RESEARCH

Preventing Fatalities in Building Bombings: What Can We Learn From the Oklahoma City Bombing?

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ABSTRACT

Background: Bombings are an increasing threat to the public's health. Descriptive studies of blast injuries have been published, but these injuries have not been studied using analytical epidemiological methods. This study assesses factors associated with fatality risk among individuals exposed to the 1995 Oklahoma City bombing.

Methods: Retrospective case-control analysis using multivariable logistic regression. Odds ratios (OR) of fatality are calculated among occupants of the Alfred P. Murrah Federal Building on April 19, 1995.

Results: Of the 348 occupants exposed, 163 (46.8%) were fatally injured. Fatality risk was greatest in the collapsed region of the building (adjusted OR 176.7, 95% confidence interval [CI] 65.9–474.2). Age ≥40 was also associated with a significantly increased risk of fatality (OR 3.7, 95% CI 1.4–9.8). Among people found in the noncollapsed region of the building, employees' status compared to a visitor's or child's status was protective (OR 0.13, 95% CI 0.01–1.3)

Conclusions: Structural collapse is the most important risk factor for fatality in a building bombing. Progressive collapse may be prevented through more supportive building design. Protection of vulnerable building occupants can be improved by placement of relevant facilities in more structurally reinforced areas. Regular evacuation training of personnel and clear egress routes may also reduce fatality in a building bombing. (*Disaster Med Public Health Preparedness.* 2007;1:27–33)

Key Words: bombing, injury, fatality, terrorism

Terrorism is an increasing threat to the public's health.[1] The incidence of bombings, the most prevalent form of terrorist attack, is growing. Approximately 57% of all terrorist attacks since 1988 involved conventional bombs, which killed 21,882 people and injured 76,236.[2] The total number of terrorist bombing deaths worldwide since 1998 is greater than 7 times the death toll from all of the bombings in the previous 20 years (1968–1987).[2]

Buildings are a frequent target of terrorist bombings. The explosives used in most building bombings are homemade weapons that typically explode underneath or adjacent to a building in a car or truck/van.[3] Automobiles can hold enough explosive material to cause significant structural damage to multiple-story buildings, including progressive collapse of the building itself.[1,2]

Americans have been the targets of 5 significant building bombings in the past 15 years, 2 of which occurred in the United States. These events—the 1993 World Trade Center bombing in New York City, the 1995 Oklahoma City bombing, the 1996 bombing of the US military housing compound Khobar Towers in Dhahran, Saudi Arabia, and the 1998 bombings of the US embassies in Dar es Salaam and Nairobi—resulted in approximately 430 fatalities and more than 6000 injuries.[3–9]

Blast intensity, the nature of the surrounding environment, and victim proximity to the explosives are integral components of modeling the effect of a bombing on injury.[10–18] Investigation of the Khobar Towers bombing revealed possible protective effects of the structural durability of the buildings involved. The buildings damaged in this bombing sustained local but not progressive structural collapse. These buildings contained reinforced concrete floors and ceilings, which are credited with absorbing some of the blast forces and protecting occupants.[21]

In addition to these bomb-related factors and structural characteristics, individual susceptibility to injury may affect survival in building bombings. Vulnerable age groups, notably old and young people, may have increased susceptibility to the effects of the blast.[22,23]

Although mechanisms for and contributory factors to blast injury fatalities have been described, no comparative analyses have quantified the independent effects of factors that result in blast injuries, given a building bombing. The identification of modifiable risk factors is integral to protecting building occupants from fatality and severe injury. Using data from building occupants affected by the Oklahoma City bombing, this study assesses the independent effects of various risk factors for sustaining a fatal injury in this event.

THE OKLAHOMA CITY BOMBING

At 9:02 AM on April 19, 1995 a homemade truck bomb containing more than 4000 lbs of ammonium nitrate exploded outside the north entrance of the Alfred P. Murrah Federal Building in Oklahoma City, OK. The explosion caused progressive structural collapse of the Murrah building and serious damage to surrounding buildings.[5] The federal building was 9 stories high and contained glass panels on the north face, with reinforced concrete on the south face. An estimated 361 people occupied the building at the time of the bombing, including employees of several federal agencies, visitors to the federal credit union and other offices, and children and caregivers in a daycare center.[10]

Mallonee and colleagues mapped the locations of the majority of building occupants affected by the bombing. Although several nearby buildings were also affected, 98% of fatalities and 26% of people with nonfatal injuries were located in the Murrah Federal Building, with a case–fatality ratio of 45%. A significantly greater risk of death was observed in the collapsed portions of the building, a risk that was even more pronounced in the upper, compared with lower, floors.[10] The findings from this initial descriptive study, however, are not adjusted for potential confounding of possible risk factors that may have contributed to death from injury.

> “. . . older occupants’ odds of fatality remained elevated even after controlling for location in the collapsed region.”

METHODS

Data Source

The primary data for this study are from the 1995 Oklahoma City Bombing Database, a detailed registry of building occupants affected by the bombing compiled by the Injury Prevention Service of the Oklahoma State Department of Health. Data were collected from medical records, medical examiner reports, surveys and follow-up interviews of survivors. Medical record data include hospital, emergency department and ambulance records, and medical charges from all area hospitals that treated people injured in the Oklahoma City bombing. In addition, medical examiner reports for all of the people who died as a result of the bombing were collected.[7] The database includes data from 348 injured occupants of the Murrah Federal Building.

Study Design and Explanatory Variables

This analysis used a retrospective case-control design to assess personal and circumstantial factors associated with fatality risk among occupants of the Murrah Federal Building exposed to the bombing. Study subjects are defined as individuals who sustained injuries in the Murrah Federal Building at or soon after the time of the April 19, 1995 bombing. “Cases” are people fatally injured, and “controls” are nonfatally injured occupants of this building. Fatality is defined as incident injury caused by the bombing that resulted in immediate death, or death in the first 30 days following the blast. Incident nonfatal injury refers to injury that was caused directly by the bombing or during building evacuation immediately following the bombing, and did not result in death within 30 days after the blast. There were only 13 people in the Murrah building who sustained no injury. These occupants were excluded from this analysis.

Demographic variables include race, age, and sex. Individual factors also include building familiarity, measured by proxy through occupancy status, which classifies occupants as employees, visitors, or children. We hypothesized that employees may be more familiar with the building than visitors and children, and therefore may have experienced greater ease of evacuation following a severe injury sustained in the moments after the bomb’s detonation. Environmental variables include occupants’ floor level and location in the collapsed region of the Murrah building.

Analysis

Data were initially explored through frequency and distribution statistics. Because all variables for analysis are categorical, contingency tables were constructed with Pearson’s χ^2 testing to determine variability in the distribution of explanatory variables for each study outcome. Statistical significance was evaluated, with $P \leq 0.05$ considered sufficient evidence to reject the null hypothesis of no association. Simple binary models examined associations between each outcome and each exposure variable to determine the magnitude, direction, and statistical significance of each unadjusted association.

A multivariable logistic regression model was then estimated using several criteria. Risk factors identified in qualitative interviews with 16 Oklahoma City bombing survivors were initially included in the multivariable model regardless of their statistical significance in bivariate analyses. Covariates were also initially included if there was a plausible theoretical relationship, based on prior research, between the variable and the outcomes of interest. Variables that were statistically significant in bivariate analyses were also included. Variables with $\leq 10\%$ missing responses that met these inclusion criteria were included in the final model. Model fit was assessed

TABLE 1

Demographic and Location Characteristics of Injured Murrah Federal Building Occupants in the Oklahoma City Bombing, April 19, 1995 (n = 348)

	Cases	Controls
	Fatally Injured Occupants (n = 163 [%])	Nonfatally Injured Occupants (n = 185 [%])
Sex		
Female	89 (54.6)	88 (52.4)
Male	74 (45.4)	97 (47.6)
Age, y**		
0–5	19 (11.7)	6 (3.3)
6–13	0 (0.0)	0 (0.0)
14–39	48 (29.4)	71 (38.6)
40–59	82 (50.3)	95 (51.6)
60–88	14 (8.6)	12 (6.5)
Missing	0 (0.0)	1 (0.5)
Race		
White	122 (74.8)	94 (50.8)
Black	33 (20.2)	17 (9.2)
Asian	2 (1.2)	1 (0.5)
Native American	1 (0.6)	1 (0.5)
Missing	5 (3.0)	72 (38.9)
Collapsed region***		
No	10 (6.1)	158 (85.4)
Yes	134 (82.2)	21 (11.3)
Unknown	19 (11.7)	6 (3.4)
Occupancy status***		
Employee	120 (73.6)	169 (91.3)
Visitor	24 (14.7)	9 (4.9)
Child	19 (11.7)	7 (3.8)
Floor level**		
1	43 (26.4)	54 (29.2)
2	19 (11.7)	6 (3.2)
3	27 (16.6)	24 (13.0)
4	18 (11.0)	34 (18.4)
5	10 (6.1)	12 (6.5)
6	2 (1.2)	7 (3.8)
7	19 (11.7)	15 (8.1)
8	15 (9.2)	17 (9.2)
9	10 (6.1)	16 (8.6)

χ^2 test of independence performed excluding missing values. **$P \le 0.05$, ***$P \le 0.001$.

with Hosmer-Lemeshow goodness-of-fit tests. Classification tables and ROC curves were assessed in sensitivity analyses. Coefficients in the final model were exponentiated for interpretation as odds ratios (ORs), and significance of coefficients was measured with z statistics. The study was approved by the Committee on Human Research of the Johns Hopkins Bloomberg School of Public Health and the Oklahoma State Department of Health Institutional Review Board.

RESULTS

Sample Characteristics

A total of 168 people died in the Oklahoma City bombing, 163 of whom were located in the Murrah Federal Building.[10] Among the 185 nonfatally injured Murrah building occupants, 50 (27%) were hospitalized, 75 (40.5%) were treated and released from emergency departments, 43 (23.2%) were treated by private physicians, and 17 (9.2%) did not receive medical treatment.

TABLE 2

Unadjusted and Adjusted Odds Ratios of Fatal vs Nonfatal Injury Among Injured Occupants in the Oklahoma City Bombing, April 19, 1995 (n = 348)*

	Unadjusted OR (95% CI)	Adjusted OR (95% CI)
Sex		
Female	1.09 (0.71–1.66)	1.01 (0.44–2.28)
Male	1.00 (—)	1.00 (—)
Age, y		
0–5	4.68 (1.74–12.58)†	1.40 (0.12–15.4)
6–13‡	—	—
14–39	1.00 (—)	1.00 (—)
40–59	1.28 (0.80–2.04)	3.68 (1.38–9.79)†
60–88+	1.72 (0.73–4.05)	2.24 (0.42–12.05)
Status		
Visitor or child	1.00 (—)	1.00 (—)
Employee	0.26 (0.12–0.59)§	0.68 (0.16–2.91)
Floor		
1	1.00 (—)	1.00 (—)
2$^{\|}$	3.90 (1.43–10.63)†	—
3	1.39 (0.70–2.74)	0.40 (0.12–1.32)
4	0.65 (0.32–1.31)	1.08 (0.28–4.12)
5	1.02 (0.40–2.60)	0.52 (0.08–3.49)
6	0.35 (0.07–1.78)	1.59 (0.31–6.81)
7	1.56 (0.71–3.43)	1.44 (0.20–4.82)
8	1.09 (0.49–2.43)	0.98 (0.23–5.67)
9	0.77 (0.32–1.88)	1.39 (0.12–15.4)
Collapsed region		
No	1.00 (—)	1.00 (—)
Yes	100.8 (45.87–221.57)§	176.73 (65.9–474.2)§
Unknown	50.0 (16.35–153.10)§	69.47 (8.34–577.4)§

*Adjusted for sex, age, occupancy status, floor, and location in collapsed region. † $P \le 0.05$. ‡Not represented in the database. § $P \le 0.001$. $^{\|}$Not able to be estimated in multivariable analysis.

The case–fatality ratio among injured occupants of the Murrah building was 46.8% (163/348). Table 1 describes the demographic, occupancy status, location in the collapsed region, and floor distributions of cases and controls. Significant differences between cases and controls are noted in age, occupancy status, and location in the collapsed region of the Murrah building. Only 6% of Murrah building occupants located outside the collapsed region were fatally injured, compared with 85% of occupants within the collapsed area. Fatally injured occupants were more likely to be located on the second floor of the Murrah building, although location in the collapsed region could not be determined for any occupants on the second floor. There were no statistically significant differences in sex or race for cases and controls.

Multivariable Analyses

The unadjusted and adjusted ORs for fatality among injured occupants of the Murrah Federal Building are presented in Table 2. The only demographic variable that remained statistically significant after adjustment for other covariates was age. Individuals who were 40 to 59 years old at the time of the bombing had significantly higher odds of suffering a fatal injury, compared to younger adults (OR 3.68, 95% CI 1.38–9.79). Comparing adults ages 40 years and older to those under age 40 (OR 3.47, 95% CI 1.33–8.99) produced similar results (not in Table 2).

The strongest predictor of fatality was location in the collapsed region of the building, with an adjusted OR of 176.7 (95% CI 65.9–474.2). Similarly, location in the part of the building where collapse was unknown had a strong association with fatality (OR 69.5, 95% CI 8.3–577.4). The collapse variable alone accounted for 53% of the variability in the fatality outcome.

Given the magnitude of this finding, a secondary analysis was performed, stratifying occupants by location in the collapsed region. Occupants ages 40 to 59 (OR 7.6, 95% CI 1.97–29.64) and occupants ages 60 and older (OR 7.2, 95% CI 0.7–74.8) in the collapsed region had greater odds of dying than younger adults after controlling for sex, floor level, and occupancy status. Among individuals in the noncollapsed region, employee status, compared with adult visitor or child status, was protective (OR 0.13, 95% CI 0.01–1.3) after adjustment for sex, age, and floor level, although this finding was not statistically significant at the $\alpha = 0.05$ level.

Multivariable modeling was affected by the similarities among the 25 occupants for whom collapse location could not be determined. All 25 of these occupants were located on the second floor, where the daycare center was housed, and 21 of these occupants were children ages 0 to 5 years. Although there were 6 injured survivors among these children, there were no other injured child survivors in the building. The 5 remaining children in the building were located on other floors but were either uninjured or fatally injured. Therefore, there was not enough variability to model child age, location in the collapsed region, and location on the second floor simultaneously. As a result, second-floor location was dropped from multivariable models.

> “The location of the daycare center in the Murrah Federal Building may have inadvertently placed child occupants in a structurally vulnerable part of the building.”

DISCUSSION

The present study statistically models the independent effects of fatality risk and protective factors in a building bombing. By better understanding these factors, there may be opportunities to reduce the risk of serious injury or death in future bombings.

The analysis confirms the overwhelming effect of structural collapse on fatality risk in building bombings. Although this effect has been previously cited as a primary cause of death from the Oklahoma City bombing,[10] it is noteworthy that older occupants’ odds of fatality remained elevated even after controlling for location in the collapsed region. Stratified analyses indicated this age effect persisted among occupants in the collapsed region. The finding that visitors’ and children’s odds of dying in the noncollapsed region were greater than those of employees could indicate an increased risk for people unfamiliar with the building and its egress procedures. However, this finding must be interpreted with caution because familiarity with the building was not directly measured.

These conclusions are subject to certain study limitations. The analysis presented was designed to maximize available data. Because some data were collected from medical records and surveys of medically treated survivors, many environmental exposure variables were more complete for the nonfatally injured building occupants than for fatally injured occupants, and were not able to be estimated. Given this restriction, certain variables modeled were proxies for risk factors of interest, and were constructed within the confines of data availability (eg, occupancy status as employee, visitor, or child).

In addition, comparisons between fatally and nonfatally injured occupants of other buildings affected by the Oklahoma City bombing were not conducted in the present study. Whereas 166 building occupants were killed in the bombing, all but 3 were located in the Murrah Federal Building. The analysis was therefore restricted to Murrah building occupants, who accounted for 98% of the total mortality in the Oklahoma City bombing.

CONCLUSIONS

The findings of the present study provide support for public health preparedness activities and policies. The most significant factor related to fatality, the progressive structural collapse of the Alfred P. Murrah Federal Building, may have been prevented through more supportive building design[21] and by increasing the distance between the detonation and the building. The absence of building collapse in the Khobar Towers bombing, even after exposure to a bomb 5 times the magnitude of the bomb used in Oklahoma City, has been attributed to the UK building codes that governed the building’s design. These codes included provisions to reduce collapse potential and were instituted following the collapse of a high-rise apartment building in the UK.[19,22] Distance between buildings and bombs could be increased by designing structures outside potentially vulnerable buildings that prevent unidentified vehicles from gaining access.

In addition, individual factors associated with fatality also have important injury prevention implications. The location of the daycare center in the Murrah Federal Building may have inadvertently placed child occupants in a structurally vulnerable part of the building. Similarly, a Social Security Administration office was located in close proximity to the blast site. Protection of older and younger building occupants can be improved by placement of such facilities in more structurally reinforced areas. Regular evacuation training of personnel and clearly defined egress points and routes may also reduce fatality in a building bombing.

The generalizability of these findings to other building bombings is unknown. However, the characteristics of the Oklahoma City bombing—a targeted building accessed by a civilian vehicle containing a charge and significant explosive material that was detonated remotely, with significant resultant injury morbidity and mortality—is a pattern used frequently worldwide.[3] Future analyses of risk and protective factors in other bombing events are needed to better understand the influence of other bomb, building, and victim characteristics. Although primary prevention efforts are essential, in light of the increasing magnitude of terrorist bombings, this research can inform policy and injury prevention endeavors to significantly reduce morbidity and mortality.

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Received for publication March 2, 2007; accepted March 26, 2007.

Authors' Disclosure

This study was not funded by an external source.

ISSN: 1935-7893

DOI: 10.1097/DMP.0b013e3180640cd7

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EDITORIAL COMMENTARY

Terrorism events around the world have been rising sharply in terms of overall numbers and people affected. Terror-related injuries have become a threat to almost every population throughout the world. Explosive events occur more frequently and are more sophisticated, causing larger numbers of injuries and more cases of multitrauma. Most of the recent attacks related to terrorism have been conventional bombings. Although these bombings comprise 53% of the total number of terrorism events in the world, they were responsible for 85% of all of the injuries caused by terrorist attacks.[1]

Glenshaw and her colleagues' research article on the bombing of the Alfred P. Murrah Federal Building in Oklahoma City in 1995 investigates aspects of preventive injuries and public health in the collapse of buildings.[2] The explosive device used in the bombing was made of 1814 kg of ammo-