culture, detection of viral antigens, or visualization of the virus by EM (19). Instructions from the Centers for Disease Control and Prevention (CDC) for collecting specimens to evaluate outbreaks of viral gastroenteritis are summarized in Table 1.

Norwalk Virus IEM

Norwalk virus was first identified in filtrates of stools from people who were part of an outbreak of AING in Norwalk, Ohio. Convalescent-stage sera from these patients were used to aggregate virus particles for detection by EM (67). The ability of convalescent-stage sera to aggregate virus allowed

IEM to be used as a serologic assay and for virus detection. The utility of IEM in detecting Norwalk virus has been limited by poor sensitivity. Norwalk virus was identified in stool by IEM in only three of eight outbreaks investigated from 1977 through 1982 in which Norwalk virus was serologically determined to be the causative agent (16, 43, 44, 47, 70, 74, 75, 108). In two of these outbreaks, Norwalk virus was identified in only 1 of 18 and 2 of 30 stool specimens. Reports of greater success in detecting Norwalk virus by IEM appear to be exceptions (44). Because electron microscopes scan a field 0.000001 m wide, between 10^5 and 10^6 virus particles per ml of stool must be present to be detectable (21). Within 48 to 72 h after onset of symptoms, the virus concentration in stool declines below levels detectable by these methods (109). This fact, and the logistics of stool collection and shipping to an appropriate reference laboratory, makes IEM impractical for most public health investigations.

Norwalk Virus RIA and Biotin-Avidin Immunoassay

IEM remained the only method of virus detection for Norwalk virus until the development of a radioimmunoassay (RIA) technique at the National Institute of Allergy and Infectious Diseases in 1978 (42). However, antigen detection by RIA is not significantly more sensitive than antigen detection by IEM (43, 47, 74). In addition to detection of Norwalk virus antigen, one of the first applications of RIA was for the detection of antibodies to Norwalk virus in sera collected during 25 AING outbreaks that occurred between 1966 and 1977 (40). Ill persons from 11 of these outbreaks had fourfold or greater rises in antibody titer between acute- and convalescent-stage sera (40). This study and a subsequent evaluation of AING outbreaks reported to the CDC from 1976 through 1980 suggested that Norwalk virus was a major cause of AING outbreaks in the United States (68). Detection of a rise in antibody by RIA has been sufficiently sensitive to provide useful epidemiologic data. In several studies, the number of patients with significant antibody titer rises was apparently reduced by the collection of acute-stage sera a week or more after onset of symptoms (4, 77). However, in these and other studies, geometric mean antibody titers in convalescent-stage sera were greater in patients than in controls, supporting the conclusion that Norwalk virus was the cause of the outbreak (43, 72, 75, 82, 111).

Shortcomings of the RIA include the 6 days required to perform the test and the need for radioactive isotope-labeled reagents (34). To simplify antigen detection and serologic testing for Norwalk virus, the CDC developed a biotin-avidin immunoassay (34). This method was first used in 1984 to confirm an outbreak of food-borne Norwalk virus gastroenteritis in a school (58). Since then, it has become the CDC's standard method of testing for the Norwalk virus antigen and antibody (19). The sensitivity of the assay appears to be comparable to that of RIA (19).

Antibody to Norwalk virus begins to develop within 5 days after onset of illness, peaks within 3 weeks, and begins to decline by week 6 (30). The early antibody response of immunoglobulins A and M peaks 2 weeks after onset of illness. The presence of immunoglobulin G antibody in approximately half of the adult population in the United States precludes the use of single specimens to document recent infection in most instances (39). Unless a sufficient number of patients and controls can be evaluated to show greater antibody prevalence among the patients, it is necessary to obtain paired acute- and convalescent-stage specimens and demonstrate a rise in antibody titer. This complicates the process of confirming the cause of an outbreak and requires repeated contacts with patients after they have recovered from their illness.

Norwalk Virus EIA and Polymerase Chain Reaction

In addition to IEM, RIA, and biotin-avidin immunoassay, an enzyme immunoassay (EIA) for detecting Norwalk virus antigen in stool has been developed (56). In two outbreaks, this assay detected Norwalk virus in 4 of 6 stool samples collected 2 days after onset of symptoms and in 3 of 15 stool samples collected 4 to 5 days after onset of symptoms (31). Although these data suggest that the EIA may be more sensitive than previous antigen detection methods, the inability to cultivate Norwalk virus in cell culture has limited the supply of viral antigen available for use in developing reagents (21). Recent developments in the genetic sequencing of Norwalk virus has led to the development of recombinant Norwalk virus capsids (63, 64, 85). Thus, the development of Norwalk virus EIAs is no longer dependent on harvesting virus from stool samples. In addition, Norwalk virus can now be detected by polymerase chain reaction (27, 65). The development of laboratory-based production methods for Norwalk virus antigens, the availability of polymerase chain reaction, and the potential for development of additional test methods should result in more widespread confirmation of food-borne and waterborne outbreaks of Norwalk virus gastroenteritis. However, the utility of those virus-specific methods is limited by the fact that Norwalk virus is only one of several viruses that cause outbreaks with similar clinical and epidemiologic features.

Methods for Norwalk-Like Viruses

A variety of methods used to identify Norwalk viruses have been used, or adapted, to identify other Norwalk-like viruses in food-borne or waterborne outbreaks. In England, EM has been used to identify viruses associated with consumption of cockles and a Norwalk-like virus associated with a hospital-based food-borne outbreak (3, 95). In Japan, EM has been used to identify Norwalk-like viruses from several food-borne outbreaks (52, 73, 90).

IEM has been used in England to detect viruses in an outbreak associated with oysters (36). Similarly, Norwalk-like viruses were detected in fecal specimens by IEM in outbreaks from Marin County, California, and Snow Mountain, Colorado (28, 93). An EIA for Snow Mountain virus detected virus particles in fecal specimens from a clam-associated outbreak and from an outbreak in a retirement home (37, 110).

Both IEM and RIA have been used to distinguish Norwalk-like viruses from Norwalk virus (3, 28, 93). Serologic rises in antibody titer to Norwalk-like viruses have been demonstrated by IEM, RIA, and EIA (8, 36, 37, 46, 93, 110). An immunoblot assay has recently been developed for one Norwalk-like virus (SRSV-9) in Japan (52). Development of these methods has required both the recovery of large quantities of virus from the patient's stool specimens and technical capabilities present in relatively few research or reference laboratories.

The isolation of astrovirus in cell culture allowed development of monoclonal antibodies that were used to identify

the Marin County virus as an astrovirus (57). Subsequently, a nucleic acid dot blot hybridization procedure for astroviruses has been developed (114). Use of these techniques may allow identification of astroviruses that do not show the typical morphology by EM (114).

Methods for Rotavirus

Outbreaks of group A rotavirus infection in day-care centers and nursing homes have been detected and confirmed by IEM, detection of viral antigen in stool by latex agglutination or EIA, and detection of a rise in complement-fixing antibodies (26, 50, 81, 84). In general, these outbreaks have not been attributed to transmission by food or water. However, an outbreak of waterborne gastroenteritis caused by group A rotavirus was demonstrated by IEM and RIA in Colorado (60). An outbreak of waterborne group B rotavirus infection was demonstrated by EM and IEM in China (105). Similarly, an outbreak of food-borne group C rotavirus infection in Japan was demonstrated by polyacrylamide gel electrophoresis of virus particles detected by EM (86).

Commercial kits for the detection of antigens to group A rotaviruses and adenoviruses have been developed and marketed. EIAs for rotavirus are widely used by clinical laboratories (21). Several studies comparing the performances of these assays with virus isolation have demonstrated test sensitivities of 70 to 100% and test specificities of 50 to 100% (21, 22, 83). Problems with false-positive test results have led to recommendations to avoid use of specific test kits and to perform other confirmatory tests when situations in which rotavirus is not a common diagnosis are being evaluated (83).

Virus Isolation

Isolation of rotaviruses, adenoviruses, and astroviruses can be performed in laboratories by using special techniques (19, 80, 116). Few clinical laboratories or public health reference laboratories are staffed or equipped to isolate these viruses.

Epidemiologic Methods

Several factors make it unlikely that laboratory confirmation of outbreaks of food-borne or waterborne viral gastroenteritis will become commonplace in the near future. Most of these viruses cannot be isolated in cell culture, and detection of virus particles by EM or IEM is not sensitive. Although antigen and antibody detection assays have been developed for a number of viruses, their use is limited to a few reference centers. The logistics of obtaining appropriate stool and serum specimens makes it impractical for many public health agencies to attempt to confirm the viral etiology. Finally, public health interventions needed to control outbreaks of food-borne or waterborne disease must usually be made before results of viral testing are available.

In the absence of specific laboratory confirmation, outbreaks of food-borne and waterborne gastroenteritis can be evaluated by epidemiologic means (68). Proposed criteria for considering an outbreak due to a Norwalk-like virus included stool cultures negative for bacterial pathogens, median incubation period of 24 to 48 h, median duration of illness of 12 to 60 h, and vomiting in ≥50% of patients (68). However, among adults, the frequency of vomiting may be reduced. We have found that a more consistent criterion is the increased frequency of vomiting in relation to the frequency of fever. This relationship holds for both adults and children. In 38 outbreaks of laboratory-confirmed, Norwalk virus-caused gastroenteritis investigated by the CDC from 1976 through 1980, the median percentage of patients with vomiting was 69%, with a range of 25 to 100%. The median percentage of patients reporting subjective fever was 37%, with a range of 13 to 71% (69). For 29 groups of patients in outbreaks for which frequency of vomiting and fever were both reported, vomiting occurred in ≥50% of cases in 19 outbreaks (66%) (1, 4, 17, 18, 31, 43, 48, 62, 70, 72, 82, 88, 108, 111, 112). Outbreaks in which <50% of patients experienced vomiting involved groups of adults. However, vomiting was reported more frequently than fever for 27 groups (93%) in these outbreaks. In neither of the two outbreaks in which fever was more common than vomiting was vomiting reported by ≥50% of patients (31, 111). Although reporting of fever is subjective in most public health investigations, we believe that the relative frequency of reporting of vomiting and fever has discriminatory value. For example, similar subjective assessments in outbreaks of salmonellosis result in frequencies of fever greater than frequencies of vomiting (54, 91, 106, 107). We propose that epidemiologic criteria for classifying outbreaks of Norwalk-like viral gastroenteritis be broadened to include the increased frequency of vomiting relative to fever as an alternative to an absolute frequency of vomiting in ≥50% of cases.

Epidemiologic assessment of outbreaks does not allow for differentiation of specific viruses, but it does allow for determination of the public health importance of Norwalk-like viruses relative to outbreaks of illness caused by bacterial, chemical, and parasitic agents (5). In practice, this requires collecting appropriate stool specimens to rule out bacterial agents and collecting sufficient epidemiologic evidence to demonstrate that the outbreak is similar to other outbreaks for which a viral etiology has been confirmed.

CLINICAL AND EPIDEMIOLOGIC FEATURES OF OUTBREAKS OF VIRAL GASTROENTERITIS

Norwalk virus and Norwalk-like viruses have been the predominant reported causes of outbreaks of food-borne and waterborne viral gastroenteritis (20, 40, 52, 69). Of 74 outbreaks of acute nonbacterial gastroenteritis investigated by the CDC from 1976 to 1980, 42% were attributed to Norwalk virus (69). More recently, in a serologic analysis of 100 outbreaks of apparent viral gastroenteritis reviewed by the CDC from 1985 through 1988, 20 were attributed to Norwalk virus and 40 were attributed to antigenically related viruses (20).

Clinical Features

Outbreaks caused by Norwalk-like viruses are characterized by median incubation periods of 24 to 48 h, median durations of 12 to 60 h, and a high percentage of patients with diarrhea, nausea, abdominal cramps, and vomiting (Table 2). Children and adolescents are likely to experience vomiting more frequently than diarrhea, while adults experience higher rates of diarrhea than of vomiting (1, 62, 72, 108, 112). This combination of incubation period, duration of illness, and relative frequency of reported symptoms is unlike those associated with outbreaks of bacterial infection or intoxication. In particular, outbreaks of *Salmonella* infections typically feature longer illnesses and more fever than vomiting. However, it is prudent to obtain stool cultures for bacterial enteropathogens when an outbreak of gastroenteritis is being

TABLE 2. Clinical and outbreak characteristics for confirmed outbreaks of Norwalk virus gastroenteritis, 1976 through 1989

Characteristic	Median % (range)[a]	
	1976–1980 (n = 38)	1980–1989 (n = 23)
Clinical[a]		
Nausea	79 (51–100)	78 (33–99)
Vomiting	69 (25–100)	57 (16–81)
Diarrhea	66 (21–100)	78 (9–96)
Abdominal cramps	71 (17–90)	60 (37–87)
Fever	37 (13–71)	31 (3–52)
Outbreak		
Incubation period, 24–48 h	91[b]	100[c]
Duration of illness, 12–60 h	93[b]	100[c]

[a] Clinical data for 1976 through 1980 were summarized by Kaplan et al. (69). Information was available on vomiting and diarrhea for 34 outbreaks, on nausea and abdominal cramps for 30 outbreaks, and on fever for 29 outbreaks for those years. For 1980 through 1989, information was available on vomiting and diarrhea for all 23 groups, on nausea for 22 groups, on abdominal cramps for 19 groups, and on fever for 18 groups.

[b] Information was available on incubation period for 22 outbreaks and on duration of illness for 28 outbreaks.

[c] Information was available on incubation period and duration of illness for 14 outbreaks.

TABLE 3. Clustering of outbreaks of food-borne viral gastroenteritis by month in Minnesota, 1981 through 1991

No. of outbreaks/mo	No. of mo with reported outbreaks		$[(O - E)^2]/E$[a]
	Observed (O)	Expected (E)[b]	
0	97	89.7	0.6
1	21	34.6	5.3
2	12	6.7	4.2
3	2	0.9	1.3
4	0	0.1	0.1
Total	132	132.0	11.5[c]

[a] Observed minus expected value squared divided by the expected value, for each level of observation.

[b] Expected values on the basis of the Poisson distribution; $\lambda = 0.386$ (51 outbreaks in 132 months).

[c] Chi square for the sum of $[(O - E)^2]/E$ with 3 df = 11.5; $P < 0.01$.

investigated. A common feature of outbreaks due to Norwalk-like viruses is the occurrence of secondary transmission to household members who were not exposed to the implicated food or water source.

Epidemiologic Features

In the United States, infection caused by Norwalk virus generally occurs among older children and adults (39). This is in contrast to the epidemiology of infections due to rotaviruses, caliciviruses, and astroviruses, which typically occur among young children (20). This age-specific risk of acquiring infection undoubtedly influences the likelihood of transmission by way of food handler contamination of food. Furthermore, antibody to Norwalk virus does not appear to protect individuals from reinfection (6, 94). Thus, although infection confers short-term immunity, the pool of susceptible food handlers does not diminish with age, and outbreaks may occur whenever the virus is introduced (66).

Outbreaks of Norwalk virus and Norwalk-like virus gastroenteritis occur year-round, and no seasonality has been described. However, 20 (65%) of 31 Norwalk virus outbreaks in the United States from 1967 through 1980 (reviewed by Kaplan et al. [69]) occurred during the spring (April through June) or fall (October through December) (69). Similarly, in Minnesota from 1981 through 1991, 39 (76%) of 51 outbreaks of the food-borne disease that met Kaplan's criteria (i.e., vomiting in ≥50% of cases, incubation period of 24 to 48 h, and duration of 12 to 60 h) occurred during the spring or fall. While these data may not be sufficient to establish a seasonal pattern for the occurrence of Norwalk virus outbreaks, our experience in Minnesota suggests that outbreaks tend to cluster in time. From 1981 through 1991, the number of months with multiple confirmed outbreaks of food-borne Norwalk-like viral gastroenteritis was twice the expected frequency (Table 3). This temporal clustering of outbreaks suggests that outbreaks occur in the context of periodic or seasonal transmission of virus in the community, as is seen with rotavirus (23, 79, 104). In fact, many outbreaks of food-borne viral gastroenteritis may not be recognized because individual cases may be attributed to "a flu going around."

The occurrence of outbreaks of food-borne or waterborne rotavirus infections among children may be difficult to detect. In the day-care setting, outbreaks are generally attributed to person-to-person transmission, contamination of fomites, and contamination of environmental surfaces (99, 100, 113). Transmission of virus by these means will result in an outbreak that may progress over a couple of weeks. An outbreak that suggests a point source may be due to transmission by aerosol or food (96). Transmission by aerosol may be detected by time-space clustering of exposed persons. Transmission by food may be difficult to assess because of the limited ability of young children to recall food items eaten.

Similarly, outbreaks of food-borne or waterborne disease in nursing homes and other residential geriatric care facilities may not be recognized. Food consumption histories may be difficult to obtain from residents, and those that are obtained may not be reliable. In one study, temporal and spatial clustering of cases among residents and staff and the occurrence of illnesses over a period of 2 weeks demonstrated person-to-person transmission of Norwalk virus in a nursing home (71). In a second outbreak, 55% of residents and 25% of staff in a geriatric convalescent facility became ill during an outbreak that persisted for 9 weeks. Onsets of illness among residents peaked during the fourth week of the outbreak. Thirteen staff members who had direct contact with ill residents but no stool contact became ill (35). In contrast, an outbreak of food-borne Snow Mountain virus in a nursing home was accompanied by the sudden onset of illness among 41 residents within 48 h of an implicated meal, with subsequent person-to-person transmission to over 100 other residents and staff (37). In another study, a similar epidemiologic appearance was reported for sequential outbreaks of astrovirus type 1- and rotavirus-caused gastroenteritis among geriatric residents of a large psychiatric hospital in which transmission by food was not implicated but could not be thoroughly assessed (81).

MODES OF TRANSMISSION, PREVENTION, AND CONTROL

Outbreaks of viral gastroenteritis have occurred in defined populations, such as families, day-care centers, schools, nursing homes, and cruise ships, in which identifying a mode

of transmission has not been possible or multiple modes of transmission seemed likely. Contamination of food or ice, aerosolization of vomitus, and direct contact with an infected person and fomites may all contribute to transmission in these settings (9, 26, 32, 37, 41, 45, 48, 51, 59, 62, 81, 93). Transmission by food has resulted from contamination of cold food items by food handlers or water and from consumption of raw shellfish. Transmission by water has resulted from contamination of groundwater supplies, food handler contamination of ice, and swimming.

Contaminated Shellfish

Raw shellfish have been implicated in outbreaks of food-borne viral gastroenteritis in the United States, Europe, and Australia (2, 36, 44, 47, 88, 89). Outbreaks occur following consumption of shellfish harvested from waters contaminated with human sewage (47, 49, 98, 110). Oysters, clams, and other shellfish filter virus particles from contaminated water and accumulate them in their tissues. Norwalk virus has been detected by RIA in outbreak-associated clam and oyster specimens (44, 88).

Prevention of shellfish-acquired viral gastroenteritis depends on harvesting shellfish only from waters that are free of contamination by human sewage or on cooking the shellfish long enough to inactivate viral contaminants. Attempts to purify shellfish by placing them in tanks of pathogen-free water for a time have failed to eliminate virus or prevent transmission (36). Current standards rely on the presence of bacterial indicators of viral contamination of both shellfish and the waters from which the shellfish were harvested (49, 98). These bacterial indicators may not be reliable for detecting the presence of viruses. In addition, once shellfish are harvested, they may pass through several hands before reaching the consumer. Thus, it may be difficult to certify the source of shellfish in commerce or trace the origin of shellfish associated with an outbreak (49).

Infected Food Handlers

Although shellfish have been important regional vehicles for outbreaks of food-borne viral gastroenteritis, transmission from infected food handlers appears to be a common and widespread phenomenon. However, despite the relative frequency of its occurrence, important questions about how such transmission occurs remain to be answered. Of 14 published reports of viral gastroenteritis outbreaks that probably resulted from transmission by food handlers, a food handler who was ill before or while handling the implicated food item was identified in 8 outbreaks (57%) (8, 31, 43, 45, 46, 58, 61, 73, 75, 82, 95, 97, 102, 112). Salads were the implicated vehicle in five outbreaks (36%), and cold food items or ice were implicated in all but one outbreak.

The dynamic nature of transmission by food handlers was demonstrated by an outbreak in a bakery in which a single food handler experienced onset of vomiting and diarrhea on the way to work and had at least five episodes of diarrhea and two episodes of vomiting during his 6-h shift. During this time, he made 76 liters of butter cream frosting that was used on 10,000 frosted food items that were sold to the public. At least 3,000 cases were attributed to this outbreak (75).

In two outbreaks, asymptomatic food handlers prepared the implicated food items (29, 76). One of these food handlers had an ill child at home and also had a significant rise in antibody titer to Norwalk virus (31). This episode suggests asymptomatic virus excretion. Norwalk virus has been detected in stool from an implicated food handler 48 h after recovery from symptoms (97). In addition, food handlers have been implicated in transmission of Norwalk virus up to 48 h after clinical recovery (112).

More problematic are the four outbreaks (29%) in which food handlers became ill after preparing or serving implicated food items (43, 45, 46, 95). The first of these was associated with green salads served at a restaurant. The outbreak was initially recognized because of illness in patrons of two luncheon banquets. Transmission occurred over a period of 6 days. One of two workers who prepared lettuce for the green salads reported onset of illness the day after preparing lettuce for the index banquets. This employee had a diagnostic rise in antibody titer to Norwalk virus (43). Two other outbreaks occurred among students and staff eating lunches prepared in their school cafeterias. An outbreak of gastroenteritis caused by a Norwalk-like virus was associated with sandwiches that may have been contaminated by a cafeteria worker who placed the sandwiches on plates without wearing gloves. This worker had a diagnostic rise in antibody titer to Norwalk virus but did not become ill until 36 h after serving the implicated sandwiches (45). In the second school-associated outbreak, infection was associated with consumption of hamburgers or french fries handled 1 to 2 days before onset of diarrhea in two food servers who did not wear gloves while serving. In addition, their contact with the implicated food items was reportedly restricted to handling prewrapped hamburgers and taking french fries with a scoop from a warming tray and placing them in plastic containers (46). Finally, an outbreak of gastroenteritis in two hospitals due to a Norwalk-like virus was associated with a food handler who became ill the day after preparing the implicated chicken sandwiches. This food handler had two children at home who were ill at the time (95).

In these outbreaks the reported onsets of illness in food handlers overlapped the distribution of illness onsets among patrons. Possible explanations for these observations include inadequate recall or lying on the part of the food handler regarding illness onset, transmission of virus during the incubation period, or another unrecognized source of virus contamination. From the standpoint of implementing public health control measures, these alternatives have very different implications. Although food handlers may seek to avoid taking blame for an outbreak and there is a natural tendency for investigators to be suspicious of food handlers who deny being ill, investigators must not let their biases analyze their data. Many establishments use produce that is chopped or shredded by the distributor. Contamination at the distributor level could be missed if a source within the establishment's kitchen is assumed at the expense of other possibilities.

In Minnesota, 12 outbreaks of Norwalk-like viral gastroenteritis were reported from 1981 through 1983 (76). Salad items were implicated in six of these outbreaks, and an ill food handler was identified in five of these six outbreaks (76). From 1984 through 1991, an additional 39 outbreaks of food-borne viral gastroenteritis were reported in Minnesota. Cold food items were implicated as the vehicles in each outbreak; salad items were implicated in 12 outbreaks (31%). Ill food handlers were identified in 23 outbreaks (59%). In six outbreaks (15%), the food handler who prepared the implicated food item was not ill but had ill household members. Thus, in 74% of outbreaks of food-borne viral gastroenteritis in Minnesota, a food handler source was identified. In three outbreaks (8%), food handlers had onset of illness at the same time as patrons, and no ill food handlers or other

sources were identified in seven outbreaks (18%). These cumulative results of food-borne disease surveillance in Minnesota provide some perspective for evaluating the relative importance of transmission routes in outbreaks of food-borne viral gastroenteritis.

Control of outbreaks of food-borne disease resulting from food handler transmission requires removal of infected food handlers from contact with cold foods or food preparation surfaces, cleaning and disinfection of contaminated surfaces and equipment, and disposal of contaminated food items. In the 11 outbreaks in which the roles of food handlers were evaluated, multiple ill food handlers were identified in 10 outbreaks (91%) (31, 43, 45, 46, 75, 82, 95, 97, 102, 112). Similarly, of 18 restaurant-based outbreaks of food-borne viral gastroenteritis in Minnesota from 1984 through 1991, multiple ill food handlers were identified in 14 outbreaks (78%). The frequency of transmission between food handlers within a kitchen, transmission from asymptomatic persons, transmission by persons who have recovered from symptoms, and apparent transmission from persons who are incubating infections complicate outbreak control efforts. The absence of sick leave benefits for many food handlers makes it economically difficult for them to remain home when they are ill. Removal of cold food items from the menu controlled one outbreak (95). However, hot foods were implicated in an outbreak of gastroenteritis caused by Snow Mountain virus, and the potential for transmission from infected servers has not been adequately evaluated (46). In outbreak settings in Minnesota, we recommend exclusion of ill food handlers for 72 h. When there is evidence of transmission among food handlers and transmission to patrons on multiple days, we recommend that restaurants close for 72 h. This provides an opportunity for the virus to "burn itself out" of the food handlers and allows time for thorough cleaning and sanitizing of environmental surfaces and disposal of all potentially contaminated cold food items. In 6 (33%) of 18 restaurant-based viral gastroenteritis outbreaks in Minnesota from 1984 through 1991, the involved restaurant voluntarily closed for 72 h because of the risk of ongoing transmission to patrons.

Waterborne Transmission

The definition of waterborne disease outbreaks used by the CDC for surveillance purposes is restricted to illness that occurs after consumption or use of water intended for drinking (78). Classic outbreaks of waterborne viral gastroenteritis have been associated with private wells, small water systems, and community water systems (10, 13, 14, 18, 53, 70, 77, 87, 92, 108, 115). Groundwater contamination of wells has occurred as a result of a municipal sewage lagoon leak, leakage from septic tanks, flooding after heavy rainfalls, and back siphonage through a cross-connection between a well and a septic tank (10, 13, 16, 17, 77, 108). Surface water sources, including springs and streams, have also been contaminated from runoff associated with heavy rainfall (18, 60, 92). Contributing factors in these outbreaks included the absence of filtration and the absence of or inadequate chlorination of the water supply. In one outbreak, a community water system with an adequately functioning water treatment plant was contaminated by water from an industrial plant that operated its own wells (70). The industrial water system normally operated at a negative pressure relative to the community water system. However, during periods of heavy water use in the community, a drop in pressure allowed contamination of the community water system (70).

The role of water in outbreaks of viral gastroenteritis is broader than the CDC's surveillance definition implies. An outbreak involving 1,500 cadets and staff at the U.S. Air Force Academy was attributed to consumption of chicken salad. No ill food handlers were identified. However, celery used in the chicken salad had been washed and soaked for an hour in water obtained from a hose that had been used previously to unclog floor drains after sewage had backed up into the kitchen (111). It was hypothesized that virus particles were rinsed from the hose and taken up by the celery during the wash and soak. Although this outbreak was food borne, it appears that water played the critical role in causing the outbreak.

A major class of outbreaks associated with water not intended for drinking is made up of outbreaks associated with recreational waters (111). Outbreaks of Norwalk virus gastroenteritis have been associated with swimming in lakes and swimming pools (4, 15, 72, 74). These outbreaks typically occur during summer months in the United States. Infected individuals contaminating crowded swimming areas can produce apparent point source outbreaks among exposed groups. As with the potential for ongoing transmission in food service operations, it may be necessary to close implicated swimming areas for 72 h to prevent additional transmission.

Airborne Transmission

Although airborne transmission has not been positively demonstrated in food service settings, this failure is probably due to technical difficulties in confirming that transmission by aerosol occurred rather than to the frequency of its occurrence. Transmission by aerosol has been demonstrated in outbreaks on cruise ships and in schools and was the likely cause of a common-source outbreak in a hospital (9, 59, 101).

Outbreak Control

Investigating common-source outbreaks of viral gastroenteritis to determine modes of transmission and necessary control measures can be complex and frustrating. The absence of routinely available laboratory tests to confirm the etiology of an outbreak is ameliorated by the characteristic epidemiology of viral gastroenteritis. However, the occurrence of illness in persons who handle or serve both food and ice may make it difficult to distinguish between the possible roles of contaminated raw food items, food handler contamination, or contaminated water sources as etiologic factors. Complicating these assessments is the additional potential for transmission of viral gastroenteritis from an infected serving person or party member by the respiratory or airborne route (96, 101).

Determining the mode of transmission is necessary to implementing appropriate control measures. However, regardless of whether food or water is identified as a primary source for that outbreak, ill food handlers and servers can perpetuate the outbreak. Thus, all ill food handlers and servers need to be excluded from contact with food or ice for 72 h. In addition, when ongoing transmission to patrons is demonstrated, the food service should close for a similar period.

RELATIVE IMPORTANCE OF VIRAL GASTROENTERITIS TO ALL OUTBREAKS OF FOOD-BORNE AND WATERBORNE DISEASE

Outbreaks of food-borne and waterborne viral gastroenteritis appear to be both common and underreported. Outbreaks of Norwalk virus infection have served as the epidemiologic prototype of viral gastroenteritis outbreaks. In the United States, Norwalk virus itself appears to be the major cause of outbreaks of viral gastroenteritis and has been identified as the cause of 32 to 42% of such outbreaks (40, 69). A review of U.S. national surveillance data compiled by the CDC for 1979 revealed that 6 (67%) of 9 outbreaks in nursing homes, 3 (60%) of 5 outbreaks in summer camps, 5 (28%) of 18 outbreaks on cruise ships, and 22 (23%) of 96 outbreaks of waterborne disease were epidemiologically typical of Norwalk virus (62). However, only 18 (4%) of 430 outbreaks of food-borne disease were consistent with Norwalk virus (62). Serologic evidence of Norwalk virus infection was demonstrated for 10 (71%) of 14 outbreaks of Norwalk-like viral gastroenteritis that could be evaluated.

Similarly, from 1973 through 1987, only 15 outbreaks of food-borne disease in the United States were attributed to Norwalk virus and 10 were attributed to other viral agents (5). These 25 outbreaks account for 1% of the 2,841 outbreaks of food-borne disease with confirmed etiology reported to the CDC during this period. The reliance on confirmation of the viral etiology of these outbreaks diminishes the apparent significance of viral gastroenteritis. Of 4,617 outbreaks of unknown etiology, 450 (10%) had median incubation periods of 24 to 47 h and ≥50% of persons reported vomiting. Outbreaks in this group met at least two of the criteria specified by Kaplan et al. for outbreaks of Norwalk virus gastroenteritis (68).

In contrast to national surveillance data, statewide surveillance data in Minnesota suggested that 12 (35%) of 34 outbreaks of food-borne disease involving five or more persons from 1981 to 1983 were due to Norwalk-like viruses (76). Furthermore, outbreaks of viral gastroenteritis were more common than outbreaks due to *Salmonella*, *Shigella*, and *Campylobacter* spp.

The relative importance of viral gastroenteritis to the epidemiology of food-borne illness in Minnesota has been consistent from 1984 through 1991. Of 100 outbreaks of food-borne disease reported in Minnesota during this period, 39 (39%) were typical outbreaks of viral gastroenteritis, with median incubation periods of 24 to 48 h and vomiting in ≥50% of cases. Viral gastroenteritis was the most common food-borne illness in Minnesota during this period.

Stools for bacterial culture were not collected during every outbreak. However, stools negative for *Salmonella*, *Shigella*, or *Campylobacter* spp. appear to be the least important of the criteria of Kaplan et al. (68). In all 10 confirmed outbreaks due to *Salmonella*, *Shigella*, or *Campylobacter* spp. in Minnesota during this period, fever was reported more frequently than vomiting. In contrast, fever was more common than vomiting in only 2 of 39 outbreaks of apparent viral gastroenteritis (rate ratio, 19.5; 95% confidence interval, 5.1 to 75.2; $P < 0.001$). Thus, as suggested in the initial report of an outbreak of nonbacterial gastroenteritis in an elementary school in Norwalk, Ohio, outbreaks of viral gastroenteritis can generally be distinguished from outbreaks caused by common bacterial pathogens on the basis of clinical and epidemiologic criteria (1). However, because the typical epidemiology of a viral gastroenteritis outbreak may not be apparent until late in the investigation, it remains a good practice to obtain stool samples for bacterial culture during all investigations of outbreaks of food-borne disease.

In contrast to the 22% of outbreaks of waterborne disease reported to the CDC in 1979 that met the epidemiologic criteria for Norwalk-like virus, only 3 (6%) of 50 outbreaks of waterborne disease reported to the CDC from 1986 through 1988 had a confirmed viral etiology (78). Similarly, only 40 (8%) of 495 outbreaks of waterborne disease reported to the CDC from 1971 through 1985 had a confirmed viral etiology. However, as in 1979, many of the 208 outbreaks (49%) of acute gastroenteritis of unknown etiology were likely to have been caused by Norwalk-like viruses. In Minnesota from 1981 through 1991, 14 confirmed outbreaks of waterborne disease were reported. Eight (57%) were apparent outbreaks of viral gastroenteritis. As with food-borne disease surveillance, national surveillance data for waterborne disease underestimates the public health importance of viral gastroenteritis because of the lack of available laboratory tests. As new methods allow production of viral antigens without the need to harvest viruses from stool samples, reagents will become available to a wider variety of laboratories, and testing for Norwalk virus may become more routine.

Outbreaks of food-borne and waterborne viral gastroenteritis have been reported from around the world, and Norwalk virus and other Norwalk-like viruses are recognized as important food-borne pathogens in the United Kingdom, Japan, and Australia (24, 33, 44, 52, 103). However, in the United Kingdom, as in the United States, these outbreaks appear to be underreported (5). In Scotland from 1980 through 1985, only 6 (<1%) of 1,380 reported outbreaks of food-borne disease were attributed to viruses. The agent was not identified in 86 outbreaks (6%) (96). Systematically collected food-borne disease surveillance data are not available for much of the world.

SUMMARY

Norwalk virus infection is the epidemiologic prototype for outbreaks of food-borne and waterborne gastroenteritis. Around the world, Norwalk virus and Norwalk-like viruses appear to be major causes of food-borne and waterborne illness. Assessment of the overall significance of viral agents to the epidemiology of food-borne and waterborne illness is hampered by the lack of surveillance throughout much of the world. In areas where food-borne and waterborne illness surveillance is conducted, outbreaks of viral gastroenteritis are underreported because of the lack of availability of routine laboratory services to confirm the viral etiology. Routine use of epidemiologic criteria as an alternative to laboratory confirmation will allow better assessments of the importance of viral gastroenteritis until effective laboratory methods can be widely implemented.

Outbreaks of viral gastroenteritis have been propagated by contamination of water supplies, raw foods, and ill food handlers. Controlling an outbreak depends on identifying and removing the source of contamination. The demonstrated occurrence of person-to-person transmission and the likely occurrence of transmission of Norwalk-like viruses by aerosol make it necessary to evaluate the potential for transmission by food handlers and servers in every outbreak, regardless of primary source.

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