Rapid Assessment of Exposure to Chlorine Released from a Train Derailment and Resulting Health Impact

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SYNOPSIS

Objectives. After a train derailment released approximately 60 tons of chlorine from a ruptured tanker car, a multiagency team performed a rapid assessment of the health impact to determine morbidity caused by the chlorine and evaluate the effect of this mass-casualty event on health-care facilities.

Methods. A case was defined as death or illness related to chlorine exposure. Investigators gathered information on exposure, treatment received, and outcome through patient questionnaires and medical record review. An exposure severity rating was assigned to each patient based on description of exposure, distance from derailment, and duration of exposure. A case involving death or hospitalization ≥3 nights was classified as a severe medical outcome. Logistic regression was used to examine factors associated with severe medical outcomes.

Results. Nine people died, 72 were hospitalized in nine hospitals, and 525 were examined as outpatients. Fifty-one people (8%) had a severe medical outcome. Of 263 emergency department visits within 24 hours of the incident, 146 (56%) were in Augusta, Georgia; at least 95 patients arrived at facilities in privately owned vehicles. Patients with moderate-to-extreme exposure were more likely to experience a severe medical outcome (relative risk: 15.2; 95% confidence interval 4.8, 47.8) than those with a lower rating.

Conclusions. The rapid investigation revealed significant morbidity and mortality associated with an accidental release of chlorine gas. Key findings that should be addressed during facility, community, state, and regional mass-casualty planning include self-transport of symptomatic people for medical care and impact on health-care facilities over a wide geographic area.

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At approximately 2:40 a.m. on January 6, 2005, in Graniteville, South Carolina, a train carrying three tanker cars of liquid chlorine under pressure was inadvertently switched onto an industrial spur, where it crashed into a parked locomotive. The train derailed and one of the chlorine tankers was breached, releasing approximately 46 tons of chlorine immediately and an additional 14 tons over the next three days, until a patch could be applied. The incident occurred on the grounds of a textile mill where 183 people were reported to be working the night shift. The mill is located in the center of a small town with 7,009 residents.[1]

Chlorine, which is used in paper production, water treatment, and in the textile industry, is commonly transported by rail. Substantial numbers of people were exposed to chlorine as a result of derailments in Florida in 1978,[2] Montana in 1996,[3] and Texas in 2004.[4] Despite these events, information is limited regarding the physical effects, both acute and long-term, of varying levels of exposure.

Personnel from the Division of Acute Disease Epidemiology and the regional and county offices of the South Carolina Department of Health and Environmental Control (DHEC) and the Centers for Disease Control and Prevention (CDC) collaborated to design and conduct a rapid assessment of the effects of the chlorine exposure. The goals of the investigation were to determine the extent and location of exposure, morbidity caused by the chlorine, health services use related to the incident, risk factors for more severe outcomes, and people at risk for long-term sequelae. The rapid assessment was undertaken to determine the health status and needs of people exposed to the chlorine, aid in planning future interventions in the community, and evaluate the effect of this mass-casualty event on health-care facilities.

This article describes the demographic characteristics of people who sought medical care following chlorine exposure, the locations of facilities where they sought care and how they were transported, and the symptoms they experienced. It also details the exposure severity ratings assigned to those affected based on information obtained during interviews and describes the logistic regression models developed to predict longer hospital stays or death as a result of chlorine exposure.

METHODS

Case finding

A case was defined as death or illness attributed to chlorine exposure, reported January 6 through February 17, 2005, from the Graniteville area. A six-week reporting period was chosen to include people who waited to seek care because of financial or transportation reasons, who developed secondary bacterial infections, or who had worsening symptoms.

Active case finding was undertaken by gathering information from physicians and health-care facilities in the neighboring city of Aiken and the surrounding areas. A health alert was distributed through the South Carolina Health Alert Network that mandated reporting of people treated for chlorine-related symptoms. Emergency department logs listing patients treated for chlorine exposure were obtained from area hospitals, as were contact information and basic patient demographics. Local physicians reported information on patients who had been examined in their practices to an epidemiologist at the regional health department.

Interviews and medical chart reviews

Interviews were conducted with people who sought medical care after chlorine exposure, using a questionnaire developed for this health assessment. The questionnaire was designed to capture exposure information, symptoms experienced, details about decontamination and transport to medical care, psychosocial impact, preexisting cardiac or pulmonary medical conditions, and effects on pets. Face-to-face interviews were conducted on January 8 with patients who were hospitalized and able to be visited. Attempts were made to contact the remainder of the people who sought medical care to administer the questionnaire by telephone. Those who could not be reached after three attempts by telephone were mailed letters requesting they contact an answering service at a toll-free number.

A medical record abstraction form was developed based on a review of the medical literature and reports from previous chlorine exposures. Complete medical record abstractions were performed for patients who were hospitalized and those examined during multiple emergency department visits. An abbreviated review was performed on charts from patients examined only once at either of the two closest hospitals; the presenting complaint, symptoms experienced, method of transport to the hospital, and any exposure information were obtained. The county emergency medical services coordinator was interviewed to obtain information about the emergency response and decontamination.

Exposure and outcome categorization

A panel of five team members involved in administering questionnaires met to assign an exposure rating for each patient. The person who conducted the interview, if present, read the respondent's narrative

description of exposure, which had been obtained during the interview, and the other four panelists assigned an exposure rating as follows: 1 = no exposure, 2 = mild exposure, 3 = moderate exposure, 4 = high exposure, and 5 = extreme exposure. To assign the exposure ratings, the panel used information describing patient location during exposure, duration of exposure, description of exposure, and any symptoms described in the narrative; panelists were blinded to the patients' health outcomes. When multiple people, such as a household, shared a common exposure history, the severity of exposure rating was determined once and assigned to all individuals with that history. A more in-depth description of the process by which the panel assigned the exposure ratings is described in the companion report.[5] Exposure ratings of 1 and 2 were combined as the reference category during analysis; the other three categories were combined to make a dichotomized exposure category and analyzed individually in linear regression models.

The locations where patients were exposed to the chlorine were identified from the interviews and, in certain cases, medical chart reviews. Often, patients had been mobile during the incident and were exposed to chlorine in multiple locations. In these cases, the exposure point closest to the site of the incident was chosen to represent their place of exposure.

Medical care required as a result of chlorine exposure was used as the outcome measure. Eight categories of medical care specified location where care was received, with further stratification based on level of care required and severity of symptoms; deceased individuals were placed in the final category. The nine categories of medical care were dichotomized into severe and less severe medical outcome for analysis. People who died as a result of chlorine exposure or were hospitalized for ≥3 nights were classified as experiencing a severe medical outcome. Those hospitalized for 1 to 2 nights or treated as outpatients were classified as having a less severe medical outcome.

Data analysis

A Microsoft® Access®-based outbreak management system was used to manage the data. Data analysis was conducted by using SAS® 8.2 and included frequencies, means, the Chi-square (χ^2) test for general association, Mantel-Haenszel estimates of relative risk (RR), analysis of variance (ANOVA), and logistic regression.[6] Odds ratios (ORs), 95% confidence intervals (CIs), and *p*-values were calculated. The Chi-square test for trend was performed with Epi Info™ 6.04d.[7]

Maps were generated with ArcView® 9.1, illustrating the locations of exposure in relation to the site of the derailment.[8] The direction and distance within quarter-mile increments from the derailment location were measured either manually or through a script within ArcView. Hospitals providing care for those exposed to the chlorine were also mapped.

RESULTS

The assessment identified a total of 597 people who had sought medical care after chlorine exposure; 72 (12%) were hospitalized, and 525 (88%) were examined as outpatients in hospital emergency departments or at private physicians' offices. Nine deaths occurred from chlorine inhalation, including eight deaths that occurred in the area of the train derailment and one at a hospital. Patients were treated for chlorine inhalation at 10 hospitals, with nine of these facilities providing inpatient care. These counts do not indicate the true impact on hospital emergency departments: 69 (13%) of the people receiving care as outpatients were examined at hospital emergency departments more than once and 71 (99%) of those hospitalized were admitted from the emergency department.

Interviewers were able to reach 291 people (49%) who had received medical care. Of these, 11 people refused to be interviewed, and 280, or their proxies, completed the questionnaire, for a 96% participation rate.

Characteristics of people who sought medical care

Demographic characteristics of the people who sought medical care are displayed in Table 1. The mean age of patients was 36 years (range, <1 year–85 years). Sixty percent were white and 35% black. Fifty-nine percent of the patients were male.

Those working the night shift at the mill and rescue workers were primarily male (89% and 83%, respectively), whereas area residents and those exposed in vehicles were approximately equally proportioned male and female.

Seventy-eight patients (29%) reported that they had one or more diagnosed preexisting conditions (e.g., asthma, chronic obstructive pulmonary disease or emphysema, heart disease, bronchitis within the past year, or pneumonia within the past year) that could potentially have affected the patient's reaction to the chlorine. Smoking status was known for 271 of the respondents aged ≥16 years; 115 (42%) were current smokers, and 36 (13%) were former smokers. Influenza vaccination status was obtained for 201 patients during interviews; 38 (19%) reported having received an influenza vaccination during the 2004–2005 season.

Table 1. Demographic characteristics of people who received medical care for chlorine exposure, stratified by primary location or role at time of exposure

Patient category[a]	*Mean age (years)*	*Age range (years)*	*Male (percent)*	*White (percent)*	*Black (percent)*	*Hispanic (percent)*	*Other race*[b] *(percent)*	*Total (percent)*
Working at mill	37.6 ± 12.4	18–64	91 (89.2)	42 (45.2)	44 (47.3)	5 (5.4)	2 (2.2)	103 (17.0)
Resident of Graniteville, SC	36.7 ± 21.2	<1–78	56 (51.4)	57 (57.0)	36 (36.0)	3 (3.0)	4 (4.0)	110 (18.2)
Resident of contiguous town	39.8 ± 21.8	1–70	7 (30.4)	19 (95.0)	1 (5.0)	0 (0.0)	0 (0.0)	23 (3.8)
Resident of noncontiguous town	37.4 ± 17.4	10–60	8 (44.4)	8 (61.5)	4 (30.8)	0 (0.0)	1 (7.7)	19 (3.1)
Vehicle close to site	34.4 ± 17.4	1–66	21 (60.0)	32 (91.4)	2 (5.7)	0 (0.0)	1 (2.9)	36 (6.0)
Vehicle farther from site	36.0 ± 15.1	5–57	12 (57.1)	14 (70.0)	6 (30.0)	0 (0.0)	0 (0.0)	21 (3.5)
Rescue worker	39.4 ± 11.0	28–69	10 (83.3)	8 (80.0)	1 (10.0)	1 (10.0)	0 (0.0)	12 (2.0)
Other	48.6 ± 18.3	23–81	2 (28.6)	3 (42.9)	4 (57.1)	0 (0.0)	0 (0.0)	7 (1.2)
Unknown	35.1 ± 18.0	<1–85	125 (52.5)	72 (56.3)	52 (40.6)	2 (1.6)	2 (1.6)	274 (45.3)
Total	36.3 ± 17.7	<1–85	332 (58.8)	255 (59.9)	150 (35.2)	11 (2.6)	10 (2.4)	605 (100.0)[c]

[a]Patient category describes where the person was at the time of exposure. Night-shift mill workers were categorized as "Working at mill" even if they lived in Graniteville. Day-shift mill workers who lived in Graniteville were categorized as "Graniteville residents."

[b]Other race includes Native American, Pacific Islander, Indian, and multiracial or ethnic backgrounds.

[c]Although row percentages of gender and race equal 100%, the actual numbers might not equal the total of that patient category because of missing data.

Timeline of obtaining care and symptoms experienced

The nine deaths occurred on the day of the derailment, and 66 (92%) of the hospitalized patients were admitted on that same day. One hundred ninety-two (37%) of the patients treated as outpatients in hospital emergency departments and private physicians' offices sought care on the day of the incident. Figure 1 illustrates the timeline of date of death, hospitalization, or initiation of care for those treated as outpatients.

Eight people died in the area of the derailment; their cause of death was attributed to asphyxia. Lactic acidosis and acute respiratory failure from severe pulmonary edema was reported as the cause of death of the ninth person, who died at a hospital. Seven of the people who died had been located within a quarter-mile of the derailment site; the other two were located within a half mile.

The most frequently reported symptoms among the 280 people interviewed were coughing and burning eyes (Table 2). These symptoms reflect the mucosal irritation caused by chlorine. Self-reported symptoms were not sufficient to distinguish mild from severe injury. Pulmonary edema, a potentially life-threatening condition that was diagnosed radiographically among 25 (45%) of hospitalized patients, led patients to report the same symptoms as did those with respiratory tract irritation. An in-depth report about the clinical course and pathology of hospitalized patients will be published separately.

There were 12 emergency workers identified among those who sought medical care following the derailment; one worker was hospitalized for one night and the others were treated as outpatients. Ten of the emergency workers had symptoms of respiratory irritation, one presented for skin burning and a rash, and one had both respiratory and dermal symptoms.

Location where care was received, method of transport, and decontamination

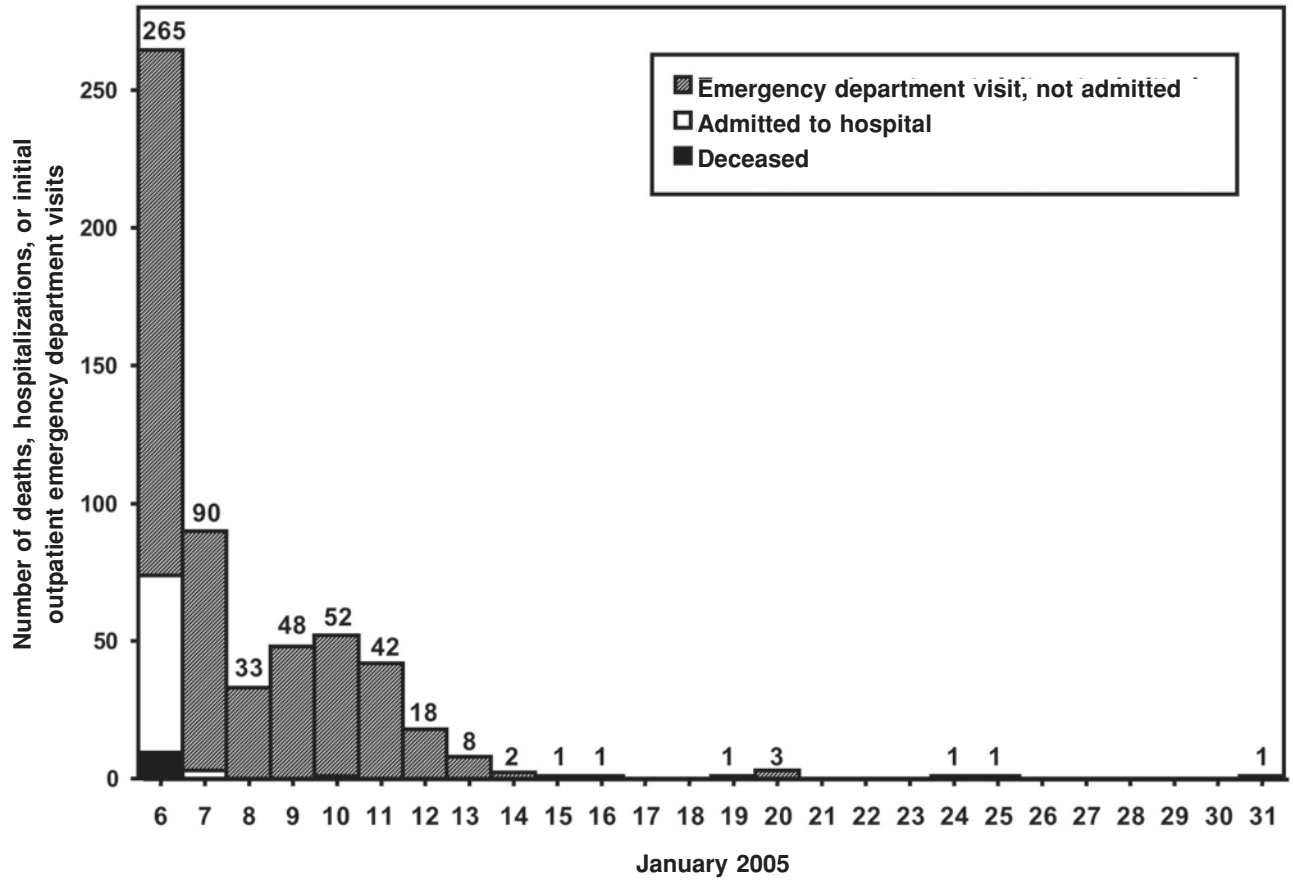
A total of 263 people were examined at emergency departments within 24 hours of the derailment, of whom 66 (25%) were hospitalized and 197 (75%) were treated as outpatients; 109 (41%) were examined at nearby Aiken Regional Medical Center, and 146 (56%) were treated at hospitals approximately 15 miles away in Augusta, Georgia (Figure 2). The majority of these

Table 2. Symptoms reported as a result of chlorine exposure

Symptoms experienced[a]	*Number (percent)*
Coughing	219 (81.1)
Burning eyes	204 (75.8)
Shortness of breath	199 (73.2)
Headache	163 (62.2)
Chest pain	156 (58.0)
Nausea	141 (53.0)
Burning nose	137 (51.5)
Coughing up phlegm	130 (49.2)
Choking	123 (46.1)
Dizziness	110 (41.2)
Vomiting	90 (33.7)

[a]Information was obtained during interviews of 280 people who sought medical care after chlorine exposure.

Figure 1. Epidemiologic curve illustrating deaths, hospitalizations, and initial outpatient visits at hospital emergency departments for treatment of chlorine exposure



patients were examined before 10 a.m. on the morning of the derailment; however, a peak occurred, primarily at the Aiken hospital, between 6 p.m. and midnight. At 4:20 p.m. the day of the derailment, shortly before this cluster of visits, an evacuation order was issued for the remaining residents within a one-mile radius of the site.

The majority of patients, including the severely ill and those who sought care immediately after the derailment, arrived at health-care facilities in privately owned vehicles. The method of transport was known for 150 (57%) of the patients treated within 24 hours of the incident; 95 (63%) were transported in privately owned vehicles, including at least 33 (22%) who had driven themselves to the hospital; 52 (35%) were transported by emergency medical services; and three (2%) were transported for medical care by the police.

Aiken County Emergency Services established three decontamination locations in the Graniteville area, which were operational at approximately 4 a.m. As people fled the chlorine, they were intercepted and decontaminated. Patients also reported being decontaminated at four hospitals, some even before the Graniteville area locations were established. These decontamination sites used wet decontamination: victims were provided with a private place to remove their clothes, were hosed with cold water, and given disposable clothing or blankets. One hundred eight (38%) of the people interviewed reported being decontaminated.

Exposure and outcome status

Exposure severity ratings were determined for 292 patients; 27 (9%) did not have identifiable exposures and were classified as having no exposure (rating 1); 120 (41%) were categorized as having mild exposures (rating 2); 67 (23%) had moderate exposures (rating 3); 36 (12%) had high exposures (rating 4); and 42 (14%) were classed as having extreme exposures (rating 5). Patients with a moderate-to-extreme chlorine exposure (exposure ratings 3–5) were more likely to experience a severe medical outcome than those

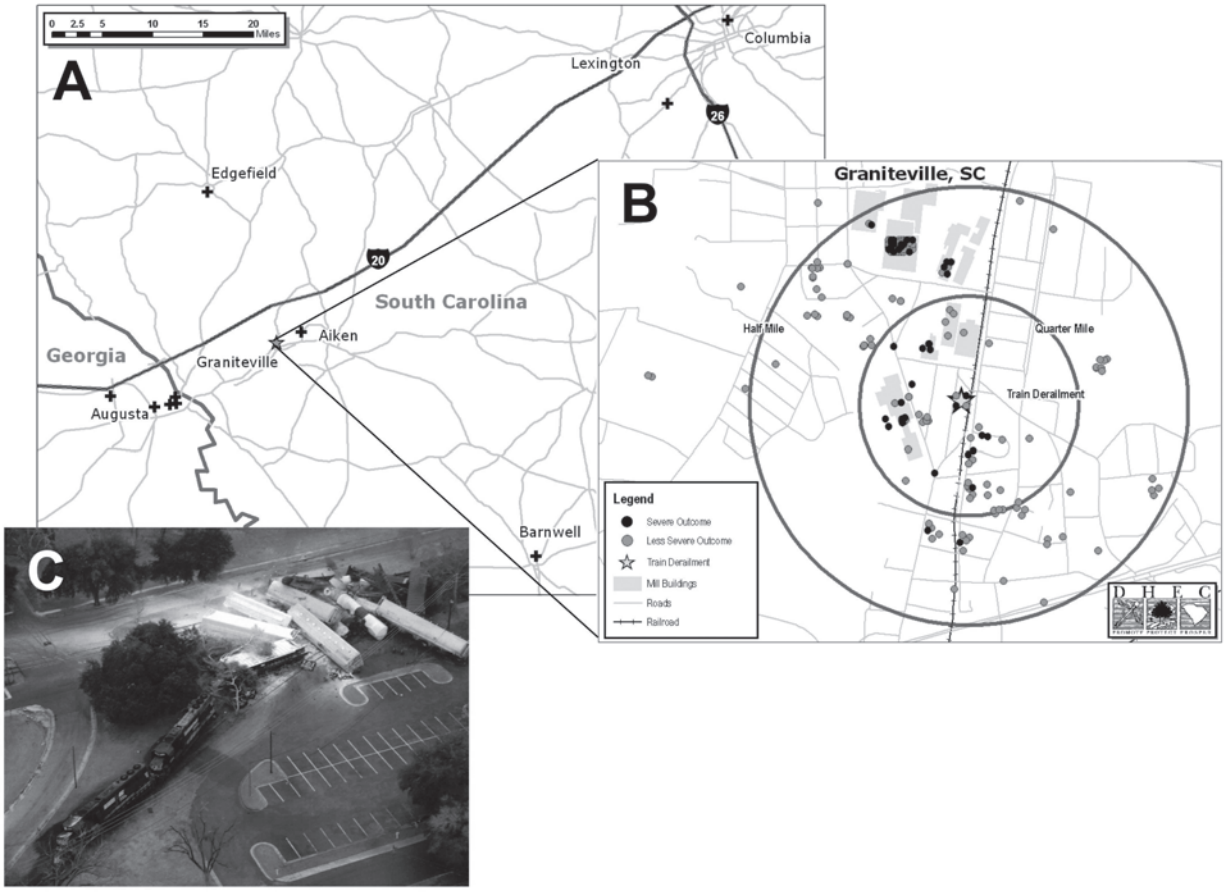
with a mild or unidentifiable chlorine exposure, with an RR of 15.2 (95% CI 4.8, 47.8). The proportion of patients reporting all symptoms except headache showed a statistically significant increasing linear trend as exposure increased above the reference category (ratings 1–2).

Sufficient information was known about 435 people who received medical care following chlorine exposure to categorize their outcome into one of nine medical outcome categories (Table 3), although all people could be assigned to the dichotomized severe and less severe medical outcome categories. Fifty-one (8%) of the 605 people identified during the assessment had a severe medical outcome, and 554 (92%) had a less severe outcome. A map indicating the locations where people were exposed to chlorine, stratified by medical outcome, is provided in Figure 2.

Model to predict severe medical outcome

We assessed individual associations among age, tobacco use among those aged ≥16 years, and preexisting medical conditions with medical outcome; none was a significant predictor of severe medical outcome. Being decontaminated was not associated with medical outcome, even with adjustment for exposure rating. The distance a person had been from the derailment site when exposed to the chlorine was a significant predictor of medical outcome; the odds of developing a severe outcome decreased by a factor of 0.14 (95% CI 0.04, 0.49) for every quarter-mile distance from the

Figure 2. Location of derailment



A. Locations of hospitals treating people for chlorine exposure. Graniteville, SC, is indicated by a star.

B. Locations where patients reported being exposed to chlorine. Black dots indicate sites of exposure for those with severe medical outcomes, and gray dots indicate sites for those with less severe medical outcomes. The site of the derailment is indicated by a star. Locations representing private residences have been randomly shifted by 100 yards to protect their privacy.

C. Photo courtesy of the South Carolina Department of Health and Environmental Control

Table 3. Medical care required for acute symptoms following chlorine exposure

Medical outcome category[a] *(n=435)*	*Number (percent)*
1. Deceased	9 (2.1)
2. Hospitalized ≥3 nights with ventilator and/or ICU support	15 (3.4)
3. Hospitalized ≥3 nights	27 (6.2)
4. Hospitalized 1–2 nights	29 (6.7)
5. ED multiple visits during acute period	69 (15.9)
6. ED with substantial respiratory symptoms	67 (15.4)
7. ED with mild symptoms	121 (27.8)
8. ED with no symptoms at presentation	61 (14.0)
9. Physician's office visit	37 (8.5)

[a]For analysis, categories 1–3 were classified as experiencing a severe medical outcome and categories 4–9 were classified as having a less severe medical outcome.

ICU = intensive care unit

ED = emergency department

site. We were unable to detect an association between the direction of the victims' location relative to the derailment site and severe medical outcome. In multivariate modeling, the exposure severity rating, which considered duration of exposure, sheltering within buildings or vehicles, and distance from the derailment site, was chosen for the exposure measure.

In multivariate modeling to predict severe medical outcome, three levels of exposure (exposure severity ratings 3, 4, and 5: moderate, high, and extreme exposures) were compared with the reference category (exposure ratings 1 and 2: no exposure and mild exposure) while controlling for age and gender. All three exposure ratings were highly significant in the model; the ORs were extreme exposure, OR 49.2 (95% CI 12.8, 190); high exposure, OR 11.7 (95% CI 2.9, 47.8); and moderate exposure, OR 8.2 (95% CI 2.2, 30.7). Increasing age in years was associated with severe medical outcome, OR 1.03 (95% CI 1.00, 1.05), $p=0.04$. The gender of the person was not significant in the multivariate model (OR for males 2.7; 95% CI 0.92, 7.8).

DISCUSSION

The symptoms caused by chlorine depend on the concentration to which a person is exposed. At high levels, chlorine displaces oxygen in the air and can lead to asphyxia, which was the reported cause of death of the eight people who died in the area of the Graniteville derailment. When chlorine gas contacts moist surfaces (e.g., those of the eyes, mucus membranes, or respiratory tract), it hydrolyzes into hypochlorous and hydrochloric acids. These acids are responsible for the detrimental effects of chlorine exposure. At high concentration or long duration of chlorine exposure, these acids can reach small airways in the lungs and cause damage.[9]

The symptoms experienced by the people of Graniteville as a result of chlorine exposure were consistent with those observed in previous community exposures.[3,9] In addition to the acute symptoms of coughing, choking, and burning eyes caused by the irritant action of the chlorine, several patients experienced a delayed onset of pulmonary edema hours after the exposure. Emergency department physicians should be aware of this possibility and use caution in sending patients with substantial chlorine exposure home after a short period of observation.

A disaster of this magnitude illustrates that, in a mass-casualty situation, people will escape however possible and present to emergency departments of their own choosing. By the time emergency responders arrive and establish a means to direct patients to facilities identified in local emergency plans, exposed people will often have already left the area and sought care. Health-care facility mass-casualty plans should consider not only the impact that patients arriving by emergency medical service transport might have, but also the potential for substantial numbers of symptomatic patients arriving in their own vehicles. In addition, vehicles brought from the area of a chemical spill might be contaminated with that chemical. Plans should be in place to identify these vehicles and perform needed decontamination or disposal.

Large-scale events of public health importance might also affect multiple states, with health-care facilities close to state borders receiving patients from neighboring states. As reported in this assessment, more than half of those who received medical care within the first 24 hours of the derailment were treated in Georgia, and more than half self-reported to those medical care facilities in privately owned vehicles.

According to our findings, chlorine from this spill did not follow a typical plume model of dispersion during the initial hours of the event. Multiple factors might have played a part in this. As the liquid chlorine was released from the ruptured tanker, it boiled into a gas that was heavier than air. This dense cloud of chlorine behaved like a liquid and flowed downhill to the mill buildings. Then the chlorine spread along the low point of the valley where a creek flowed. Large ventilation fans brought chlorine into at least two of

the mill buildings located near the creek, negating protection that being inside a building might have offered mill workers. The surface wind speed was two to four miles per hour between 3 a.m. and 6 a.m., which was believed to be sufficient to cause mixing and erosion of the chlorine along the periphery of the dense cloud.[10] However, this mixing did not prevent a high concentration of chlorine gas from settling to the low points of the valley. The combination of the geography and low wind speed led those working at the mill to experience higher concentrations of chlorine and, therefore, more severe outcomes than among the Graniteville residents, whose homes were predominantly located uphill from the mill.

During our assessment, we identified a means to quantify exposure to the chlorine. As in previous incidents, quantitative measurements of chlorine levels were not taken during the early hours of the event; therefore, no objective exposure level could be assigned. Moreover, even if measurements had been available, assigning exposures to people who were mobile or did not know how long they were exposed would have been difficult. As described in the companion report,[5] the panel-assigned exposure severity rating provides a useful tool for epidemiologists to categorize obtainable interview data for use in analysis and makes performing multivariate analysis to search for risk factors possible, while adjusting for exposure. Our exposure ratings proved to be highly predictive of medical outcome, as would be expected if correlated with true exposure.

Univariate and multivariate logistic regression were employed to search for factors that predicted severe outcome. Tobacco use and preexisting medical conditions were not predictive of severe outcome among the group who sought medical care. A limited number of patients had each of the preexisting medical conditions; therefore, this might have constrained our ability to identify an effect. Any contribution toward severe outcome that preexisting medical conditions and smoking made was probably minor, compared with the substantial effect of the concentration of chlorine inhaled and the duration of exposure.

Limitations

Limitations to this assessment are associated with identifying and locating cases and self-reporting of symptoms. We probably did not identify every person who received medical care after the chlorine exposure. Although we requested reporting of people treated for chlorine exposure through the South Carolina Health Alert Network, the majority of cases were not identified in this manner. Instead, the majority of cases were identified by a review of hospital emergency department logs from hospitals known to have treated people exposed to chlorine. Because we did not individually contact all of the private physicians' offices in the area, many probably did not report cases they had treated.

Additionally, we were only able to contact 49% of the patients. Factors that limited our ability to locate the patients were the evacuation, which was in effect for 12 days after the incident, and incomplete or inaccurate addresses and telephone numbers on the hospital records. This assessment relied on self-reports of preexisting medical conditions and symptoms experienced after chlorine exposure rather than obtaining this information from medical records. However, because symptoms might have resolved before the patient sought medical care, this might have been more accurate than symptoms recorded by the medical staff.

CONCLUSION

Rapid epidemiologic assessments after natural disasters are often used to target resources and aid. In this instance, a rapid assessment was used to determine the extent of medical care sought after a substantial mass-casualty incident, identify people in need of public health interventions (e.g., decontamination of their motor vehicles and influenza vaccinations, which were offered to patients experiencing significant respiratory compromise who had not been vaccinated that season), and evaluate situations that should be addressed in mass-casualty plans. Key findings that should be addressed among facility, community, state, and regional mass-casualty planning include self-transport of symptomatic people for medical care and impact on health-care facilities over a wide geographic area.

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