

Widespread Outbreak of Norovirus Gastroenteritis among Evacuees of Hurricane Katrina Residing in a Large “Megashelter” in Houston, Texas: Lessons Learned for Prevention

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Background. After Hurricane Katrina, an estimated 200,000 persons were evacuated to the Houston metropolitan area, >27,000 of whom were housed in 1 large “megashelter,” the Reliant Park Complex. We investigated an outbreak of gastroenteritis reported among the evacuees who resided in the Reliant Park Complex to assess the spread of the infectious agent, norovirus, and to implement and evaluate the effectiveness of interventions used for control.

Methods. Public health authorities conducted surveillance of gastroenteritis among evacuees treated at the Reliant Park Medical Clinic during 2–12 September 2005. Basic demographic and clinical data were recorded. Specimens of stool and vomitus were collected and tested for bacteria, parasites, and viruses. Shelter census data were used to estimate the daily incidence of disease.

Results. During a period of 11 days, >1000 patients were treated at the clinic for gastroenteritis, which accounted for 17% of all clinic visits. Norovirus was the sole enteric pathogen identified, but multiple different strains were involved. Among the evacuees residing in the Reliant Park Complex, the incidence of gastroenteritis was estimated to be 4.6 visits per 1000 persons per day, and among the evacuees who resided there for 9 days, 1 (4%) of 24 persons would have been ill. Intensive public health measures were promptly instituted but did not definitively slow the progression of the outbreak of norovirus gastroenteritis.

Conclusions. Our investigation underscores the difficulties in managing such outbreaks in crowded settings and the need for rapid, sensitive laboratory assays to detect norovirus. Additional research is needed to establish more effective measures to control and prevent this highly contagious gastrointestinal illness.

On 29 August 2005, Hurricane Katrina, a category 4 storm, made landfall on the Louisiana coast and caused catastrophic damage in many areas, resulting in many deaths and leaving thousands homeless and displaced,

particularly residents of New Orleans. Many of these residents were evacuated to a temporary shelter in the New Orleans Superdome. As conditions in New Orleans deteriorated, many individuals who weathered the storm at the Superdome and/or other New Orleans locations were quickly relocated to other cities. On 31 August 2005, buses carrying evacuees from New Orleans began arriving at the Reliant Park Complex, a multifacility sporting complex in Houston, Texas. Approximately 27,000 evacuees were housed in the Reliant Park Complex during the ensuing 3 days. Evacuees were provided clean food, water, and clothes; a cot with linens; access to lavatories and showers; and other essential toiletries.

A temporary clinic was established and rapidly ex-

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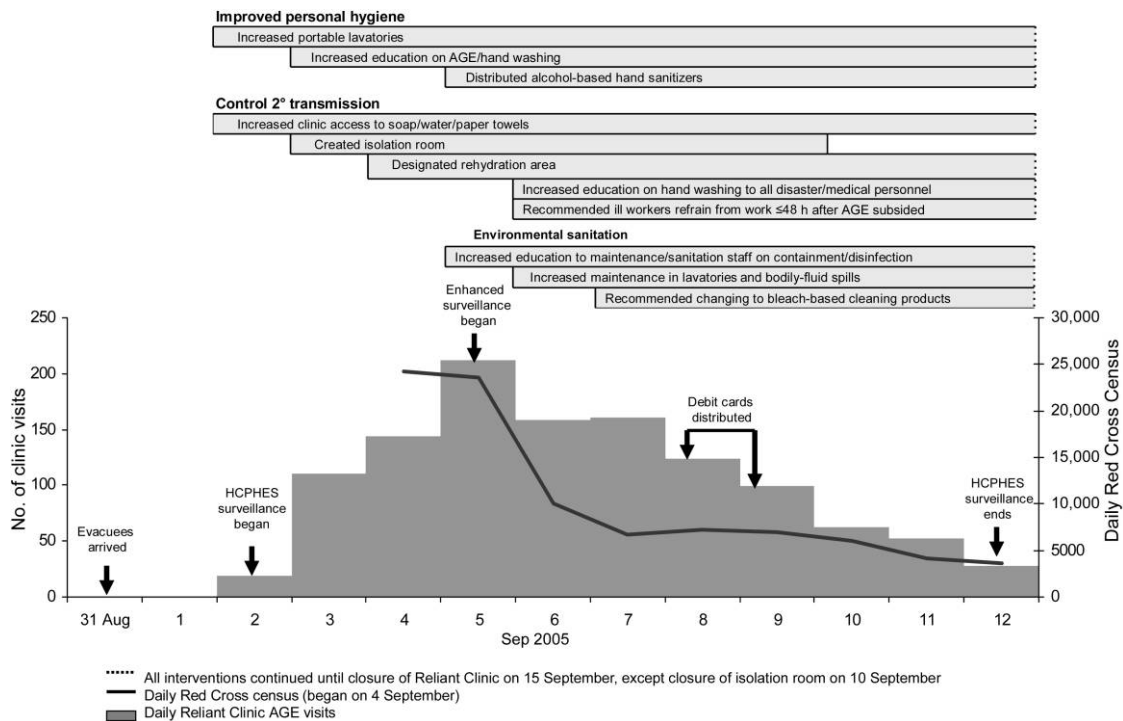


Figure 1. Timeline of interventions used, events, and epidemic curve for the outbreak of norovirus gastroenteritis at the Reliant Park Complex, with the daily Red Cross census, during 2–12 September 2005. AGE, acute gastroenteritis; HCPHES, Harris County Public Health and Environmental Services.

panded to be a comprehensive outpatient clinic, staffed mostly by local physicians from the Harris County Hospital District, Baylor College of Medicine, and Texas Children’s Hospital. The clinic was open 24 h per day until 12 September 2005 and subsequently operated with more limited hours until its closure on 15 September 2005. Many of the evacuees arrived exhausted and disheveled, and many had preexisting medical conditions that were exacerbated by lack of medication and treatment during the stressful evacuation process. Volunteers and staff at the Reliant Clinic performed triage of evacuees who were ill or needed immediate treatment; recorded a simple checklist of symptoms used to monitor common diseases, such as gastroenteritis; and noted the treatment being administered.

On 2 September, physicians and staff of the Harris County Public Health and Environmental Services (HCPHES) noted a substantial increase in the number of persons presenting at the Reliant Clinic with symptoms of acute gastroenteritis, defined as diarrhea and/or vomiting. Because of the growing number of acute gastroenteritis cases, on 5 September, the HCPHES, Texas Children’s Hospital, Centers for Disease Control and Prevention, and medical personnel at the Reliant Clinic enhanced surveillance of gastroenteritis to gather more information on cases, identify the infectious agent, seek a source of transmission, evaluate interventions already implemented, and institute additional control measures as needed.

METHODS

Syndromic surveillance was initially established by the HCPHES to monitor general disease trends using a simple checklist of symptoms, including diarrhea and vomiting. In the triage area at the Reliant Clinic, the gathered information was entered nightly into a large, centralized database by staff of the HCPHES; tabulated rapidly for a brief report each morning, which was given at the Reliant Park Complex Incident Command Center; and further disseminated to the medical staff and the Harris County Joint Information Center, a group composed of representatives from all of the disaster relief agencies and organizations to handle public information needs.

As clinic visits for gastroenteritis increased and the outbreak was recognized, a broad range of interventions were introduced to reduce spread of the illness. These included measures to: (1) improve personal hygiene (e.g., installation of additional portable bathrooms throughout the facility; education of evacuees on proper hand-washing techniques via flyers, banners, newsletters, and public announcements; and distribution of alcohol-based hand sanitizers), (2) prevent secondary transmission of virus (e.g., installation of additional rows of portable sinks at the Reliant Clinic to increase access to soap, water, and paper towels; designation of a rehydration area in the clinic for those with gastroenteritis who required intravenous fluids; creation of an isolation room for all ill evacuees with active diarrhea

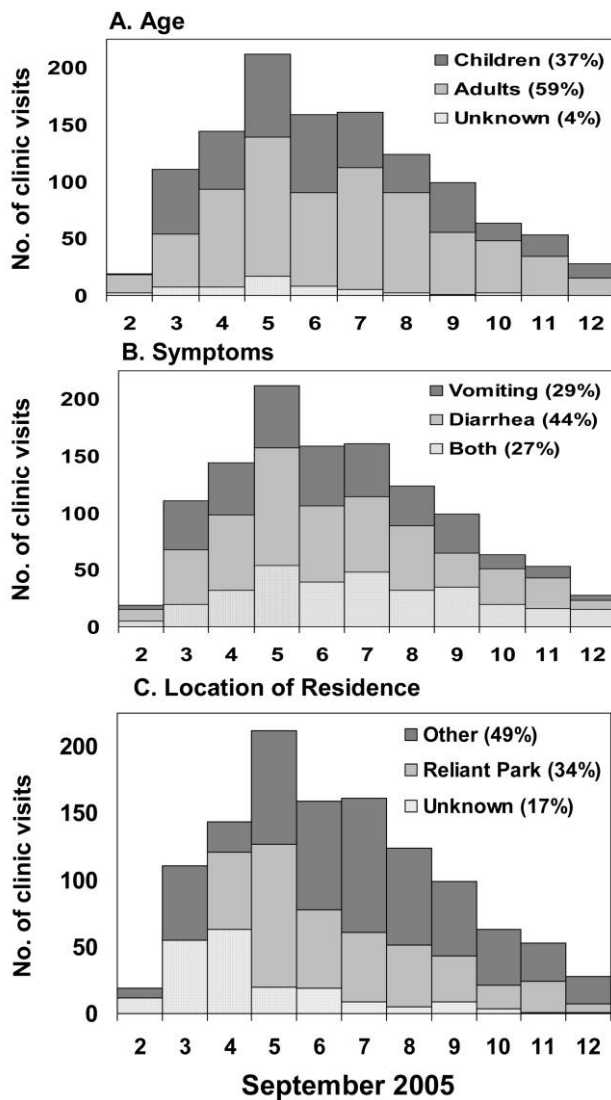


Figure 2. Daily clinic visits for acute gastroenteritis among 6985 clinic visits for all causes seen at the Reliant Park Medical Clinic, by patient age, symptoms, and location of temporary housing, during 2–12 September 2005.

and/or vomiting after stabilization; education of disaster relief staff and medical personnel on proper hand-washing techniques; and prohibition of ill staff members from returning to work until their gastrointestinal illness had resolved), and (3) implement environmental controls (e.g., increase of maintenance for lavatories and clean-up of all public spaces contaminated by ill patients, recommendation of a change to bleach-based cleaning products, and education of maintenance staff on proper handling of soiled laundry and bedding).

Completed records from the HCPHES Reliant Clinic triage database were then analyzed, using SAS software, version 9.0 (SAS Institute), to characterize and describe the magnitude of the outbreak of norovirus gastroenteritis and confirm the daily

reports. Total daily clinic visits for gastroenteritis, the epidemic curve, key events, and the interventions used were graphed.

Beginning on 4 September, stool and/or vomitus samples were collected from patients with gastroenteritis seen at the Reliant Clinic for diagnostic purposes, as well as from patients seen at the George R. Brown Convention Center, Ben Taub General Hospital, and Michael E. DeBakey Veterans Affairs Medical Center. Specimens were submitted to laboratories at the Baylor College of Medicine, Harris County Hospital District, and Texas Children's Hospital. Samples were tested for bacteria (using stool culture and real-time PCR for enterohemorrhagic *Escherichia coli*), parasites (using stool antigen immunoassays and ova and parasite microscopic examinations), and enteric viruses, including rotavirus and norovirus. Testing methods for enteric viruses included electron microscopy, stool antigen immunoassays for rotavirus, and RT-PCR for norovirus. Results were reported to the local health departments for any additional tracking.

Norovirus was detected in specimens of stool (bulk stools and rectal swabs) and/or vomitus by RT-PCR, using region B [1] and region C primers (G2SKF, G2SKR, and mon383) [2, 3]. Norovirus-specific amplicons were identified by direct sequencing of amplicons or by Southern blot hybridization analysis. The open reading frames of the norovirus genome, which encodes for 2 capsid proteins, VP1 and VP2, were cloned and sequenced for strain Hu/NoV/Katrina-17/2005/US, and the sequence was placed in GenBank (accession number, DQ438972).

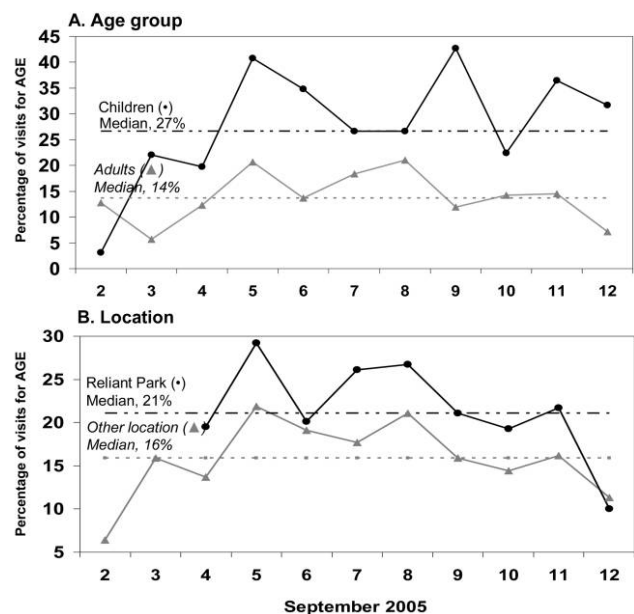


Figure 3. Proportion of all visits seen at the Reliant Park Medical Clinic for acute gastroenteritis (AGE), by age and location of temporary housing, during 2–12 September 2005.

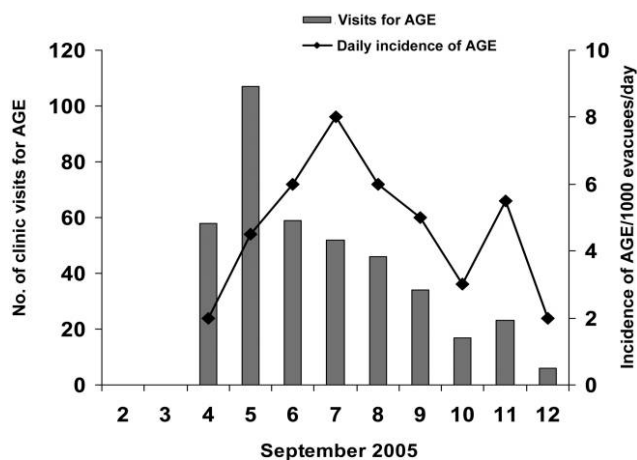


Figure 4. Daily incidence of clinic visits for acute gastroenteritis (AGE) per 1000 evacuees housed at the Reliant Park Complex during 2–12 September 2005.

RESULTS

We plotted an epidemic curve of clinic visits for gastroenteritis, along with the daily census in the Reliant Park Complex, and noted the timing of introduction of different interventions and key events affecting clinic attendance (figure 1). A total of 6985 visits were registered at the Reliant Clinic, of which 1173 (17%) were for gastroenteritis. Visits for gastroenteritis began on 2 September, peaked on 5 September, and decreased slowly until clinic surveillance ended on 12 September. The rise and fall of the epidemic curve paralleled the arrival and relocation of evacuees, which was reflected by the daily Red Cross census that began on 4 September, because many evacuees were relocated shortly after arrival. Health authorities recognized the increase in clinic visits for gastroenteritis on 2 September and implemented new control measures almost daily to stop the outbreak.

Key events that occurred in the Reliant Park Complex, such as the distribution of debit cards, drew large numbers of evacuees and corresponded with a marked decrease in clinic visits on 8 and 9 September.

We further analyzed the epidemic curve of clinic visits for gastroenteritis by patient age (adults vs. children), symptoms, and temporary residence to identify the key characteristics of this outbreak (figure 2). The norovirus outbreak affected persons of all ages, with 59% of clinic visits being by adults and 37% being by children (4% of the patient records had ages missing), a trend that continued throughout the outbreak and was consistent with norovirus being the etiologic agent (figure 2A). The distribution of symptoms did not change markedly over time, as vomiting was reported in >50% of ill persons (figure 2B). During the peak of the outbreak, most clinic visits were by residents of the Reliant Park Complex, and over time, as evacuees were relocated, more clinic visits were reported for evacuees who were seen at Reliant Clinic but were residing outside the complex than for those who were residing in the complex (figure 2C).

Because the population of the Reliant Park Complex fluctuated in parallel with the epidemic curve, we sought to determine whether the epidemic was a result of a common source or whether it merely reflected the increase and decrease of the population in residence at the Reliant Park Complex. Therefore, we used the proportion of the number of clinic visits for gastroenteritis per the total number of clinic visits as an indicator of the extent of the outbreak (figure 3). Overall, a median of 27% of the 1516 pediatric visits and 14% of the 5017 adult visits were for gastroenteritis (figure 3A). However, >40% of clinic visits by children on 5 and 9 September and >21% of clinic visits by adults on 5 and 8 September were for gastroenteritis. The outbreak affected both residents of the Reliant

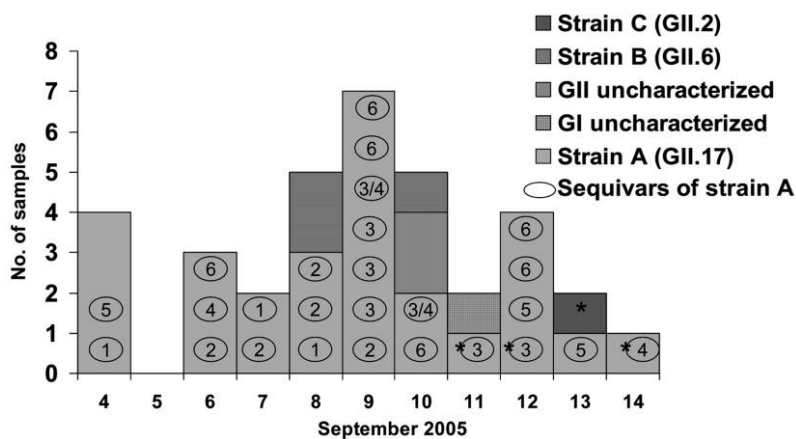


Figure 5. Distribution of norovirus strains and sequivars by date and site of collection, Houston, Texas, September 2005. All samples are from the Reliant Park Complex, except for those denoted with an *. Numbers in ovals represent each different sequivar of strain A.

Table 1. Interventions used to prevent the spread of norovirus infection on the basis of modes of transmission and the source of contamination.

Mode of transmission and source of contamination	Interventions	References
Foodborne: ill food-handlers and contaminated food source	Identify source of contamination; proper food preparation, storage, serving, and monitoring; ^a adequate number of trained staff; ^a and restriction of ill workers ^a	[4, 5]
Waterborne: ill workers/servers and improperly treated or contaminated water source, ice, or containers; bulk delivery contamination	(See "foodborne interventions"); proper treatment and storage of clean, safe water and containers; ^a and proper disinfection of water-hauling trucks	[4, 5]
Environmental		
Bathroom facilities (toilets, sinks, and showers)	Adequate number of and access to bathrooms, portable toilets, and showers; ^a adequate number of trained cleaning staff with proper PPE; ^a adequate supply of soap, hand towels or dryers, and alcohol-based hand sanitizers in each facility, especially in portable toilet areas; ^a increased frequency, proper cleaning, and disinfecting using bleach; ^a education for management and maintenance staff on proper cleaning methods; ^a increased accessibility to soap and water, especially near high-volume bathrooms, showers, and eating areas; ^a and separate facilities for ill residents ^a	[5–7]
Special areas (day care areas, medical clinic, elderly care areas, and special needs areas)	Increase vigilance to proper cleaning and disinfecting with bleach, ^a restriction of ill residents to special areas and isolation, ^a and restriction of ill volunteers and medical staff ^a	[8]
Surfaces (cots, handrails, door handles, escalator rails, tabletops, and chairs)	Proper cleaning and disinfecting using bleach, ^a cots cleaned and disinfected and dried in sunlight, ^a and reduce contact with surfaces by leaving and propping doors open	[7]
Fomites (in clothing, linens, and toys)	Proper cleaning and disinfecting using bleach ^a and proper management of laundry	[5, 7]
Droplets (i.e., vomitus or fecal matter): close proximity to vomitus and/or feces (i.e., distance between cots, infected persons, disrupted laundry, and changing diapers)	Isolation of ill patients, ^a prompt clean-up of spills with proper PPE, ^a provide OSHA body fluid spill kits, education about vigilance to hand-washing and personal hygiene, ^a separate containers for soiled laundry and diapers, ^a and proper infectious waste and solid waste management ^a	[5–7, 9]
Person-to-person: hands and soiled body parts	Proper hand washing with soap and water and use of alcohol-based hand sanitizer, ^a proper personal hygiene, ^a and mass educational campaigns on importance of proper hand-washing and hygiene ^a	[5, 6, 9]

NOTE. OSHA, Occupational Safety and Health Administration; PPE, personal protective equipment.

^a Interventions in place or used while managing this norovirus outbreak.

Park Complex, as well as those who had relocated elsewhere in Houston, with the residents of the Reliant Park Complex having a higher median proportion of visits for gastroenteritis than those residing outside of the complex (21% of visits vs. 16% of visits, respectively). We would have expected a higher percentage of clinic visits for acute gastroenteritis among residents of the Reliant Park Complex than among those who lived outside of the complex if crowding were important in continuing the spread of disease in this outbreak; however, no apparent differences were noted in the numbers of clinic visits between these groups.

We estimated the daily incidence of cases of gastroenteritis

per 1000 residents housed in the Reliant Park Complex from data on the daily number of clinic visits for gastroenteritis by residents during 2–12 September 2005 and the daily census of residents conducted by the Red Cross from September 4th until the end of surveillance. These estimates of incidence were plotted as a function of time (figure 4). The mean incidence of gastroenteritis in the Reliant Park Complex was 4.6 visits per 1000 residents per day. In other words, 1 (4%) of 24 evacuees among all evacuees residing in the Reliant Park Complex for a 9-day stay would develop gastroenteritis.

Norovirus was identified in 35 (45%) of 78 patients who submitted a stool and/or vomitus specimen, and no bacteria,

Sequivar	Strain	Sept	134	154	178	191	206	269	308	482
1	1	4	T	G	G	G	G	T	T	T
	16	7							-	-
	17	8								
2	13	6		A						
	15	7								
	66	9								
	68	8							-	-
	70	8								
3	28	9							Y	
	34	9							C	
	40	9								
	73 (GRB)	11								
	74 (GRB)	12								
3/4	41	9							-	-
	44	10							-	-
4	14	6								
	75 (GRB)	14								
5	8	4	C							
	78	12								
	81	13							-	-
6	20	6								
	43	9							-	-
	63	9							-	-
	79	12								
	80	12								
	82	10							-	-

Figure 6. Sequence polymorphisms for sequivars of strain A. The sites of polymorphisms in the nucleotide sequence obtained following amplification using primers G2SKF and G2SKR (302 nucleotides) or G2SKF and mon383 (596) are shown. Sequivars 3/4 did not have sufficient sequence available to categorize the strain into one of these sequivars. Stippled areas represent polymorphisms resulting in changes in amino acid sequence. In addition, samples from the George R. Brown Convention Center (GRB) were included.

parasites, or other enteric viruses were found. We hypothesized that, if much secondary spread had occurred in the crowded complex or if the outbreak were a result of a point source, such as contaminated food or water, a single strain of norovirus might have been implicated. However, sequence analysis of norovirus isolates identified at least 3 different strains in circulation with 1 predominant cluster type, GII.17 (strain A). The extent of strain diversity was much greater than expected, because in strain A, 26 (74%) of 35 strain sequences had small differences representing 7 different sequence variants or sequivars (figure 5). These differences within sequivars ranged from 1–6 nucleotide changes between strains over the 596 nucleotides analyzed (figure 6). Patients with different sequivars of strain A were identified throughout the entire period of the outbreak of gastroenteritis and were found in both the Reliant Park Complex and the other large evacuation shelter, the George R. Brown Convention Center.

DISCUSSION

This report documents a large outbreak of >1000 patients with gastroenteritis among evacuees of Hurricane Katrina who were sheltered in the Reliant Park Complex in Houston over an 11-day period. The outbreak affected persons of all ages and involved multiple norovirus strains, which suggests that there were multiple introductions of epidemic strains, multiple sources of infection, and a continuing epidemic with new cases

appearing daily. At its peak, >40% of all clinic visits by children and 20% of those by adults were for treatment of gastroenteritis, a problem that required a great amount of staff and time during a period of chaos and uncertainty.

Public health staff worked diligently to implement all previously recognized and documented interventions for the control of this outbreak (table 1). Despite daily concerted efforts by all public health authorities to interrupt and contain this outbreak of norovirus gastroenteritis, it continued until the clinic was closed. There was no substantial evidence to demonstrate that any one of these interventions had a direct impact to reduce the spread of disease, although the decrease in incidence rates from 8 September 2005 until the close of the clinic is suggestive that the combination of all of the interventions may have contributed to the decrease. Of note, we did notice a small peak in the incidence rate on 11 September, which may be attributed to the closure of the isolation room the previous day, but the significance of this observation remains unclear.

The molecular epidemiological characteristics and verbal reports from medical staff and police officers who had direct contact with ill evacuees and subsequently had gastroenteritis suggest that person-to-person transmission and contact with contaminated surfaces or large aerosolized vomitus droplets were the primary modes of spread. The multiplicity of strains demonstrated that the outbreak was not a result of a single

point source, but that residents in the Reliant Park Complex were infected with multiple strains, either from different sources or from a mixed source, such as sewage. In addition, the staff of the Reliant Park Complex who worked closely with private food contractors and ill evacuees did not report having eaten a common food item or drunk from a common source that may have been contaminated.

The mean incidence of gastroenteritis was 4.6 visits per 1000 residents per day, leading to a cumulative incidence rate of 4% among Reliant Park residents who stayed for the full 9 days. A number of patients were also transferred to area hospitals for additional treatment, although the exact number of those patients with gastroenteritis went unrecorded, indicating substantial morbidity among patients and heavy use of limited health care resources. No deaths were reported as a direct result of this outbreak of gastroenteritis.

Conditions in this outbreak of gastroenteritis that may have facilitated the spread of virus included crowding, close contact among evacuees with potentially soiled fomites (cots, linens, and toys), insufficient sanitation in lavatories, lack of adequate hand-washing facilities, and delays in cleaning and decontaminating soiled areas and bedding. Groups living in similar crowded conditions, such as aboard cruise ships, in nursing homes, and at military camps, are well documented to have high attack rates, with up to 50% of group members becoming ill; in the absence of a contaminated food or water source, person-to-person contact or large droplet spread are considered to be the most commonly reported modes of transmission [10–14]. However, multiple modes of transmission in an outbreak have also been reported and are fairly common, especially when the outbreak becomes widespread [15].

Several challenges and limitations were posed during this investigation. First, we had difficulty in precisely measuring the extent of the outbreak of gastroenteritis initially, because the accurate estimate of the overall evacuee population fluctuated daily, and the open setting allowed all evacuees access to the Reliant Clinic and other social services provided in the Reliant Center, which did not make tracking patients for additional investigation feasible. A baseline census was attempted by the Red Cross at 2 A.M. daily but only included those evacuees visibly sleeping in a cot. Therefore, we chose to use proportional statistics to describe the outbreak, and reports that at its peak, 40% of visits to the clinic by children and 20% of visits by adults were for acute gastroenteritis, were clearly above normal. Secondly, we were unable to quantify the impact of our control measures, because many aggressive interventions were implemented simultaneously and paralleled the census data from the Reliant Park Complex. In addition, traditional public health control measures were modified to achieve balance between the competing demands of this emergency situation. For example, the isolation area was in a different facility of the Reliant Park

Complex (Reliant Arena) than the 2 facilities that housed the most evacuees (Reliant Astrodome and Reliant Center). Thus, family members who had been traumatized by family separations during the hurricane evacuation were permitted to stay in the isolation area with other ill family members if they chose to do so.

Despite these challenges and limitations, this outbreak provides insights and lessons that can be considered in preparing for future disasters, especially in contexts where crowding can be anticipated, and suggests areas for future research in prevention. Although many infectious agents of gastroenteritis can cause the same symptoms, the public and staff need to be aware that norovirus, which is highly contagious, is a common cause of outbreaks of gastroenteritis, especially in crowded settings, and can be difficult to control [16]. Emphasis on preventing person-to-person spread may require special attention to promoting good personal hygiene. This might be achieved by educating evacuees and staff about the importance of washing their hands after using the bathroom, before and after eating, and after contact with ill persons or soiled objects and by providing easy access to hand-washing facilities in high-risk areas, such as bathrooms, eating areas, day care and diaper-changing areas, and medical facilities. Although alcohol-based hand sanitizers may be useful in situations in which water is limited or inaccessible, these sanitizers may not be most effective against human norovirus if used alone, and their effectiveness may be dependent on the alcohol type and concentration, as well as viral load [6]. Improvements in aggressive environmental sanitation by containing, cleaning with proper sanitizers, and disinfecting all soiled areas, bathroom surfaces, and bedding and linens are also essential to decrease secondary spread. Bleach-based cleaning products have been documented to inactivate noroviruses, using feline caliciviruses as a proxy, and are superior to quaternary ammonium compounds and phenols [17]. When possible, ill persons who are actively vomiting or who continue to have diarrhea should be isolated until symptoms subside. Sensitivity must be exercised to not retraumatize evacuees by separation. Disaster relief staff in direct contact with evacuees, food handlers, and child care workers who develop gastroenteritis should be asked to refrain from returning to work for at least 24–48 h after all symptoms subside [4].

The inability to fully control these outbreaks of norovirus gastroenteritis will require new laboratory research to establish the best measures to inactivate the virus on hands, fomites, and contaminated surfaces. Although such research has been hampered in the past because noroviruses cannot be grown in cell culture, a new strain of virus identified in mice, which grows well in cell culture, may permit such research on critical questions related to virus inactivation and spread [18, 19]. However, early surveillance and identification of outbreaks, with rapid detection of etiologic agents, still remains paramount

in managing outbreaks of gastroenteritis. Future disaster preparedness and response planning should anticipate outbreaks caused by norovirus among evacuees, better prepare shelters with appropriate materials to educate about disease transmission and the importance of surveillance and prevention, and provide the proper policies, procedures, and resources to ensure good personal hygiene and sanitation for all involved [20].

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