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Injuries from the Wichita Falls Tornado: Implications for Prevention

Roger I. Glass, Robert B. Craven, Dennis J. Bregman
Barbara J. Stoll, Neil Horowitz, Peter Kerndt, Joe Winkle

Tornadoes rank among the top natural disaster killers in the United States (*1*). During the past 50 years, more than 9000 people have died from tornado-related injuries and another 9500 have died in severe windstorms. Improved severe storm forecasting with radar and satellites, tornado warning systems, mass public awareness programs, and improved house construction may have helped decrease this toll of tornado deaths over the years (*2*). Nonetheless, in areas such as Wichita Falls, tornadoes devastate approximately one out of every 2500 square miles of land per year and periodically strike populated communities. New approaches to preventing these tornado-related deaths and injuries are needed (*3*).

Current guidelines for public safety in severe storms are prepared by the National Oceanic and Atmospheric Administration's (NOAA) disaster preparedness staff (*4*). Observations and anecdotal information collected by architects, engineers, and meteorologists after major disasters are translated into safety recommendations (*5*). Currently, people at home are advised to seek shelter in a basement, hallway, closet, or interior room, and to cover themselves with pillows, blankets, or mattresses; people in cars in open areas are advised to drive in a direction perpendicular to the path of the tornado, but if this is not possible, to leave the vehicle and lie flat in the nearest ditch or ravine. People in cars in urban areas are advised to seek shelter indoors. Despite widespread dissemination of these recommendations, their effectiveness in reducing the toll of deaths and injuries has never been tested.

The tornado that struck Wichita Falls, Texas, at 6:15 p.m. on 10 April 1979 provided an opportunity to apply epidemiologic methods to examine the causes of death in these severe storms and to assess the effectiveness of current safety recommendations. The Wichita Falls tornado was ranked at four on the Fujita scale of tornado strength, placing it among the severest 3 percent of all tornadoes in the United States (*6*). The tornado, which had wind speeds estimated to be in excess of 200 miles per hour, devastated an 11-square-mile area (Fig. 1) of residential community and caused damage in excess of $300 million (*7*). Forty-seven people died and hundreds were injured and required emergency care. More than 3000 of the approximately 4800 homes in this area were either completely destroyed or rendered uninhabitable and in need of major repair.

R. I. Glass, R. B. Craven, and D. J. Bregman are with the Bureau of Epidemiology at the Center for Disease Control, Atlanta, Georgia 30333. B. J. Stoll is with the Department of Pediatrics, Emory University School of Medicine, Atlanta, Georgia. N. Horowitz is an instructor at the School of Health Care Sciences, Sheppard Air Force Base, Texas. P. Kerndt was an elective student at the Center for Disease Control, and J. Winkle was the Federal Coordinating Officer, Federal Disaster Assistance Administration, assigned to Wichita Falls.

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Summary. We examined the circumstances of death and injury among victims of the tornado that struck Wichita Falls, Texas, on 10 April 1979. We also assessed the protective measures taken by a representative sample of community residents who suffered no major injury in order to estimate the relative risk of injury to people directly in the tornado's path. Twenty-six (60 percent) of the 43 traumatic deaths and 30 (51 percent) of the 59 serious injuries occurred in people who, despite ample warning, went to their cars to drive out of the storm's path. These people had a risk of serious or fatal injury of 23 per 1000. People who remained indoors and in stationary homes were at relatively low risk (3 per 1000) if they took simple precautions; people in mobile homes were at greatest risk (85 per 1000). Current safety recommendations and housing codes for single family homes and mobile homes need to be amended to decrease the impact of future tornadoes on human health.

Methods

In the 2 weeks following the tornado, we interviewed families of the deceased Wichita Falls residents and persons who were seriously injured and conducted a random survey of the community. The survey queried where people were when the tornado touched down, how prepared they were, what measures they took to protect themselves, and how well different types of building construction withstood the tornado.

A registry of disaster victims was set up to record information concerning the circumstances surrounding each death and serious injury and the specific causes of death or injury (Survey of the Seriously and Fatally Injured). An initial list of tornado-related deaths was provided by the American Red Cross–Disaster Relief Agency (ARC-DRA). Hospital records and death certificates were added to the registry as they became available and were used to establish the medical cause of death and the patient's correct age. No postmortem examinations were performed, and all death certificates from the first 48 hours were completed by funeral directors and a pathologist without specific types of trauma or sites of injury being recorded. The alleged circumstances of death were gathered from newspaper accounts and from conversations with funeral directors, relief workers, and friends. A physician checked the information for accuracy by telephone interviews with the family of the deceased.

An injury to a surviving patient was defined as serious if the patient remained in the hospital for more than 1 week. Hospitalized patients were interviewed by a doctor or nurse to obtain specific diagnostic information as well as details of the circumstances leading to their injury.

The Wichita Falls Planning Office plotted the path of the tornado through the city from aerial photos (Fig. 1). From plat maps of the tornado zone, which identify every family homesite, we selected 239 homesites (5 percent) to survey using the attribute sampling method of Serfling and Sherman (*8*).

On Saturday, 21 April 1979, the homesites were visited by 20 two-person teams made up of volunteers from the School of Health Care Sciences at Sheppard Air Force Base, Midwestern University, and the American Red Cross. So that we would find the greatest number of people home on the day of the survey, the date chosen was the last Saturday that people could salvage articles from their homesites before workmen were to clear remaining debris.

The following information was collected in the survey. Census data—the age and sex of everyone normally living in the house and their exact location and the location of any visitors when the tornado struck (for example, at home, in a car in the tornado zone). Preparedness information—were the occupants adequately warned about the tornado? What shelter or protection did they seek? House construction information—main building materials (wood, brick, or mixed wood and brick). What was the extent of the damage to the house?

The informants were also asked if any of their immediate neighbors had been taken to the hospital for treatment. Data on the type of construction and the degree of destruction were recorded for homes where a neighbor had been injured. These data, together with the same housing data from injured people in the random survey, were grouped and contrasted to similar data from the full population of the random survey to iden-

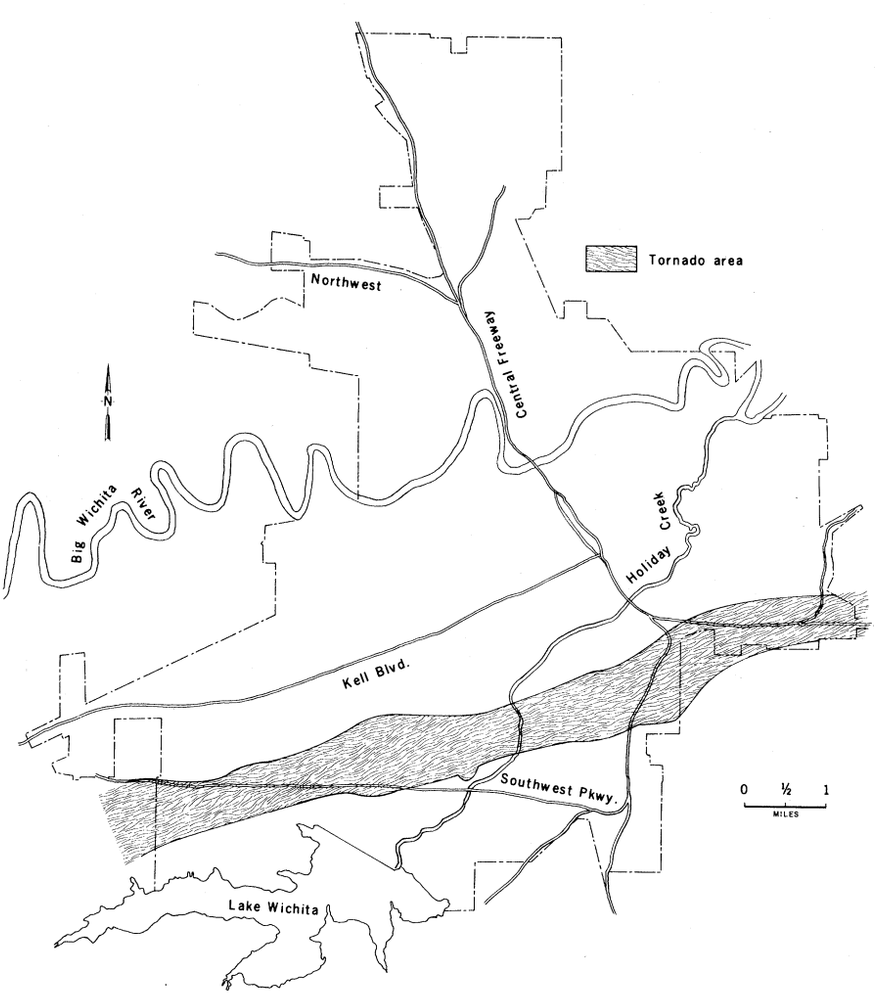

Fig. 1. Tornado area, Wichita Falls, 10 April 1979.

tify any house-construction materials that were likely to be associated with injury.

Mobile homes are at high risk of damage in a tornado, and the number of mobile homes in the tornado zone was small (89). We therefore attempted to interview as many of these mobile-home owners as we could. All apartment complexes in the area had been condemned because of tornado-related damage by the time of the survey, and we were unable to gather adequate information about their 3510 occupants. To approximate the number of apartment dwellers at various locations in the tornado zone, we made the simplifying assumption that their responses would have been the same as the responses of residents of single-family homes.

Results

Forty-seven people in Wichita Falls died as a result of the tornado—43 within minutes of the tornado's touchdown from "multiple trauma," two others (one from trauma, one from a heart attack) within 24 hours, and three (one each from sepsis, tetanus, and the gunshot wound of a suspected looter) in the subsequent month.

Fifty-nine people were seriously injured. The primary diagnoses noted in the hospital records of these patients included trauma to the head (8), extremities (21), and thorax (11), severe lacerations and abrasions (8), and other diagnoses (11) (Table 1). Lacerations and abrasions (42) and extremity fractures (30) were the most commonly noted injuries. Physicians commented that most patients who received major abrasions and lacerations had not covered themselves with blankets, pillows, or mattresses, but we did not collect data to substantiate this clinical impression. We were also unable to determine the number of injuries due to projectiles rather than to the collapse of a structure. No deaths or serious injuries were attributed to lightning or hailstones accompanying the storm.

Initial review of the circumstances surrounding serious and fatal injuries indicated that 26 (60 percent) of the 43 traumatic deaths and 30 (51 percent) of the 59 serious injuries occurred among people who were in motor vehicles when the tornado struck (Table 2); only five deaths occurred among people who stayed indoors. Of the 56 individuals injured in their vehicles, 43 (77 percent) had entered their vehicles expressly to outrun the tornado. The homes left by 20 of these victims, including eight of those who died, suffered little or no damage according to the Red Cross housing survey (Table 3).

The relatively small number of injuries among people in homes compared to those in vehicles could be explained if, during the long warning period, many people had left home to escape in their cars. To address this possibility and to examine the adequacy of the warning provided by the weather service as well as protective measures taken by people living in the community, we conducted a random survey of the population.

Table 1. Diagnosis of 59 patients seriously injured in the Wichita Falls tornado, 10 April 1979.

Diagnosis	Primary (N = 59)	Primary or secondary (N = 110)
Fractures		
Extremities		
Upper	9	14
Lower	12	16
Vertebrae	5	6
Pelvis	2	3
Other sites	1	2
Rib fractures with pulmonary complications	11	12
Head trauma		
Skull fracture	3	3
Intracranial bleeding	2	2
Concussion	3	3
Laceration or abrasion	8	42
Heart attack	3	3

Table 2. Location of persons seriously or fatally injured in the Wichita Falls tornado, 10 April 1979.

Location	Injuries		
	Fatal	Serious	Total
At home	12	23	35
Indoors	5	19	24
Outdoors	7	4	11
In vehicles	26	30	56
In public buildings	5	6	11
Indoors	4	3	7
Outdoors	1	3	4
Total	43	59	102

*An injury resulting in hospitalization for more than 1 week.

Table 3. Extent of home damage for people who suffered serious or fatal injury while escaping from their home in a vehicle. The extent of damage was graded according to the Red Cross classification (0 = none; 1 = minor; 2 = major-reparable; 3 = major-irreparable).

Extent of home damage	Injury sustained while escaping from home in vehicle		
	Serious	Fatal	Total
None or minor (0, 1)	12	8	20
Major (2)	2	3	5
Irreparable (3)	12	6	18
Total	26	17	43

Despite the devastation, streets had been cleared and names and addresses of occupants were prominently labeled on signs for insurance assessors and cleanup crews. At 75 percent of the index homesites, a family member was found and interviewed. At 25 percent of the homesites, the nearest available neighbor was able to provide the needed information about the absent index family.

The estimated total population of the tornado zone was 18,043; this number included 14,254 people living in single-family dwellings, 279 in mobile homes, and 3,510 in apartment complexes. The survey responses of 729 residents of 239 single-family homes allowed us to estimate the total number in a specific location when the tornado struck: 9705 were at home, 1768 were in vehicles, 1158 were in buildings in the tornado zone, and 1623 were outside of the tornado zone (Table 4). Residents of 14 mobile homes were interviewed and their responses, though they represent a sample with an unknown bias, were used to make crude population estimates of the number of mobile-home residents who were at home when the tornado struck. Fifteen people were injured who were not residents of the tornado zone (for example, a truck driver passing through Wichita Falls); they were excluded from our calculations because we had no way to determine the total number of this nonresident group at risk.

The rate of injury was calculated by using as a numerator the number of people injured obtained from the Survey of the Seriously and Fatally Injured (minus the 15 nonresidents) and as the denominator, the resident population estimated from the random survey to be in the community when the tornado struck. Injury rates increased with age: people over 60 were injured seven times more frequently than individuals under 20 (Fig. 2). Above age 40, women were at greater risk of injury then men; above age 60, this difference was nearly twofold and was statistically significant ($P < .01$). Apartments and single-family homes were the safest places to be when the tornado struck, and the risk of being killed in either location was only one per

Table 4. Risk of serious or fatal injury from the Wichita Falls tornado of 10 April 1979 by location when the tornado struck.

Location	Injured		Estimated number of people in location when tornado struck (± 1.96 S.D.)	Risk per 1000 of injury (95 percent confidence interval)*		
	Serious	Fatal		Serious	Fatal	Total
Single family homes	22	9	9,705 ± 426	2.3 (2.2 to 2.4)	0.9 (0.8 to 1.0)	3.2 (3.1 to 3.3)
Vehicles†	21	20	1,768 ± 351	11.9 (9.9 to 14.8)	11.3 (9.4 to 14.1)	23.2 (19.3 to 28.9)
Public buildings†	4	3	1,158 ± 292	3.5 (2.8 to 4.6)	2.6 (2.1 to 3.5)	6.1 (4.8 to 8.1)
Mobile homes	4	0	47‡	85.1	0	85.1
Apartments	1	3	3,111§	0.3	1.0	1.3
	52	35	15,789	3.8	2.7	6.5

*The 95 percent confidence interval is based on the variance of the estimated population. †Sixteen injured persons (eight serious, eight fatal) who were not residents of the affected area were excluded from the calculation of risk since we had no way of estimating the denominator population of nonresidents. ‡Estimated from nonrandom survey of 14 residents. §Estimated to be the same as single-family home residents.

thousand (Table 4). Other public buildings (for example, restaurants, churches, shops) were less safe. People in motor vehicles had a tenfold greater risk of severe injury than people at home. If the 1768 people in their cars had sought shelter in single-family homes, we can estimate that they would have suffered roughly 80 percent fewer serious injuries (4 as opposed to 21) and 90 percent fewer fatal injuries (2 as opposed to 20). Mobile-home residents who remained at home probably fared worst of all (85 injuries per thousand) although this calculation is based on a small nonrandom sample of 14 of the 89 households.

Ninety-six percent of all people surveyed felt that they had been adequately warned that the tornado was approaching: sirens had been sounded twice beginning 1 hour before the tornado struck and all local radio and news stations were reporting the National Weather Service's advisories. Fifty-three percent of people who were in a single-family home took shelter in an interior closet, bathroom, or hallway; 24 percent took shelter in a basement or storm cellar.

Twenty residents or neighbors who suffered some injury requiring hospital or emergency-room care (that is, not necessarily death or serious injury) were identified during the community survey. The houses of these 20 individuals differed significantly from those in the random sample: they were most likely to be made of wood than of brick ($P < .002$) (Table 5). Data from all 226 houses confirmed that brick houses were safer: only 33 (35 percent) of 94 all-brick houses but 63 (50 percent) of 127 frame houses (with or without brick veneer) suffered major irreparable damage ($P < .05$).

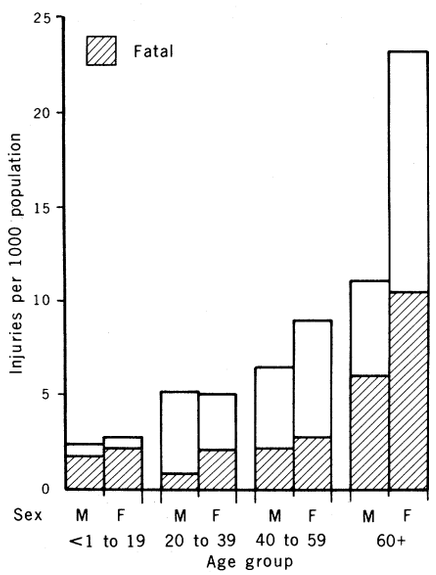

Fig. 2. Rates of severe tornado-related injuries by age and sex, Wichita Falls, 10 April 1979.

Discussion

Considering the magnitude of the destruction, it is remarkable that the tornado caused so few deaths in Wichita Falls. The relatively low mortality must be explained in part by the length of the warning period and by the awareness of safety recommendations by the residents of the area. Current recommendations that people at home should seek shelter in an interior location proved to be sound: even in a direct tornado hit, the chance of a person at home suffering a fatal injury was only about one per thousand. If one lives in a brick house or has a storm cellar or basement, the risk of injury may be reduced even further.

The results of this investigation indicate that if the people who were in their cars when the tornado struck had stayed home or had abandoned their cars for more secure shelter, their risk of sustaining injury would have been greatly reduced. People may have taken to their cars in part because of the recommendation urging people in cars *on the open road* to drive at right angle to the path of an oncoming tornado. They were unfamiliar with the newer and less publicized NOAA recommendation urging drivers in urban areas to seek shelter indoors. Once in their cars, the drivers were unable either to determine the direction and speed of the tornado or to avoid traffic congestion at major intersections in the city. Since 96 percent of people claimed they had adequate warning, the problem was one of proper education and response.

Mobile homes fare poorly in severe straight-line windstorms and tornadoes. Proper tiedowns that anchor the trailer are effective when wind speeds do not exceed 50 miles per hour, but cannot protect a mobile home in greater winds or from a direct tornado hit. The high rate of injury we observed, despite the small number of cases and the nonrandom sample, is consistent with previous observations and research (*9*).

We were unable to establish the exact cause of death for any of the deceased victims. Forensic pathologists are not currently assigned to perform postmortem examinations on-site following federally declared disasters. Accurate pathologic information on the cause of death and the specific types of injuries could lead to specific preventive inter-

Table 5. Housing factors associated with tornado injuries.

Housing factors	Distribution among		P*
	Injured (N = 20)	Total sample (N = 226)	
Construction material			
Wood	12	80	
Wood and brick	6	52	<.01
Brick	2	94	
Destruction index†			
Minor (0 to 1)	3	81	
Major (2)	1	48	<.01
Irreparable (3)	16	97	

*χ^2 for linear trend. †Red Cross estimates of damage (see Table 3).

ventions and better assessment of emergency medical needs, and could rule out any suspicion of death from foul play in a period of chaos. We did collect information on the circumstances surrounding the deaths of disaster victims, a practice that is useful in identifying new prevention strategies and that is not routinely performed after natural disasters. Observations such as the high mortality associated with vehicles in this tornado might well be overlooked in the normal, post-disaster inspections by meteorologists, engineers, and architects who assess the extent of the physical damage rather than the impact of the disaster on human health.

Local physicians in hospitals were effectively organized to deal with the extensive trauma suffered by the Wichita Falls residents. People who survived the initial impact of the tornado were at little risk of death thereafter, and of the hundreds of people who were injured seriously enough to seek medical attention, only two ultimately died from their injuries after the first 24 hours. In future tornadoes, medical attention is best focused on those surgical and life support interventions required in the first few hours and days (*10*).

Although fears of epidemic disease popularly occur in the wake of a natural disaster, they are usually unjustified (*11*). In the 3 weeks after this tornado, there were no outbreaks of illness caused by food, water, or person-to-person contact. A campaign to boost the tetanus immunity of all those injured was conducted in Wichita Falls in the first 2 weeks after the tornado. One death from tetanus occurred in an elderly woman, who received a toxoid booster 5 days before she became ill, but whose history of prior immunization was unclear. In the United States, elderly women who were neither immunized as children nor in the military are at particular risk to develop tetanus (*12*).

Both serious and fatal injuries were more common in women than in men, particularly in the above 60 age group, a finding noted previously following earthquakes and cyclones (*13*). Elderly, postmenopausal women have a higher prevalence of weakened, brittle, osteoporotic bones that make them more susceptible to bone injuries from trauma.

Recommendations

On the basis of the findings of this investigation, we can make several recommendations concerning the protection of individuals in future tornadoes. People in motor vehicles, whether they be in the country or the city, should seek shelter immediately upon hearing a tornado warning and should not attempt to drive from the tornado's path. People in single-family homes in a tornado-prone area should identify and reinforce some interior portion of their home as a shelter. Mobile-home parks should provide community shelters for their residents, and public buildings should designate shelter areas that are clearly identified. Finally, after a disaster has occurred, forensic pathologists should be enlisted to examine the victims for clues to further prevention. Post-disaster investigations can provide insights important to reducing the toll of death and injuries from these catastrophic events.

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