Increased Incidence of Inflicted Traumatic Brain Injury in Children After a Natural Disaster

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Background: The incidence of child abuse following natural disasters has not been studied thoroughly. However, parental stress and decreased social support have been linked to increased reports of child maltreatment. We hypothesized that a large-scale natural disaster (North Carolina’s Hurricane Floyd) would increase the incidence of inflicted traumatic brain injury (TBI) in young children.

Methods: An ecologic study design was used to compare regions affected to those regions unaffected by the disaster. Cases of inflicted TBI resulting in admission to an intensive care unit or death from September 1998 through December 2001 in North Carolina were ascertained. Poisson regression modeling was employed to calculate rate ratios of injury for each geographic area by time period.

Results: Inflicted TBI in the most affected counties increased in the 6 months post-disaster in comparison to the same region pre-disaster (rate ratio 5.1, 95% confidence interval [CI]=1.3–20.4), as did non-inflicted TBI (rate ratio 10.7, 95% CI=2.0–59.4). No corresponding increased incidence was observed in counties less affected or unaffected by the disaster. The rate of inflicted injuries returned to baseline in the severely affected counties 6 months post-hurricane; however, the rate of non-inflicted injuries appeared to remain elevated for the entire post-hurricane study period.

Conclusions: Families are vulnerable to an elevated risk of inflicted and non-inflicted child TBI following a disaster. This information may be useful in future disaster planning.

Introduction

In September 1999 Hurricane Floyd dropped 20 inches of rain in eastern North Carolina, which caused extensive flooding in some counties. An estimated 2.1 million people were affected, with 52 deaths directly attributable to the hurricane, most from drowning. Damage was estimated at $6 billion. We hypothesized that the flooding and subsequent loss of, and disruption to, lives, property, and community ties may have contributed to an increase in parental stress and depression, and thus contributed to an increase in child maltreatment.

A report examining the changes in both reporting and incidence of child abuse after three separate natural disasters—Hurricane Hugo in South Carolina, the Loma Prieta earthquake in California, and Hurricane Andrew in Louisiana—had mixed results. It found that following Hurricane Hugo, child abuse reports and confirmations were higher at 3 and 6 months compared to the previous year after adjusting for population change. The same pattern was seen for child abuse reports after the Loma Prieta earthquake, although confirmation of abuse was not possible because of inadequate data. However, this pattern was not seen after Hurricane Andrew. Curtis et al. theorized that the population may have experienced a lower stress level, given the relatively high frequency of severe weather (hurricanes and tropical storms) in Louisiana.

The potential for disasters to increase the rates of child abuse is proposed to stem from the additional stress conferred by the event, and the subsequent effects on mental health. The mental health effects of natural disasters including hurricanes, flooding, earthquakes, and volcano eruptions have been reported. Reactions to natural disasters are proposed to stem both from the stress caused directly by the disaster such as loss of life and property and disruption of the social fabric of the community. Mental health effects that have been documented include post-traumatic stress...
disorder, depression, and anxiety. 3,4,5 Three disaster experiences (injury, fear of death, and property loss) were associated with increased scores on the Traumatic Symptom Inventory designed to measure psychological sequelae of traumatic events. 5

Physical child maltreatment is the leading cause of death from injury among infants. 7 Inflicted traumatic brain injury (TBI) (commonly referred to as shaken baby syndrome) is a common form of child abuse in the first year of life, estimated at about 30 per 100,000 infants, 8,9 and approximately 17 per 100,000 child-years in the first 2 years of life. 9 Families at highest risk appear to be those with a first child, low maternal education, and minority status. 9 Severe TBI requires urgent medical treatment, which allows ascertainment even under disaster conditions. Therefore, this ecologic study examined whether there was a temporal and geographic increase in inflicted TBI in young children in relation to Hurricane Floyd in North Carolina.

Methods

Case Ascertainment

The study population consists of children aged ≤24 months who sustained a fatal TBI and/or a TBI serious enough to be admitted into any of the nine pediatric intensive care units (PICUs) or step-down units in North Carolina between the dates of September 1, 1998 through December 31, 2001. Data from the period of January 1, 2000 to December 31, 2001 were prospectively collected as part of an ongoing project about incidence of inflicted TBI in North Carolina. Data prior to January 1, 2000 were retrospectively collected via chart review at the North Carolina Office of the Chief Medical Examiner (OCME) and each hospital. This study was reviewed and approved by the Institutional Review Board at each institution.

Time Periods

The baseline time period (pre-hurricane) was from the beginning of data collection (September 1, 1998) until the date of the hurricane (September 16, 1999). The second time period included the first 6 months following the hurricane (September 16, 1999 through March 14, 2000). The third time period started on March 15, 2000 and extended through the end of the study period to December 31, 2001. These three time periods (pre-hurricane, ≤6 months post-hurricane, and >6 months post-hurricane) were selected to correspond to periods of post-traumatic stress observed in the wake of other natural disasters. 3

Hospitalized Cases

Children included had a TBI that was not caused by a missile wound, with evidence of intracranial injury on a brain computerized tomograph (CT) or magnetic resonance imaging study as read by each study center’s radiologist. Patients with skull fractures but no evidence of intracranial injury were excluded, as were children who were not North Carolina residents. Patients prospectively enrolled were ascertained by calls to the PICU charge nurse at each hospital three times weekly (from January 1, 2000 through December 31, 2001). Medical records were reviewed every 6 months at all hospitals by ICD-9-CM codes for head injury and then matched to the PICU logbooks to ensure that no child had been missed. Retrospectively enrolled patients were identified by reviewing hospital medical records at each hospital for all children aged <24 months admitted to the PICU who had (1) the ICD-9-CM code 800.0 to 800.4, 800.6 to 800.9, 801.1 to 801.9, 803.1 to 803.4, 803.6 to 803.9, 804.1 to 804.9, 850.0 to 850.9, 851.0 to 851.9, 852.0 to 852.5, 853.0 to 853.1, or 854.0 to 854.1; and (2) brain injuries from 959.8 to 959.9. After the list of potential subjects had been generated, it was checked against the logbook of that center’s PICU and step-down unit. Charts of children who met both criteria (entrance into an appropriate unit and ICD-9-CM code) were reviewed by a trained PICU nurse to ensure that a qualifying intracranial injury had occurred; the data were then abstracted by the nurse using a standardized form that included the following data: date of birth, date of injury, race/ethnicity, gender, mechanism of injury, type of head injury, county of residence, and outcome (lived or died). Each form was then reviewed by the project manager. If a question arose about whether the child qualified for the study, the results of the CT scan were reviewed by one of the authors (HTK) to ensure uniformity of entrance criteria.

Fatalities

Fatalities were identified through the North Carolina OCME, which receives reports of all deaths in the state. All charts of children aged ≤24 months from any cause were reviewed by two of the authors (HTK, MN) to identify children with head injuries meeting the same criteria listed above for hospitalizations. A standardized form was filled out for each qualifying child death. The birth dates and dates of injury were then compared with those of the hospitalized cases to ensure that no duplication occurred between fatalities and hospitalizations.

Definitions

Children were classified into inflicted versus non-inflicted injury groups. To be classified as inflicted, children must have had an intracranial injury on a radiographic or pathologic exam. This must have been accompanied by a confession documented in the medical or OCME record that the injury was inflicted, or medical and social service agency determination that the injury was inflicted.

County-Level Ascertainment of Exposure

Of the 100 North Carolina counties, 66 counties were declared federal disaster areas after the hurricane. However, not all of these counties experienced severe flooding. Therefore, the counties considered most affected or “severely affected” were defined as counties with any drowning-related deaths, and/or ≥$500,000 of state/federal money to rebuild infrastructure, and/or ≥100 home buyouts (n =16). 10 These counties accounted for approximately 12% of the births in the state. Counties not among the severely affected were considered “less-affected/unaffected.” Counties were grouped into two categories because of the large differential
in hurricane-related damage between the “severe” counties and the remainder of the state. Figure 1 shows a map of the severely affected, less-affected, and unaffected counties.

**Statistical Analysis**

Simple proportions were calculated to ascertain demographic features of the injured children. Rates of inflicted and non-inflicted injuries were calculated for “severely affected” and “less-affected/unaffected” counties by dividing the number of inflicted and non-inflicted injuries by the person-years at risk for each county and time period. The denominator for each county group was calculated by using the number of births in that county group as an estimate of the number of person-years for 1-year-olds, and the number of births per county group minus the number of infant deaths, as an estimate of the person-years at risk for children aged 1 to 2 years. Estimating population denominators in this fashion yields overall estimates similar to those produced by vital statistics agencies, but permits finer stratification by age. Person-years were then divided into time periods by dividing the total person-years by the appropriate number of weeks at risk in each time period. Adjusted rate ratios for inflicted and non-inflicted TBI were calculated using a Poisson regression analysis. Covariates included in the analysis were county risk level (severe versus not-affected/less-affected); time period (pre-hurricane, ≤6 months post-hurricane, and >6 months post-hurricane); race/ethnicity (Caucasian versus non-Caucasian); and age (≤1 year versus 1 to 2 years). The Poisson regression model provided a good fit to the data (likelihood ratio for intercept and covariates model versus intercept-only model; $\chi^2=71.30$, df=7, $p<0.01$). No over-dispersion was present (Pearson $\chi^2$/df=1.15).

**Results**

A total of 245 children were identified as having received a TBI during the entire 40-month study period. Thirty-seven (15%) injuries occurred in the 16 severely affected counties and 208 (85%) occurred in the less-affected/unaffected counties. Intentionality was similar in the two regions across all time periods with 20 (54%) of inflicted injuries in the severe counties and 108 (51.9%) of inflicted injuries in the less-affected/not-affected counties ($p=0.81$). In the severe counties, the increase in non-inflicted TBI occurred primarily in the 2 months following the hurricane, while inflicted TBI was more uniformly distributed over the 6-month post-hurricane period. Demographics were also similar between severely affected and less-affected/unaffected counties, including age (70.3% aged ≤1 year versus 76.9% aged ≤1 year, respectively; $p=0.38$) and gender (48.7% male versus 53.4% male, respectively; $p=0.60$). Race/ethnicity differed between the two county groups with 73.0% non-Caucasian children in the severely affected counties as compared to 48.6% in the less-affected/not-affected counties ($p<0.01$).

Incidence rates for each time period and county group are shown in Table 1. The rate of both inflicted and non-inflicted injuries rose dramatically in the first 6 months after Hurricane Floyd in the severely affected counties (a fivefold increase for inflicted injury and a tenfold increase for non-inflicted injury), while the incidence rates for inflicted TBI in the less-affected/unaffected counties stayed approximately the same. The rate for non-inflicted TBI increased twofold in the less-affected/unaffected counties following the hurricane. The rate of inflicted injuries returned close to baseline in the severely affected counties 6 months post-hurricane; however, the rate of non-inflicted injuries appeared to remain elevated for the entire post-hurricane study period. The rate estimates were somewhat imprecise due to small cell sizes in some strata.

The adjusted rate ratios from the Poisson analysis showed the same pattern of increase in the immediate 6 months post-hurricane for inflicted and non-inflicted
Table 1. Incidence rates per 100,000 person-years with 95% CIs of inflicted and non-inflicted traumatic brain injury in severe and less-affected/unaffected counties over three time periods in children aged ≤2 years

<table>
<thead>
<tr>
<th>Time period</th>
<th>Severely affected Rate (95% CI)</th>
<th>Less affected/ unaffected Rate (95% CI)</th>
<th>Severely affected Rate (95% CI)</th>
<th>Less affected/ unaffected Rate (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-hurricane</td>
<td>14.5 (0.3–28.6)</td>
<td>17.9 (11.8–24.0)</td>
<td>3.6 (0.0–10.7)</td>
<td>10.3 (5.7–15.0)</td>
</tr>
<tr>
<td>≤6 months post-hurricane</td>
<td>76.6 (20.0–133.4)</td>
<td>16.7 (8.2–25.2)</td>
<td>32.8 (0.0–70.0)</td>
<td>20.0 (10.8–29.3)</td>
</tr>
<tr>
<td>&gt;6 months post-hurricane</td>
<td>16.8 (5.8–27.7)</td>
<td>15.1 (11.2–18.9)</td>
<td>22.4 (9.7–35.0)</td>
<td>16.1 (12.1–20.1)</td>
</tr>
</tbody>
</table>

CI, confidence interval.

TBI compared to the pre-hurricane time period, although the estimates were again somewhat imprecise (Table 2). The rate ratios returned closer to the null (1.00) for the time period >6 months post-hurricane. The rate ratios for the less-affected/unaffected counties remained close to null throughout the three time periods.

Discussion

These data demonstrate a county-level temporal and geographic increase in the rate of inflicted TBI following a natural disaster. While the rate of inflicted injuries rose and then returned to baseline, the rate of non-inflicted injuries rose even more dramatically and remained moderately above baseline at >6 months post-flooding, possibly reflecting increased injury risk due to prolonged stress.

These study results are consistent with the results found after Hurricane Hugo and the Loma Prieta earthquake, that is, an increase in inflicted TBI extending for 6 months post-disaster. They are also consistent with a study of mental health effects performed following the Mt. Saint Helen’s eruption. In 1980, using an affected community and control community, subjects were classified into controls and high exposure and low exposure groups. Those who had experienced significant property loss or death to a family member or close relative were in the high exposure group. Others in the exposed community were considered low exposure. A dose–response curve was observed among the exposure groups with the high exposure group exhibiting the most psychiatric morbidity (generalized anxiety, major depression, and post-traumatic stress disorder) when compared to the low-exposure group and controls.11

Child maltreatment in the first year of life has been related both to parental stress, as measured by life event scores, and social support. Kotch et al.2 found significant interaction between stress and social support in a cohort of families considered at risk for child maltreatment. In this model, the effect of family stress on increased child maltreatment reports was dependent on the level of social support, with less social support predicting increased child maltreatment reports in stressed families. Other factors found to predispose families to increased risk of child abuse reports were maternal depression and poverty.2 Both of these are stressors that might be more vividly present following a natural disaster.

The increased incidence of both non-inflicted and inflicted TBI following the flooding was unexpected. Potential reasons for the increase in non-inflicted TBI include increased risk of motor vehicle crash, increased risk of injury from environmental hazards related to the disaster, reduced opportunity for parental/adult supervision, and greater environmental hazards due to displacement from established dwelling to temporary housing. Increased stress in adults and caregivers may play an important role in the etiology of both non-inflicted and inflicted TBI. This study has several advantages over the previous reports of the risk of child abuse following natural disasters. Previous methodologic difficulties surrounding the study of abusive injuries to children after a

Table 2. Adjusted rate ratios of inflicted and non-inflicted traumatic brain injury in severe and less-affected/unaffected counties over three time periods in children aged ≤2 years

<table>
<thead>
<tr>
<th>Time period</th>
<th>Severely affected Rate (95% CI)</th>
<th>Less affected/ unaffected Rate (95% CI)</th>
<th>Severely affected Rate (95% CI)</th>
<th>Less affected/ unaffected Rate (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-hurricane</td>
<td>1.0 (referent)</td>
<td>1.0 (referent)</td>
<td>1.0 (referent)</td>
<td>1.0 (referent)</td>
</tr>
<tr>
<td>≤6 months post-hurricane</td>
<td>5.1 (1.3–20.4)</td>
<td>0.9 (0.5–1.7)</td>
<td>10.7 (2.0–59.4)</td>
<td>0.9 (0.5–1.8)</td>
</tr>
<tr>
<td>&gt;6 months post-hurricane</td>
<td>1.4 (0.4–4.8)</td>
<td>0.9 (0.6–1.3)</td>
<td>2.4 (0.5–12.1)</td>
<td>0.9 (0.5–1.4)</td>
</tr>
</tbody>
</table>

Note: Rate ratios adjusted for race (Caucasian v non-Caucasian) and age (infants v children aged 1 to 2 years). CI, confidence interval.
large-scale disaster include disruption of school, social services, and communications. Therefore, it is difficult to know whether reporting of abuse is complete, and whether the threshold for response is decreased. In our study, data were collected directly from the medical records; therefore, we did not exclusively rely on Department of Social Services records, which might be expected to be in some disarray following a major disaster. In addition, the injuries being studied were severe (required admission into a PICU, were fatal, or both) so that care-seeking would not have been delayed even in the face of a large-scale disaster. Thus, while we studied only the most severe outcome of child abuse, it has the advantages of a clear case definition, the ability to capture most cases, and few cases in which caregivers would not have sought treatment for the child. Therefore, ascertainment of cases should be more complete than those in previous reports.

Limitations of this study include the fact that exposure was defined at the county level, not at the individual level. Severely affected counties were defined on the basis of deaths and property loss because these factors have been shown to be important in predicting stress post-disaster.\(^5\) Data on potential individual-level confounders or modifiers of the effect of disaster-related stress are lacking, and therefore we cannot completely eliminate the possibility of bias.\(^12,13\) For example, not everyone in a given county will have experienced the same losses, and some families may have had more financial, social, or emotional resources to deal with losses. Therefore, stressors at the county level may not adequately reflect stressors at an individual level. However, in order for the observed findings to be spurious and entirely due to bias, a putative confounder must have had an isolated effect that coincided, geographically and temporally, with the onset of the natural disaster. This seems unlikely, given the strength, consistency, and direction of our findings. It should be noted, however, that confidence intervals were wide for some estimates.

This study shows an increase in the rate ratio of both inflicted and non-inflicted injuries following a major natural disaster. While this ecologic study cannot demonstrate causality, Hurricane Floyd was likely to have produced both an increase in psychiatric symptoms, as seen after other large-scale disasters, as well as financial hardship and loss of social ties for families caught in the worst of the flooding. It is possible that these factors played a role in the increase in inflicted TBI, and possibly non-inflicted TBI, seen in eastern North Carolina. It is important to note that the increased risk of inflicted TBI extended well past the immediate disaster period. Therefore, opportunities for injury prevention interventions exist both immediately after the disaster when families are gathered in shelters or applying for assistance, and during the ensuing months. It may be that simple interventions for non-inflicted TBI in the immediate post-disaster period, such as replacing lost car seats and home safety kits, would be the most easily implemented primary preventive interventions for unintentional injuries. When initiated prenatally, programs of intensive home visitation by nurses that address both the social and physical environment have been found to be efficacious in preventing child abuse and neglect, as well as childhood injury, in disadvantaged populations.\(^14\) Future research on this model of post-disaster intervention might be worthwhile. This information can be used to inform disaster planning as well as primary care physicians who see young children frequently in the first year of life, so that vulnerable families can receive additional support both immediately after the disaster and during the recovery period.

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References