Tornado-Related Deaths and Injuries in Oklahoma due to the 3 May 1999 Tornadoes

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(Manuscript received 28 February 2001, in final form 23 October 2001)

ABSTRACT

During the evening hours of 3 May 1999, 58 tornadoes occurred in Oklahoma. One tornado reached F5 intensity and left a widespread path of death, injury, and destruction in and around the Oklahoma City metropolitan area. Other communities across the state were also affected. Data on persons who died or were injured were collected from medical examiner reports, hospital medical records, and follow-up questionnaires. In addition, community surveys were conducted in the damaged areas, and a random telephone survey of people in the Oklahoma City area was conducted. A total of 45 persons died, and 645 survivors were treated at a hospital for injuries/health conditions related to the tornadoes. Detailed analyses were conducted on the 40 deaths and 512 nonfatal injuries that resulted directly from the tornadoes. The average age of persons who died was significantly higher than that of injured survivors. Almost three-fourths (74%) of survivors were treated in an emergency department and released; 26% were hospitalized, with an average stay of 7 days. The most common kinds of injuries were soft-tissue injuries (cuts, bruises, and scrapes), fractures/dislocations, and brain injuries. The most common causes of injuries for survivors were being hit by flying/falling debris and being picked up or blown by the tornado. Probable causes of death included multiple injuries (50%), head injuries (23%), chest trauma (18%), and traumatic asphyxia (10%). The proportion of deaths among injured persons was higher in mobile homes, apartment buildings, and outdoors than in houses. The vast majority of persons received television warnings; few persons received warnings by weatherband radio. Survey data indicated that since the tornadoes there had been only a slight increase in the proportion of persons with a storm shelter on their home premises and in the proportion of persons who know the location of the nearest shelter. Effective preparedness plans should be developed in advance of situations with tornadic potential and implemented in a timely manner when warnings are issued. The accessibility and knowledge of the location of shelters also needs to be increased. Warning systems should be integrated and duplicative, and they should include traditional methods and new technology.

1. Introduction

In the United States, tornadoes are among the most violent and lethal of all natural disasters (Lillibridge 1997). From 1950 to 1999, a yearly average of 810 tornadoes accounted for approximately 89 fatalities per year (SPC 2001a). Though tornadoes occurred in every month of the year, over three-fourths (77%) of deaths occurred during March–June. During 1999 alone, 30 fatality-producing tornadoes were reported in 13 states, resulting in 95 fatalities (SPC 2001b).

The Fujita scale is used to rate the intensity of tornadoes. The Fujita scale ranks tornadoes from F0 (gale tornadoes with wind speeds of 40–72 mi h−1) to F5 (incredible tornadoes with wind speeds from 261 to 318 mi h−1) (CDC 1997a). Tornadoes of F4 and F5 intensity are capable of leveling homes, moving foundations, and debarking trees. The risk of death and injury increases with the intensity of the tornado.

Several studies have reported that persons who died in tornadoes were generally older than persons who survived (Carter et al. 1989; Eidson et al. 1990; Glass et al. 1980; Schmidlin and King 1995). However, in the 27 May 1997 tornado that struck Williamson and Travis Counties of central Texas, advanced age was not associated with death. The median age of persons killed was 22 yr and 48% were under the age of 18 yr (CDC 1997a). Numerous studies have reported higher rates of death and serious injury associated with being inside mobile homes (CDC 1997b; Eidson et al. 1990; Glass et al. 1980; Schmidlin and King 1995). Being located outdoors or in motor vehicles has often been associated with a higher risk of death or serious injury (Carter et al. 1989; Glass et al. 1980; Schmidlin and King 1995). Studies have suggested a 10-fold increased risk in death and serious injury associated with being in motor vehicles and as a result of vehicles being lifted or rolled (Glass et al. 1980; Carter et al. 1989). Deaths and serious injuries have been associated with becoming airborne and striking a
fixed object or being crushed by objects (Bohonos and Hogan 1998; Carter et al. 1989).

The majority of direct tornado deaths are immediate, occurring at the scene (Bohonos and Hogan 1998; Carter et al. 1989; CDC 1991, 1997a,b; May et al. 2000). Direct tornado deaths result from multiple injuries, head injuries, chest injuries, crush injuries, asphyxia, and heart attacks (Bohonos and Hogan 1998; CDC 1997a,b; Glass et al. 1980; May et al. 2000). Soft-tissue wounds are among the most common kind of injuries resulting from tornadoes, and, frequently, the wounds are contaminated with debris and bacteria and require irrigation and delayed closure (Bohonos and Hogan 1998; Brenner and Noji 1992). Among seriously injured persons, fractures, brain injuries, and deep wounds are common, particularly fractures and wounds of the extremities (Carter et al. 1989; Glass et al. 1980; May et al. 2000). Indirect tornado injuries and deaths occur as a result of the rescue and recovery process and the disaster aftermath. Cleanup-related electrocutions, burns, puncture wounds, strains/sprains, sunburn, and heat exposures have been documented in various reports (Bohonos and Hogan 1998; CDC 1988, 1997b).

Oklahoma has the highest concentration of severe (F4 and F5) tornadoes per square kilometer (Lillibridge 1997) in the United States. During the evening hours of 3 May 1999, 58 tornadoes swept across Oklahoma (K. James, National Weather Service, 2001, personal communication). One of the tornadoes that tracked through the Oklahoma City metropolitan area reached F5 intensity in heavily populated areas. Total damages statewide were estimated at $225 million and included 3133 completely destroyed homes (Oklahoma Office of Emergency Management 1999).

In response to the 3 May 1999 tornado disaster, the Oklahoma State Department of Health (OSDH) conducted a field study. The main objectives of the study were 1) to collect medical data on tornado injuries systematically and to determine the types and severity of injuries, the locations, and associated causes of injuries; 2) to determine the prevalence of warnings and protective actions taken by injured and uninjured persons in areas damaged by the tornadoes; and 3) to estimate the prevalence of warnings and tornado-preparedness factors among the Oklahoma City metropolitan statistical area (OCMSA) population.

2. Methods

A retrospective study design utilizing three separate assessments was used and included 1) an injury assessment to ascertain persons who died or were treated in a hospital as a result of tornado-related injuries, 2) a community survey among a nonprobabilistic sample of residents located in severely damaged residential areas, and 3) a random telephone survey to collect data from the general population in the OCMSA.

Several data collection tools were used to obtain detailed information regarding deaths, injuries, and responses to the tornado. A hospital abstraction form was developed to collect data from medical records and medical-examiner reports. In addition, two different follow-up questionnaires were used: one to collect self-reported data from injured survivors via a mail survey, and one to collect data from family members of deceased persons via telephone interviews. Another questionnaire, the community survey instrument, was used to conduct face-to-face interviews with persons in the damaged areas. Last, a telephone survey instrument was used to interview a random sample of persons in the OCMSA.

The questions included in the follow-up questionnaire of injured persons, the community survey, and the random telephone survey were similarly coded. Geographic location at the time of the tornado, type of dwelling/structure, location inside dwelling/structure, warnings received, actions taken, and injury and medical treatment status were included in all survey instruments. Knowledge of access and availability of shelters was queried in both the community survey and the random telephone survey. In addition, public opinion regarding tornado preparedness activities was queried in the random telephone survey.

a. Injury assessment

Tornado-related injuries and other health conditions were declared a reportable condition by the commissioner of health on 4 May 1999, the day after the tornadoes. Thus, all hospitals in the state and the Office of the Chief Medical Examiner were required to report tornado-related injuries and deaths to the OSDH. All hospital emergency departments and medical records departments in the state were notified of the reporting mandate. All persons who were treated in a hospital emergency department, admitted to a hospital, or who died as a direct or indirect result of the tornado were included in the study. Injuries may have occurred before, during, or after the tornado.

The medical records and medical-examiner reports of all persons were reviewed to collect data on when the injury/health condition occurred (preparing for the tornado, directly from the tornado, during escape or rescue, or during cleanup efforts), basic demographics and medical information (including the types and severity of injuries), and the specific causes of the injuries. Information was also collected regarding specific geographic locations of persons at the time of the injury.

Because information in the medical records was limited in many cases, a follow-up questionnaire was mailed to survivors to obtain information that may have been missing from the medical records. Questionnaires were mailed out 2, 3, and 4 months after the tornado occurred. Follow-up questionnaires were received from 241 survivors. The Office of the Chief Medical Examiner also interviewed by telephone family members of persons who had died. Information obtained from the
follow-up questionnaires and the telephone interviews was incorporated into the patient data files.

b. Community survey in the damaged areas

Face-to-face interviews were conducted on site in severely damaged areas in and around Oklahoma City 4–6 days following the tornadoes. Interviews were conducted in the areas of 1) the unincorporated community of Bridge Creek; 2) southwest Oklahoma City, between SW 119th and SW 134th Streets and between Pennsylvania and Western Avenues; 3) Moore, near Interstate Highway 35 and Shields Boulevard, between NW 27th and NW 12th Streets and Santa Fe Street and Pole Road; and 4) Del City, between SE 59th and SE 44th Streets and between Sooner Road and Sunnylane Boulevard. Residents who were at the site cleaning up debris were interviewed to determine whether they were present in the area when the tornado struck, their injury and medical treatment status, the kinds of warnings they received, and their knowledge on tornado shelters in their area. A total of 611 persons were interviewed. Seventy-four percent (450/611) of persons interviewed had been in the damaged areas when the tornado struck. Of those, 70% (315/450) had not been injured and 30% suffered minor or moderate injuries (five persons had been hospitalized overnight).

c. Random telephone survey

From July through October of 2000, a random telephone survey of the six-county OCMSA was conducted to estimate the proportion of the population affected and to gauge other factors related to the tornadoes, including tornado preparedness. A random sample of households was obtained through a computer-generated random-digit dialing method. Survey respondents included persons who resided in the OCMSA at the time of the tornado. Respondents were queried on their whereabouts at the time of the tornado, warnings they received, knowledge of shelter locations, injury status, and tornado preparedness activities they would support. A total of 1000 persons 18 years of age and older were interviewed, representing a 42% response rate. Thirteen percent (125/1000) of respondents had been present in an area that was damaged by the tornado. The average age of survey respondents was 47 years of age (range 18–93 yr, std dev = 18.69) and 66% were female. (According to U.S. Census Bureau estimates for 1999, there were 770 933 persons over the age of 18 in the OCMSA, and 51% of persons of all ages in the area were female.)

d. Statistical analysis

Data were entered in Microsoft, Inc., Access proprietary software and summary statistics were generated using Microsoft Access and Excel (Microsoft 1997, 2000) and Epi Info (CDC 1994). To determine factors associated with injury, statistical tests were performed for each individual factor across injury outcome categories, that is, hospitalized, treated and released in an emergency department, and died. The Pearson’s chi-square test was used to detect statistical significance for proportions, and the Fisher’s exact chi-square test was used when expected cell values were less than five (Fleiss 1981). The t statistic was used to test statistical significance between two means according to Howell (1997). Race-specific rates were calculated using 1999 U.S. Census Bureau population estimates for Oklahoma.

Statistical associations between risk factors and injury outcomes were tested in the following manner. A statistical association was found if the null hypothesis was rejected and the two proportions were found to be statistically different at p value < 0.05, that is, statistically significant.

3. Results

A total of 690 persons were killed or treated in a hospital. Forty-five (7%) persons died, including 42 from injuries and 3 from cardiac conditions. Twenty-nine persons died at the scene and 16 at a hospital. Among the 645 survivors, 33 were not injured but were treated for other medical conditions (e.g., premature labor, heart palpitations, or lost medication); 22 persons suffered inhalation injuries from noxious gas, smoke, or dust; and it could not be determined whether 13 additional persons had an injury. These 68 persons and the 3 persons who died from cardiac deaths were not included in the data analysis. A total of 577 non-fatally injured persons and 42 fatally injured persons were included in the analysis.

Almost three-fourths (71%) of persons with nonfatal injuries and 95% of persons who died from injuries were injured directly from the tornado. There were 105 persons who went to a hospital with injuries but details on whether their injuries were a direct result of the tornado were not available. It is likely, however, that these persons were directly injured by the tornado because all of them were treated in a hospital near the damaged area shortly after the tornado occurred.

a. Injuries during tornado preparation

Twenty-six survivors and one person who died were injured while preparing or attempting to protect themselves from the tornado; 78% of these injuries were related to getting into storm shelters. Nonfatal injuries most commonly occurred when persons fell down stairs going into a storm shelter or basement; when the door of a storm shelter was closed on their head, foot, or finger; and when persons fell down or ran into something as they were running to a shelter. Virtually all of the nonfatal injuries were minor (only one person was admitted to a hospital). Seventy-seven percent of survivors suffered soft-tissue injuries (cuts, scrapes, and
Table 1. Types of injuries due to the 3 May 1999 tornadoes by treatment status and outcome, in OK. The treatment status was unknown for two injured survivors. Rates for soft-tissue injury, fracture/dislocation, brain injury, foreign bodies, severe chest trauma, eye injury, and internal organ injury were significantly higher for hospitalized persons than for persons who were treated and released. Persons who died had a significantly higher rate of fracture/dislocation than hospitalized persons. Percents add up to more than 100% because many persons sustained more than one type of injury.

<table>
<thead>
<tr>
<th>Type of injury</th>
<th>No. (%)</th>
<th>Hospitalized (134)</th>
<th>Treated and released (376)</th>
<th>Died (40)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft tissue</td>
<td>129 (96)</td>
<td>287 (76)</td>
<td>39 (90)</td>
<td></td>
</tr>
<tr>
<td>Fracture/dislocation</td>
<td>80 (60)</td>
<td>37 (10)</td>
<td>31 (78)</td>
<td></td>
</tr>
<tr>
<td>Brain</td>
<td>52 (39)</td>
<td>44 (12)</td>
<td>17 (43)</td>
<td></td>
</tr>
<tr>
<td>Foreign body</td>
<td>30 (22)</td>
<td>33 (9)</td>
<td>3 (8)</td>
<td></td>
</tr>
<tr>
<td>Severe chest trauma</td>
<td>25 (19)</td>
<td>1 (&lt;1)</td>
<td>9 (23)</td>
<td></td>
</tr>
<tr>
<td>Sprain</td>
<td>21 (16)</td>
<td>63 (17)</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Eye</td>
<td>20 (15)</td>
<td>29 (8)</td>
<td>9 (23)</td>
<td></td>
</tr>
<tr>
<td>Internal organ</td>
<td>7 (5)</td>
<td>0</td>
<td>4 (10)</td>
<td></td>
</tr>
<tr>
<td>Inhalation</td>
<td>2 (1)</td>
<td>7 (2)</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

bruises), 23% had a fracture or dislocation, 23% had a sprain or strain, and 12% had a head injury. Seventy percent of persons injured while preparing for the tornado were female; 26% of persons were 35–44 years of age, and 19% were 65 years or older. A disabled person was fatally injured prior to the tornado when he was dropped while being taken down a flight of stairs in his wheelchair to a basement for protection.

b. Injuries after the tornado

Thirty-nine survivors and one person who died were injured after the tornado. Among survivors, 21 were injured during cleanup efforts and 18 were injured while they were trying to get into or out of the area or assisting others out of the area. Injuries sustained during cleanup efforts were most commonly puncture wounds from stepping on a nail or muscle strains from lifting heavy items. The most frequent nonfatal injuries were soft-tissue injuries (79%), sprains or strains (26%), and fractures or dislocations (13%). Two survivors were admitted to a hospital; all others were treated in an emergency department and released. The two that were admitted to a hospital were involved in a motor vehicle crash while driving to assess the status of relatives after the tornado. Fifty percent of persons who were injured after the tornado were female. Nearly one-half (45%) of the injuries occurred among persons 15–34 years of age, and 18% occurred among persons 65 years and older. A person who refused to leave his damaged residence lit several candles for lighting that evening. Apparently the combination of the candles and a gas leak caused a fire, and he died several days after the tornado from smoke inhalation and burns.

c. Direct injuries and deaths

All analyses that follow include only the 40 persons who died and the 512 survivors who were known (407) or likely (105) to have been directly injured from the tornado.

1) Nonfatal injuries

The average age of injured survivors was 38 yr (range 1 month to 98 yr, std dev = 21.76). Fifty-five percent of injured survivors were female. The race was known for 64% of injured survivors. Of these, Caucasians had the highest rate of injury, followed by African Americans and Native Americans (10.8, 6.9, and 1.5 per 100,000 population, respectively).

Almost three-fourths (376/512) of survivors were treated in an emergency department and released, and 134 (26%) persons were admitted to a hospital. The hospitalization status was unknown for two persons. The length of hospitalization ranged from 1 to 68 days, with an average stay of 7 days and a median stay of 4 days. Sixty percent were hospitalized 1–5 days, 23% were hospitalized 6–10 days, and 16% were hospitalized more than 10 days. Two-thirds (66%) of inpatients were discharged home, 22% went to an inpatient rehabilitation center, 7% were discharged to other postacute care (skilled nursing, nursing home, or home health care), and 4% were discharged to another or unknown place.

A total of 2292 injuries were recorded for survivors; hospitalized persons sustained an average of eight injuries per person, and persons treated and released sustained an average of three injuries per person. Hospitalized persons were significantly more likely to suffer soft-tissue injuries (χ² = 26.12, p < 0.0001), fractures or dislocations (χ² = 138.93, p < 0.0001), brain injuries (χ² = 47.50, p < 0.0001), embedded foreign bodies (χ² = 16.91, p < 0.0001), severe chest trauma (χ² = 69.06, p < 0.0001), eye injuries (χ² = 5.92, p = 0.014), and internal organ injuries (χ² = 19.92, p < 0.0001) than persons treated and released in emergency departments (Table 1).

The most common type of injury among survivors was soft-tissue injuries. Fifty percent of soft-tissue injuries were to the upper extremities (26%) and lower extremities (24%), followed by the head, neck, or face (24%); and back, chest, or abdomen (20%); for 6% of injuries the body region was not specified. Persons who
were treated and released in emergency departments had significantly more soft-tissue injuries to the upper extremities than persons who were hospitalized ($\chi^2 = 16.07, p < 0.0001$). Thirty (22%) hospitalized persons suffered one or more severe lacerations including partial amputation (1), deep or gaping wounds (18), complex wounds (9), and cut muscles, nerves, tendons, or vessels (11). The types of medical procedures performed for these injuries included surgery, deep cleaning of wounds, wound exploration, and skin grafting.

One hundred seventeen survivors suffered 169 fractured bones. The most common locations of fractured bones were the upper extremities (32%) and lower extremities (29%), followed by the chest/ribs (15%), face (12%), and back or neck (12%). Of 89 hospitalized persons who suffered bone fractures, 39% had multiple fractures (two–seven fractures per person), and 10% had severe fractures that can result in infection or internal bleeding.

Ninety-six survivors suffered brain injuries. Persons treated and released in emergency departments suffered concussions (22), mild closed head injuries (20), and unspecified head injuries (2). Of 52 persons hospitalized with brain injuries, 22 persons suffered mild brain injuries, 14 suffered moderate brain injuries, and 16 suffered severe brain injuries. Of persons with moderate to severe brain injuries, multiple types of injuries were possible. Moderate to severe brain injuries included skull fractures (15), brain contusions and hemorrhages (24), shear injuries (2) (tearing that results from shearing forces on the brain), and brain stem injuries (2). Thirty-five percent (18) of persons hospitalized with brain injuries were under 18 years of age; seven children suffered severe brain injuries.

The majority (54%) of penetrating foreign body injuries were to the upper extremities (32%) and lower extremities (22%); 23% were to the head, neck, or face; and 13% were to the chest, back, and abdomen; for 9% of injuries the site was not specified. Foreign bodies included splinters (34%); small and large pieces of wood (16%); dirt, rocks, and debris (9%); glass (7%); fiberglass insulation (4%); and other or unspecified foreign bodies (29%). Nearly one-half (46%) of foreign bodies among persons treated and released were described as splinters; hospitalized persons sustained more serious injuries from small and large pieces of wood (22%). Among hospitalized persons, 18% of foreign bodies had penetrated muscles, bones, or joints. Examples of severe injuries included an impalement of the neck and pharynx with a large 2 in. × 4 in. board fragment, a large piece of wood driven through an arm, a large shard of wood embedded in back muscles, foreign body penetration covering 50% of the body surface area, and a nail embedded in the chest wall.

Back and neck sprains accounted for 47% of sprain injuries, followed by lower extremity (27%) and upper extremity sprains (21%), and chest or abdomen sprains (4%). Forty-nine persons suffered eye injuries, including ruptured eyeball (1), laceration of the eye (5), blood in the eye (4), fractured orbital bone (2), abrasions and/or foreign bodies of the cornea (17), inflammation of the eye (2), and bruised or black eye (18). Seven hospitalized persons suffered internal organ injuries including ruptured spleen (3), liver contusion (2), ruptured bladder (1), and internal abdominal injury (1). Twenty-five hospitalized persons suffered severe chest trauma, including lung contusions (16) and/or punctured or collapsed lungs (12). Nine persons suffered inhalation of gas (4) or dust (5).

Causes of injuries (multiple injuries and multiple causes were possible) were categorized for survivors using information from medical records and follow-up questionnaires (Table 2). The most common causes of injury among hospitalized persons were unspecified flying/falling debris, being picked up and blown by the tornado, and flying/falling wood or boards. The most common causes of injury among persons treated and released were unspecified flying/falling debris and collapsing walls, ceilings, or roof materials. Additional injuries resulted from concrete and bricks, nails and

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**Table 2. Causes of injuries from the 3 May 1999 tornadoes among survivors by treatment status, in OK. The treatment status was unknown for two injured survivors. Hospitalized persons had significantly higher rates from unspecified flying/falling debris, being picked up/blown by the tornado, being hit by flying/falling wood or boards, and being hit by objects than persons who were treated and released.**

<table>
<thead>
<tr>
<th>Causes</th>
<th>Hospitalized (134)</th>
<th>Treated and released (376)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. (% )</td>
<td>No. (%)</td>
</tr>
<tr>
<td>Unspecified flying/falling debris</td>
<td>67 (50)</td>
<td>120 (32)</td>
</tr>
<tr>
<td>Picked up/blown by tornado</td>
<td>58 (43)</td>
<td>23 (6)</td>
</tr>
<tr>
<td>Flying/falling wood or boards</td>
<td>27 (20)</td>
<td>30 (8)</td>
</tr>
<tr>
<td>Hit by object(s)</td>
<td>21 (16)</td>
<td>34 (9)</td>
</tr>
<tr>
<td>Collapse of walls, ceiling, roof</td>
<td>15 (11)</td>
<td>49 (13)</td>
</tr>
<tr>
<td>Bricks/concrete/rubble/door</td>
<td>12 (9)</td>
<td>29 (8)</td>
</tr>
<tr>
<td>Glass</td>
<td>9 (7)</td>
<td>21 (6)</td>
</tr>
<tr>
<td>Motor vehicle crash</td>
<td>2 (1)</td>
<td>22 (6)</td>
</tr>
<tr>
<td>Other (noxious gas, fell/trip, nails/screws)</td>
<td>16 (12)</td>
<td>33 (9)</td>
</tr>
<tr>
<td>Unknown</td>
<td>39 (29)</td>
<td>110 (29)</td>
</tr>
</tbody>
</table>
injuries (50%), head injuries (23%), chest trauma (18%), and traumatic asphyxia (10%).

3) LOCATION OF INJURIES AND DEATHS

Injuries and deaths occurred in 13 different counties of the state; however, 90% of injuries and 88% of deaths with a known location occurred in three counties in or near the Oklahoma City metropolitan area (Cleveland, Oklahoma, and Grady Counties) in which the strongest tornadoes occurred (F4 and F5; Fig. 2). The county of injury was not known for 103 persons who survived; however, 101 of these persons went to a hospital in the Oklahoma City metropolitan area shortly after the tornado, so they were likely injured in the Oklahoma City metropolitan area.

The locations of 353 (70%) injured survivors and 40 (100%) persons who died were available. Over two-thirds (236/353) of injured survivors and about one-half of persons who died were inside a house. The proportion of deaths was significantly higher in mobile homes (Fisher’s exact \( p = 0.008 \)), apartments (Fisher’s exact \( p = 0.026 \)), and outdoors (Fisher’s exact \( p = 0.035 \)) than in houses (Table 3).

The specific locations of the 40 persons who died were examined to determine if they were in a place that is usually recommended for tornado safety in Oklahoma (i.e., in storm shelters, center hallways, closets, bathrooms and not in mobile homes or in vehicles). Specific information was available for 27 (68%) persons to make this determination. Of the 27, 19 (70%) were clearly not in a place that was recommended. Eight of these persons were in a mobile home, seven were outdoors (two under bridge overpasses and five running for cover), one was in an upstairs apartment, two were in family rooms with exterior walls and windows, and one was in a motor vehicle. Eight (30%) persons who died were in a recommended place. All eight were in a single-family home in rooms without exterior walls; five were in a closet, and three were in a bathroom. Four of the eight persons had some kind of protective covering (e.g., mattresses, pillows, clothes). In addition, two persons who were not included above were in bathrooms with exterior walls, and one person was in a closet in an apartment but it was not known on which floor.

The following fatality case illustrations provide information about how persons died. The first describes persons who died while in a recommended place; the second describes persons who had delayed warning; and the third gives information about a person who did not seek shelter as recommended.

1) Fatality case illustration: Two persons died in separate homes while huddled with their spouses in a bathroom and a closet, respectively. In both instances, vehicles were blown into their homes on top of them, in both cases one of the two persons was killed.

2) Fatality case illustration: A couple in a mobile home...
had been on the Internet before the tornado struck and reportedly had no warning of the approaching storm. When they heard the tornado, they ran toward their neighbor’s cellar, but were picked up and killed by the tornado.

3) Fatality case illustration: A person who was in a public building left to go home to take care of her four dogs during the tornado. After the tornado, she and two of the dogs were found dead in the kitchen. It was reported that a neighbor offered to let her come into a basement, but she refused so she could attempt to save her dogs.

d. Tornado warnings and preparedness

Survey data collected in the follow-up questionnaires, the community survey, and the random telephone survey revealed that television warnings were the most prevalent kind of warning received in all populations, that is, among injured survivors, persons in the damaged areas, and the OCMSA population. Sirens were the second-most prevalent kind of warning, and weatherband radios were the least common warning received (Table 4).

Respondents to the community survey reported that the following warning actually caused them to take protective action: seeing television warnings (57%), seeing the tornado (12%), hearing sirens (8%), hearing standard radio (5%), seeing weather changes suggestive of a tornado (4%), receiving pager/telephone message (4%), receiving word of mouth (1%), and other sources (8%).

Only 16% (71/450) of persons interviewed in the community survey (areas that were heavily damaged) were inside storm shelters when the tornado struck; 80% of persons interviewed (360/450) were inside houses, 2% were in motor vehicles, 2% were in public buildings or apartments, and less than 1% were outdoors or in other locations. Of the 379 persons who were not in a storm shelter at the time of the tornado, 66% of persons...
TABLE 3. Locations of persons during the 3 May 1999 tornadoes by outcome, in OK. The proportion of deaths inside mobile homes, outdoors, and in apartments was significantly higher than in houses.

<table>
<thead>
<tr>
<th>Location</th>
<th>Died (40)</th>
<th>Injured survivors (353)</th>
<th>Total (393)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houses</td>
<td>19 (7%)</td>
<td>236 (93%)</td>
<td>255</td>
</tr>
<tr>
<td>Mobile homes</td>
<td>8 (23%)</td>
<td>27 (77%)</td>
<td>35</td>
</tr>
<tr>
<td>Outdoors</td>
<td>7 (18%)</td>
<td>84 (82%)</td>
<td>81</td>
</tr>
<tr>
<td>Apartments</td>
<td>4 (29%)</td>
<td>10 (71%)</td>
<td>14</td>
</tr>
<tr>
<td>Vehicles</td>
<td>1 (4%)</td>
<td>24 (96%)</td>
<td>25</td>
</tr>
<tr>
<td>Public buildings</td>
<td>1 (5%)</td>
<td>18 (95%)</td>
<td>19</td>
</tr>
<tr>
<td>Storm shelters</td>
<td>0</td>
<td>7 (100%)</td>
<td>7</td>
</tr>
</tbody>
</table>

did not know or were not sure of where the nearest shelter was located, 26% could name a specific shelter site, 4% had a general idea of where the nearest storm shelter was located, and data were not available for 4%.

In the random telephone survey of the OCMSA, respondents were asked whether they knew the location of the nearest storm shelter at the time of the 3 May tornadoes. This question was followed by another question asking whether they knew the location of the nearest storm shelter at the time of the telephone interview (14–17 months later). Overall, 17% of persons had storm shelters on their home premises at the time of the telephone interview as compared with 14% of persons at the time of the tornado. Thirty-seven percent of respondents did not know the location of the nearest shelter at the time of the tornado, and 32% of persons did not know the location of the nearest shelter at the time of the telephone interview.

Survey respondents were asked if they would be willing to support specific tornado-preparedness activities. Almost all participants indicated support for extending warning sirens to areas in which they are not present (91%) and for designating more public storm shelters (84%). Over three-fourths (79%) of participants said they would support legislation requiring underground shelters in mobile home parks. Almost three-fourths (74%) indicated that they would support using tax dollars to build more public storm shelters and support legislation requiring storm shelters/safe rooms in construction of apartment buildings. Only two items on the survey received less than one-half of the participants’ support: using tax dollars to subsidize the construction of safe rooms in the construction of homes and businesses (49%) and using tax dollars to provide low-cost weatherband radios to homes and businesses (49%).

4. Discussion

This study documents the magnitude of fatal and non-fatal injury associated with the 3 May 1999 tornadoes in Oklahoma. A few studies have collected comprehensive data following a tornado (Glass et al. 1980), but this study is the first of its kind to collect hospital medical record, medical-examiner, and case-survey data on the number, types, causes, and locations of tornado-related deaths and serious injuries (i.e., treated in a hospital). In addition, community survey data in the damaged areas and population data in the OCMSA were collected to assess the prevalence of tornado warnings and preparedness factors.

This study underestimates the total number of persons injured in that it does not include persons treated at an emergency medical triage station immediately following the tornado, persons treated at a physician’s office, or persons who sustained minor injuries and did not seek medical treatment. In addition, data in medical records were often not complete, especially for persons who were treated in a hospital emergency department and released. Information was especially lacking at the hospitals with the greatest intake of patients. With the rapid influx of patients, medical personnel were not able to obtain and record detailed notes in the patients’ records, especially when the injuries were minor. This phenomenon is typical in mass casualty disaster situations and was also noted following the Alfred P. Murrah Federal Building bombing (Mallonee et al. 1996).

The extensive home property destruction presented a barrier to our follow-up survey. To obtain missing details, we attempted to survey all survivors by mail. This allowed us to collect more details about the causes of injuries, warnings, and actions taken. This survey method proved to be challenging because of the degree of destruction and the number of homes destroyed or left uninhabitable. Many of the survivors had relocated several times to a hotel or shelter, a relative’s home, an apartment or rental home, and/or to another permanent residence. The surveys were mailed and then forwarded by the post office if the address was no longer correct. Three attempts to mail the survey to a valid address were made, yet, we were only able to attain a 48% response rate among survivors.

Proportionally more females than males were injured.

<table>
<thead>
<tr>
<th>Source of warning</th>
<th>Follow-up survey (n = 200)</th>
<th>Community survey (n = 450)</th>
<th>Random telephone survey (n = 1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Television</td>
<td>157 (79%)</td>
<td>407 (90%)</td>
<td>804 (80%)</td>
</tr>
<tr>
<td>Siren</td>
<td>157 (79%)</td>
<td>407 (90%)</td>
<td>804 (80%)</td>
</tr>
<tr>
<td>Saw tornado</td>
<td>52 (26%)</td>
<td>128 (28%)</td>
<td>8 (1%)</td>
</tr>
<tr>
<td>Weather changes suggestive of tornado</td>
<td>47 (24%)</td>
<td>120 (27%)</td>
<td>174 (17%)</td>
</tr>
<tr>
<td>Standard radio</td>
<td>35 (18%)</td>
<td>48 (11%)</td>
<td>40 (4%)</td>
</tr>
<tr>
<td>Word of mouth</td>
<td>18 (8%)</td>
<td>74 (16%)</td>
<td>8 (0.8%)</td>
</tr>
<tr>
<td>Pager/telephone</td>
<td>13 (7%)</td>
<td>13 (3%)</td>
<td>20 (2%)</td>
</tr>
<tr>
<td>Weatherband radio</td>
<td>15 (8%)</td>
<td>3 (0.7%)</td>
<td>36 (4%)</td>
</tr>
</tbody>
</table>

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(55% and 45%, respectively). It may be that females were more likely to seek medical attention than males, or that more females than males were at home when the tornadoes hit. As is the case in any disaster or mass casualty event, the qualities of the population affected, including gender distribution, racial distribution, kinds of property, and overall demographics, are probably reflective of the existing characteristics of the geographic area.

Consistent with other reports, we found that the average age of persons who died was significantly higher than that of injured survivors (Glass et al. 1980; Eidson et al. 1990; May et al. 2000), and we found an increased proportion of deaths among persons injured in mobile homes (Glass et al. 1980; Eidson et al. 1990; May et al. 2000; CDC 1997b), apartment buildings (CDC 1990), and outdoors (Carter et al. 1989; May et al. 2000). In addition, we found that injuries caused by being picked up and blown by the tornado, by flying and falling debris, or by being hit by objects were significantly more likely to result in hospitalization (serious injury). This is consistent with other reports that death and serious injury result from being airborne or being struck by objects (Bohonos and Hogan 1998; Carter et al. 1989; Eidson et al. 1990). The data did not support previous reports of an increased risk of death in motor vehicles (Glass et al. 1980; May et al. 2000).

Although the most common type of injury was soft-tissue injuries, many severe and potentially disabling injuries occurred, including multiple fractures, severe lacerations and penetrating foreign body injuries, and brain injuries. For all of the 16 persons who suffered severe brain injuries (including seven children), serious and permanent disabilities will likely result. Of the 14 persons who suffered moderate brain injuries, approximately 10 will likely have permanent disabilities (Sorenson and Kraus 1991). Further, 22% of all inpatients were discharged to inpatient rehabilitation facilities.

The rural community of Bridge Creek (a 6 mi × 8 mi tract with a population of approximately 3000) had a disproportionate number of deaths and severe injuries. The community sustained a direct hit from the F5 tornado and suffered 12 deaths and 44 injuries as a result. Fifty-seven percent of persons who died were inside mobile homes. Bridge Creek, like other rural areas, did not have sirens and was not on the state map because it is unincorporated. It is not clear if unincorporated communities such as Bridge Creek receive adequate warnings, including geographic-specific media warnings.

It is clear that television broadcasts were very effective in reaching a majority of the population in the path of the tornadoes. However, it was reported that alerts were issued but not received by some persons because they were on the Internet or watching satellite television or movies on a videocassette recorder instead of watching network television. This result may have been exacerbated by the low prevalence of weatherband radios found in all of our assessments.

a. Prevention recommendations

Probably the most important factor in tornado injury prevention is preparedness. Every home, school, and place of business should have an effective tornado preparedness plan in advance of a tornado alert, and tornado drills should be considered. Persons living in mobile homes should have a prearranged plan to evacuate their mobile home and go to a storm shelter or other more substantial shelter when warnings are issued. Persons caught in motor vehicles or outdoors should seek some kind of shelter (e.g., a storm shelter or public building) as soon as they are aware of the impending danger. The data show that the vast majority (80%) of persons in the OCMSA received warnings through television, and, by some reports, received them an average of 30 min before the tornado struck. Fifty-seven percent of persons in the path of the tornado reportedly took action as a result of the television warnings. Several injuries and deaths in this study were sustained as a result of waiting too long to seek shelter. It is clear that a major challenge for preventing tornado deaths and injuries is to get the public to heed the warnings and to take appropriate actions in a timely manner.

This study supports recommendations to cover the skin with blankets or heavy clothing, such as coats, to protect against soft-tissue injuries (overall, 81% of survivors suffered soft-tissue injuries) (KWTV 9 2000). The number of brain injuries sustained in these tornadoes, including several severe brain injuries, warrants a recommendation to use bicycle or motorcycle helmets to protect the head. Putting shoes on prior to the tornado to protect the feet from injuries during escape is also recommended. It may be prudent to keep car keys, wallet, identification, and money in a pocket.

Because of the impact of the F4 and F5 tornadoes, there were deaths among persons seeking shelter inside single-family homes in areas that usually have been recommended for tornado safety (i.e., lowest level of the home, in an interior bathroom, hallway, or closet). Twenty-seven percent of persons who died were in a bathroom or closet in their house. Future research should assess how accurately the public perceives the actual recommended locations inside a single-family home, and how many single-family homes actually have a location that meets these recommendations. Meteorologists and public safety officials also need to determine what the best community response is for F4 and F5 tornadoes (stay at home or leave home for a shelter), especially taking into consideration how much warning time is possible.

Data from the community survey indicated that only 16% of persons in the path of the tornado were in a storm shelter. Data from the random telephone survey showed that only 3% more OCMSA residents now have
storm shelters on their home premises as compared with on 3 May 1999 (17% and 14%, respectively). In addition, we saw little change among persons in the OCMSA regarding knowledge about the location of shelters since the 3 May tornadoes (37% vs 32%). The data indicate there is a need to increase the availability and use of shelters and the knowledge of their locations, especially during an F4 or F5 tornado. Residents of the OCMSA indicated that they would support numerous community tornado-preparedness activities, including legislation and spending of tax dollars for such efforts. Only 8% of respondents indicated that no efforts were needed.

Underground shelters and safe rooms provide a protective environment from the energy of the most destructive tornadoes (WERC 2000). Both are viable options for new construction and as retrofits in private homes. One possible advantage of in-home shelters (i.e., safe rooms, basements, underground shelters with indoor access) is that persons do not have to venture outdoors during severe rain, wind, or hail to take shelter. Aboveground shelters/safe rooms may have advantages over underground shelters in that they are not likely to become flooded. Such considerations may influence how often people use shelters or how willing people are to use them.

Community shelters are another option for protection that should be considered in new or existing housing developments, mobile home parks, apartments, assisted living centers, schools, and other community settings. Public safety concerns have existed regarding community shelters in large urban areas. These concerns include traffic congestion on routes to and from the shelter that may lead to motorists being caught outdoors in the tornado, motor vehicle crashes, panic, liability, and inadequate capacity. Issues of access for disabled persons have also been raised. Because the majority of tornadoes are not F4 and F5 tornadoes, the risk of death and injury has been estimated to be less if persons take cover inside their home in recommended locations (J. Purpura, National Weather Service, 2001, personal communication). However, these public safety concerns may not be as great in rural areas, small cities and towns, or in mobile home parks. Communities should address the issues of storm shelters in their area, including whether community shelters are needed, where they should be located, and how to notify and route persons before a tornado.

Integrated and duplicative efforts are perhaps the best approach to tornado injury prevention. For example, television is clearly the most prevalent alerting system for an approaching tornado; however, one study in Arkansas after a tornado showed that hearing sirens may have had an effect on whether persons sought shelter (Balluz et al. 1997). A few persons in the current study had very delayed warning because they were using nonpublic electronic media devices such as satellite television and the Internet. These persons may have benefited from tornado sirens or from weatherband radios, which also provide an effective alert for severe weather, yet, few (2%–7%) persons reported their use. In certain circumstances, weatherband radios can fill a gap in other alerting systems, including at night while persons are sleeping, in the event of power outages, while persons are using satellite television and the Internet, and in rural areas where sirens are not available. As an anecdote, most persons interviewed in the community survey did not know what a weatherband radio was. These results support a need to increase awareness and use of these radios through media and educational campaigns and marketing promotions. Coverage areas for these radios may also need to be expanded for optimal effectiveness.

In summary, it is important that injury-prevention and disaster-research professionals understand the devastation of this event in human terms. Quantifying injuries and deaths provides information for disaster-response teams, including medical response. Examination of how injuries occur, though difficult in a tornadic event, can aid the identification of risk factors. For instance, we have no explanation for why so few people were injured or killed in motor vehicles, which in past events have been associated with high risk. We also need to examine how and where persons were killed or injured and determine whether they were following recommended precautions. Public health officials should gather this kind of data and provide it to weather researchers and forecasters who have the burden of establishing policy regarding safety recommendations for the public. The data can be used to assess current tornado safety recommendations; to improve preparedness, warning systems, and medical response; and to prevent deaths and injuries.

Acknowledgments. This study was supported in part by funding from the Federal Emergency Management Agency and the Centers for Disease Control and Prevention. The contents of this paper are solely the responsibility of the authors and do not necessarily represent the official views of these agencies. The authors acknowledge Jerry R. Nida, former Commissioner of the Oklahoma State Department of Health, for mandating tornado-injuries-reportable conditions. We also acknowledge Robert Vincent, Deputy Commissioner of Health Promotion and Policy Analysis; Randolph Daley; Tim Davis; Dennis Christianson; Julie Gilchrist; Dahna Batts-Osborne; Karen Lee; and Christian Hanson for technical support. The authors give special acknowledgment to Sharon Asher, Fred Jordon, Ray Blakeney, and the staff of the Office of the Chief Medical Examiner for conducting family interviews and providing reports. In addition, we thank all of the hospitals for their assistance. We acknowledge Jami Canada, Leonard (Sam) Samuel III, Tori Johnson, Kali Farmer, John Bos, Ruth Azeredo, Patricia Hays-Moore, Nita Clark, Patricia Petersen, Jan White, Sandy Van Patten, Diana Lambert, Shelli Stephens Stidham, and John Pagonis for con-
ducting community surveys and chart reviews, mailing surveys, completing data entry, and assisting in the data analysis and for technical consultations. We also thank the OSDH and University of Oklahoma Health Sciences Center volunteers for conducting community surveys. We thank Nancy Kinman for all of her assistance, including preparing the manuscript and graphics.

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