ORIGINAL RESEARCH

Mass-Casualty, Terrorist Bombings: Epidemiological Outcomes, Resource Utilization, and Time Course of Emergency Needs (Part I)

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Abbreviations:
ED = Emergency Department
EMS = Emergency Medical Services
CS = confined-space
CNS = central nervous system
IQR = inter-quartile range
ISS = injury severity score
MCI = Mass-Casualty Incident
NY = New York
OA = open-air
OK = Oklahoma
SC = structural collapse
SF = structural fire
TM = tympanic membrane
TNT = trinitrotoluene
TS = terrorist suicide
US = United States of America
VD = vehicle delivery
WMD = weapons of mass destruction
WTC = World Trade Center

Abstract

Introduction: This article characterizes the epidemiological outcomes, resource utilization, and time course of emergency needs in mass-casualty, terrorist bombings producing 30 or more casualties.

Methods: Eligible bombings were identified using a MEDLINE search of articles published between 1996 and October 2002 and a manual search of published references. Mortality, injury frequency, injury severity, emergency department (ED) utilization, hospital admission, and time interval data were abstracted and relevant rates were determined for each bombing. Median values for the rates and the inter-quartile ranges (IQR) were determined for bombing subgroups associated with: (1) vehicle delivery; (2) terrorist suicide; (3) confined-space setting; (4) open-air setting; (5) structural collapse sequela; and (6) structural fire sequela.

Results: Inclusion criteria were met by 44 mass-casualty, terrorist bombings reported in 61 articles. Median values for the immediate mortality rates and IQRs were: vehicle-delivery, 4% (1–25%); terrorist-suicide, 19% (7–44%); confined-space 4% (1–11%); open-air, 1% (0–5%); structural-collapse, 18% (5–26%); structural fire 17% (1–17%); and overall, 3% (1–14%). A biphasic pattern of mortality and unique patterns of injury frequency were noted in all subgroups. Median values for the hospital admission rates and IQRs were: vehicle-delivery, 19% (14–50%); terrorist-suicide, 58% (38–77%); confined-space, 52% (36–71%); open-air, 13% (11–27%); structural-collapse, 41% (23–74%); structural-fire, 34% (25–44%); and overall, 34% (14–53%). The shortest reported time interval from detonation to the arrival of the first patient at an ED was five minutes. The shortest reported time interval from detonation to the arrival of the last patient at an ED was 15 minutes. The longest reported time interval from detonation to extrication of a live victim from a structural collapse was 36 hours.

Conclusion: Epidemiological outcomes and resource utilization in mass-casualty, terrorist bombings vary with the characteristics of the event.

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Type of Data	Data Element
Bombing characteristics	Year City Site Pre-explosion or pre-collapse evacuation Number of explosions Explosive composition Use of metallic additives Explosive magnitude Vehicle delivery system used in attack Terrorist suicide used in attack Confined-space setting (bomb detonation in same space as majority of victims) Open-air-setting *Structural collapse sequela* Structural fire sequela
Epidemiological outcomes	Number of injured Number of immediate deaths (at scene or en route to hospitals) Number of early deaths (<4 hours detonation) Number of late deaths (≥4 hours after detonation) Number of injured seeking emergency care at ED or similar type of facility with specific injury Number of injured seeking emergency care at ED or similar type of facility with ISS <16 Number of injured seeking emergency care at ED or similar type of facility with ISS ≥16 Number of hospitalized with ISS <16; Number of hospitalized with ISS ≥16
Resource utilization	Number of injured seeking emergency care at ED or similar type of facility Number of hospitalized (number of injured seeking emergency care at ED or similar type of facility admitted to hospital) Maximum number seeking emergency care at a single ED or similar type of facility
Time course of emergency needs	Time from detonation to arrival of first injured survivor at ED or similar type of facility Time from detonation to arrival of last injured survivor at ED or similar type of facility Time from detonation to extrication of last entrapped survivor from structural collapse

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Table 1—Data extracted from included articles (ED = emergency department; ISS = injury severity score)

Introduction

Despite recent concerns about weapons of mass destruction (WMD), explosions are by far the most common cause of mass-casualty incidents associated with terrorism. Of the 93 terrorist attacks in the world reported to produce ≥30 casualties from 1991–2000, 88% involved explosions.[1]

These mass-casualty bombings (defined here as bombings that produce ≥30 casualties) not only produced significant injury and destruction, but also challenged the mergency medical services (EMS), emergency departments (EDs), and hospital emergency response resources in 27 countries.[1] In East Africa, Israel, Sri Lanka, Russia, and the United States of America (US), extensive coordination enabled terrorists to stage simultaneous bombings in more than one city, dramatically expanding the scope of their attacks.[1] At least one of these attacks, the 1998 Nairobi bombing, was a catastrophic medical disaster that created thousands of casualties and acutely overwhelmed local response resources.[1–3]

The goal of this study was to characterize the epidemiological outcomes, resource utilization, and time course of emergency needs of mass-casualty, terrorist bombings. Although recent experience with terrorism suggests that it is prudent to "expect the unexpected", an understanding of the epidemiological patterns in mass-casualty, terrorist bombings provides a rational basis for emergency planning, preparedness, and response.

Methods

Search Strategy

A primary MEDLINE search was conducted using an OVID interface for articles reporting terrorist bombings published between 1966 and October 2002 in the English language using the keywords: "bombing", "explosions", "terrorism", or "terrorist bombing". Also the reference lists within these initially identified articles were searched manually for further articles relevant to the topic.

Inclusion Criteria

Each identified article was examined to confirm that it reported a bombing meeting the following inclusion criteria: (1) the bombing was attributed to a terrorist attack in at least one article; (2) the bombing produced ≥30 casualties (i.e., it was a mass-casualty, terrorist bombing); and (3) at least one bombing characteristic or result relevant to the study was reported about the bombing. Bombings in aircraft or in which additional mechanisms of interpersonal violence were reported were excluded (e.g., riot). The definition of a mass-casualty, terrorist bombing as one that generates ≥30 casualties was based on the threshold recommendation by Rignault.[4]

Data Collection and Processing

Data from the articles about each of the bombings included were abstracted as shown in Table 1.[4–64] In the case of the 2001 World Trade Center attack, it was estimated that

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Year	City	Site	Explosive Composition	Magnitude (kg)*	Type of Attack	Type of Setting or Sequela
1966[5]	Saigon	Military housing	Plastique	227	VD	OA
1969[6]	Cu Chi	Military mess hall	Claymore mine, †	10	-	-
1971[7]	Belfast	Pub & street	-	-	-	-
1972[7,8-13]	Belfast	Restaurant	-	2	-	CS
1972[7]	Belfast	Street	-	-	-	OA
1972[7]	Belfast	Street	-	-	-	OA
1972[7]	Belfast	Street	-	-	-	OA
1972[7]	Belfast	Hotel	-	-	-	-
1973[14-16]	London	Court building	-	80	VD	OA
1974[15-17]	London	Museum	-	5	-	CS
1974[15,16]	Guildford	Pub**	-	5	-	CS
1974[15,16,18]	Birmingham	Pubs**	-	-	-	CS
1975[20]	New York City	Airport	-	-	-	-
1980[21]	Bologna	Train station	-	20	-	SC
1983[22–24]	Beirut	Military barracks	-	5,500	VD, TS	SC
1985[4]	Paris	Building interior	Camping gas	-	-	CS, SF
1986[25]	Berlin	Nightclub	-	5	-	CS
1986[4]	Paris	Building interior	-	-	-	CS
1986[4]	Paris	Building interior	-	-	-	CS
1986[4]	Paris	Building interior	-	-	-	CS
1986[4]	Paris	Building interior	-	-	-	CS
1987[26,27]	Barcelona	Department store	Ammonal, soap, petrol	>227	VD	SF
1987[28]	Djibouti	Bar terrace	†	10	-	-
1987[29,30]	Enniskillen	Club building	-	-	-	SC
1988[31]	Jerusalem	Bus	-	6	-	CS
1991[32]	London	Train station	Semtex	2	-	OA
1992[13]	London	Train station	-	-	-	OA
1993[33,34]	New York City	WTC towers	-	-	VD	SF
1994[35]	Buenos Aires	Community building	Ammonal	300	VD	SC
1994[36]	Tel Aviv	Shopping mall	-	10	TS	-
1995[37–41]	Oklahoma City	Government building	NH_4 nitrate, fuel oil	1800	VD	SC
1995[42]	Tel Aviv	Road**	TNT	10	TS	OA
1995[43]	Riyadh	Military office building	"High explosives"	90	VD	-
1996[44]**	Jerusalem	Buses***	Anti-tank mine, †	-	TS	CS
1996[44]**	Jerusalem	Bus station, trading center***	Anti-tank mine, †	-	TS	OA
1996[45-46]	Manchester	Shopping center	-	-	VD	OA
1996[47]	Atlanta	Olympic Park	†	-	-	OA
1996[48–50]	Dhahran	Military barracks	Dynamite, fuel oil	4500	VD	SC
1996[51]	Ulster	Military barracks**	-	400	VD	SC
1998[52–54]	Nairobi	Embassy building	Semtex	900	VD, TS	SC
1999[55]	London	Pub	†	-	CS	CS
2001[56–64]	New York City	WTC towers**	Jet fuel	-	VD, TS	SC, SF

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Table 2—Characteristics of mass-casualty terrorist bombings (VD = vehicle delivery; TS = terrorist suicide; CS = confined-space; OA = open-air; SC = structural collapse; SF = structural fire; WTC = World Trade Center; - = Not reported; *TNT equivalent when composition not specified; **Two explosions in event; ***Two events reported together; † = Metallic additive)

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there were >3,922 total victims based on the number of dead in one article and the number of injured survivors seeking emergency care at five Manhattan hospitals in another.[58,59] The number of injured seeking care in emergency departments or similar facilities was abstracted directly and not derived from immediate mortality data. The following guidelines were used to abstract the number of patients with each type of injury who utilized an EDs: (1) *blast lung syndrome* also included adult respiratory distress syndrome (ARDS) or pulmonary blast injury requiring mechanical ventilation; (2) *penetrating, soft tissue injuries* included lacerations, puncture wounds, and wounds from foreign bodies; (3) *intracranial injuries* included open or depressed skull fractures, and intracranial hemorrhage; and (4) *crush injury* included *crush syndrome.* When the number of penetrating eye injuries was reported, but the number of eye injuries was not, then the number of penetrating eye injuries was used to represent both values, since it represents the minimum number of total eye injuries. When the number of open fractures was reported, but the number of fractures was not, then that number was used to represent both values, since it represents the minimum number of total fractures.

Primary Data Analysis

The following epidemiological outcome rates were determined for each event: (1) *immediate* mortality (number of immediate deaths/number of injured); (2) *early* mortality (number of early deaths/number of injured); (3) *late* mortality (number of late deaths/number of injured); and (4) injuries of those patients who utilized the EDs (number of specific injuries in injured persons who sought care in an EDs or similar type of facilities). The following rates of resource utilization were determined: (1) *emergency department utilization* (number of injured seeking emergency care at an ED or similar type of facility); and (2) *hospital admission* (number of hospitalized/number of injured seeking emergency care at EDs or similar type of facilities). When conflicting data were reported by two or more articles, the highest reported set of values was used for each determination, since this represents the upper limit for a given bombing. Then, the median values for the rate and the inter-quartile ranges (IQR) were calculated for each of the bombings.

Subgroup Analysis

The bombings were grouped into the following categories for the purpose of subgroup analysis: (1) bombings associated with a vehicle delivery system (VD); (2) bombings associated with terrorist suicide (TS); (3) bombings occurring within a confined-space (CS); (4) bombings occurring in the open-air (OA); (5) bombings associated with a structural collapse (SC); or (6) bombings associated with a structural fire (SF). The median values and inter-quartile ranges were determined for the total numbers of injured, epidemiological outcome rates, resource utilization rates, and injury frequencies for each subgroup. When data were available for only one event within a given subgroup, the median values and IQR were not calculated.

Results

The primary and hand searches yielded 83 articles that reported the individual or collective outcomes of terrorist bombings.[4–86] Sixty-one of these articles reported outcomes in 44 individual mass-casualty, terrorist bombings.[4–64]

Characteristics of the Bombings

The characteristics of the bombing for the 44 events that are included in this study are listed in Table 2. Vehicle delivery systems were used in 13 (30%), while terrorist suicide was used in nine (20%). Fourteen (32%) of the explosions occurred within confined-spaces (three in buses), and 12 (27%) took place in open-air settings. Eight (18%) produced structural collapses, and four (9%) resulted in structural fires. Five of the bombings could not be categorized, because the necessary information was not included in the identified articles. The composition of the explosives used was reported for only 16 of the bombings (37%); it ranged from home-made materials to Semtex. A variety of metallic additives (e.g., nails, hardware) were used in eight (18%). The explosive magnitude was reported for 21 bombings (48%) and ranged from 2.3 to 5,500 kg of TNT. Pre-explosion or pre-collapse evacuations were reported for only three bombings.[45,47,56]

Outcomes and Resource Utilization

The epidemiological outcomes and resource utilization rates for 43 mass-casualty terrorist bombings (one additional bombing was used for the analysis of injury frequency reported in the emergency departments (EDs), Table 3).[13] The total number of persons injured from the explosions ranged from 30 from a bombing in 1986 in Paris to many thousands from the 2001 New York City World Trade Center attack.[4,57–59] The *immediate* mortality rates were dependent upon whether or not building collapse resulted from the explosion: rates ranged from 0% for nine of the bombings (four of which took place in the open air) to 68% for the structural-collapse bombing of the US Marine Battalion Landing Team Headquarters at Beirut International Airport in 1983.[22] The *early* mortality rate (dead at the scene) were remarkably light and ranged from 0% for 15 of the bombings to a high of only 4% in the 1969 Cu Chi bombing in Vietnam.[6] The ED utilization rates ranged from 26% in the 1969 Cu Chi bombing to 100% for seven bombings.[6] The hospital admission rates varied from 1% for the Europa Hotel bombing in Belfast in 1972 to 88% in the 1983 Beirut bombing.[7,22] Thus, the impact of the explosions on the hospitals varied greatly by event.

Median values for mortality and utilization rates may be helpful as predictors of what to expect for specific types of attacks (i.e., terrorist suicide, open-air structural collapses, etc.) The median values for outcomes and resource utilization rates overall and for the six subgroups are listed in Table 4. The median values for the *immediate* mortality rates (deaths at the site of the explosion or during conveyance to an ED or similar type of facility) ranged from 1% for the open-air bombings to 18% for the structural-collapse bombings, and 19% for the suicide bombings. The median values for the *early* mortality rates (deaths <4 hours of detonation—at the ED or similar type of facility, or in-hospital) were 0% for five of the bombing subgroups and 1% for

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Year	City	Number Injured	Immediate Mortality (%)	Early Mortality (%)	Late Mortality (%)	ED Utilization (%)	Hospital Admission
1966[5]	Saigon	141	1	0	0	87	-
1969[6]	Cu Chi	46	26	4	2	26	67
1971[7]	Belfast	35	3	-	-	97	56
1972[7-13]	Belfast	83	2	0	0	98	31
1972[7]	Belfast	54	0	-	-	100	11
1972[7]	Belfast	57	0	-	-	100	4
1972[7]	Belfast	127	3	-	-	97	14
1972[7]	Belfast	68	0	-	-	100	1
1973[14–16]	London	160	0	1	0	100	12
1974[15–17]	London	37	0	3	0	100	51
1974[15,16]	Guildford	67	7	0	0	-	-
1974[15,16,18,19]	Birmingham	140	14	1	1	-	-
1975[20]	New York City	66	-	-	-	-	-
1980[21]	Bologna	291	25	1	3	75	83
1983[22–24]	Beirut	346	68	0	2	28	88
1985[4*]	Paris	35	0	-	-	-	-
1986[25]	Berlin	263	1	0	-	-	-
1986[4]	Paris	30	7	-	-	-	-
1986[4]	Paris	41	0	-	-	-	-
1986[4]	Paris	52	2	-	-	-	-
1986[4]	Paris	58	12	-	-	-	-
1987[26,27*]	Barcelona	66	32	0	5	68	53
1987[28]	Djibouti	52	-	-	-	-	-
1987[29,30]	Enniskillen	65	15	1	0	85	36
1988[31]	Jerusalem	58	5	0	5	95	53
1991[32]	London	51	2	0	0	92	-
1993[33,34]	New York City	1,040	1	0	0	53	-
1994[35*]	Buenos Aires	286	28	1	1	29	46
1994[36]	Tel Aviv	150	-	-	-	-	-
1995[37–41]	OK City	759	21	1	1	58	19
1995[42]	Tel Aviv	94	19	-	-	81	-
1995[43]	Riyadh	77	-	-	-	-	-
1996[44**]	Jerusalem	93	44	0	5	56	77
1996[44**]	Jerusalem	204	7	0	1	93	38
1996[45–46]	Manchester	208	0	0	0	100	9
1996[47]	Atlanta	111	1	0	0	99	23
1996[48-50]	Dhahran	519	4	-	-	-	-
1996[51*]	Ulster	32	0	0	3	100	-
1998[52–54]	Nairobi	4,257	5	-	-	-	-
1999[55]	London	61	3	0	0	97	15
2001[57–59***]	New York City	>3,922	-	-	-	-	16***

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Table 3—Outcomes and resource utilization for mass-casualty terrorist bombings (- = Not reported; *Data from one hospital; **Data from two events; ***Data from first 48 hours at five hospitals; ED = emergency department)

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Subgroup	Median value (IQR)					
	Number Injured	Immediate Mortality (%)	Early Mortality (%)	Late Mortality (%)	ED Utilization (%)	Hospital Admission (%)
Vehicle delivery	286 (141–759)	4 (1–25)	0 (0–1)	1 (0–2)	68 (53–100)	19 (14–50)
Terrorist suicide	102 (94–346)	19 (7–44)	0 (0–0)	2 (1–5)	69 (56–90)	58 (38–77)
Confined-space	55 (42–66)	4 (1–11)	0 (0–0)	1 (0–5)	96 (66–98)	52 (36–71)
Open-air	102 (76–134)	1 (0–5)	0 (0–0)	0 (0–1)	97 (93–100)	13 (11–27)
Structural collapse	346 (286–759)	18 (5–26)	1 (0–1)	2 (1–3)	67 (36–83)	41 (23–74)
Structural fire	553 (58–1,761)	17 (1–17)	0 (0–0)	3 (1–4)	61 (57–64)	35 (25–44)
All	77 (54–204)	3 (1–14)	0 (0–1)	1 (0–2)	94 (70–100)	34 (14–53)

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Table 4—Median values for outcome and resource utilization rates in bombing subgroups and overall (ED = emergency department; IQR = inter-quartile ranges)

structural-collapse bombings. The median values for the ED utilization rates were 61% for structural-fire bombings, 67% for the structural-collapse bombings, and 97% in open-air bombings. The median values for hospitalization rates ranged from 13% for the open-air bombings, to 52% for the confined-space bombings, and 58% for the suicide bombings.

Types and Frequencies of Injuries

The types and frequencies of the patients that presented to an emergency department are listed in Table 5. *Primary blast* injuries are caused by barotrauma from blast overpressure, including spalling, implosion, inertial, and pressure differential mechanisms. In general, the highest rate of primary blast injuries were associated with confined-space bombings. For example, the highest rate of *blast lung syndrome* was 44% for two suicide bombings that occurred aboard buses in Jerusalem in 1996,[44] the highest rate of *tympanic membrane rupture* was 81% from the confined-space bombing that took place within the Abercorn Restaurant in Belfast in 1972,[7–10] and the highest rate of *intestinal perforation* was 4% for three bombs that were detonated aboard buses in Israel and for one open-air bombing in Tel Aviv in 1995, which was associated with terrorist suicide amidst a crowd of people.[31,42,44]

Secondary blast injuries are caused by primary shrapnel from the bomb contents or casing or secondary shrapnel from the effect of the explosion on surrounding materials or structures (e.g., glass, wood, masonry). In general, the highest rates of secondary blast injuries were associated with open-air bombings. For example, the highest rate of penetrating, soft tissue injuries was 100% for the open-air bombings that occurred at a train station in London in 1991 and at Olympic Park in Atlanta in 1996.[32,47]

Tertiary blast injuries are caused by the blast wind, either when it accelerates victims against fixed objects or it differentially accelerates exposed body parts. In general, tertiary blast injuries, such as traumatic amputations, were associated with all bombing subgroups. Several injury types may be attributable to primary, secondary, or tertiary blast mechanisms. Accordingly, eye injuries, fractures, serious intracranial injuries, and solid organ injuries, were reported in almost all of the bombing subgroups.

Quaternary blast injuries are caused by other environmental effects of explosions, such as the direct effect of blast heat on victims, structural fires, or structural collapse. The highest rate of burn injuries reported was 94% for a bombing in Paris in 1996 in which the structure caught fire,[4] and the highest rate of *inhalation injury* was 93% in the 1993 World Trade Center bombing in which structural fire occurred (and delayed evacuation led to prolonged smoke exposure).[34] The highest rate of *crush injuries* was 6% in the structural-collapse bombing of the Argentine Israeli Mutual Association building in Buenos Aires in 1994.[35] Crush injuries were not reported from open-air or confined-space bombings.

The median and IQRs for injury frequencies encountered by the six subgroups of the victims who presented to the EDs are presented in Table 6. In general, the median values for the rates of *primary blast injury* were highest in the terrorist-suicide and confined-space subgroups. For example, the median values for the rates of pulmonary blast injury were 11% for confined-space bombings and 25% for suicide bombings. The median values for the rates of tympanic membrane perforation were 32% for the confined-space bombings, and for intestinal perforation were 4% for confined-space bombings and 2% for suicide bombings. In contrast, the median value for the rates of secondary blast injuries was the highest from open-air bombings. For example, the median value for the rates of penetrating, soft tissue injuries was 91% for the open-air subgroup versus 42% for structural-collapse bombings, and 54% for confined-space bombings. The median values for the rates of penetrating eye, abdominal, and vascular injury were ≤3% across all bombing subgroups. The median values for the rates of burns were highest for the confined-space bombings subgroup (23%), and for the victims of structural fires (50%). The median value for the rates of the subgroup that sustained inhalation injuries was highest for those bombings that resulted in structural-fires (73%). The median values for

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Year	City	Pulmonary contusion (%)	Pneumothorax (%)	Blast lung syndrome (%)	TM rupture (%)	Intestinal perforation (%)	Penetrating soft tissue (%)	Eye (%)	Penetrating eye (%)	Penetrating abdomen (%)	Penetrating vascular (%)	Fracture (%)	Open fracture (%)	Amputation (%)	Intracranial (%)	Liver or spleen (%)	Burn (%)	Inhalation (%)	Crush (%)
1966[5]	Saigon	-	-	-	-	-	91	-	-	1	-	2	-	-	-	-	-	-	-
1969[6]	Cu Chi	0	0	0	-	0	-	25	25	8	8	8	8	0	25	0	0	0	0
1971[7]	Belfast	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1972[7–13]	Belfast	-	-	-	81	-	-	-	-	-	-	-	-	6	-	-	-	-	-
1973[14–16]	London	-	-	-	-	-	72	-	-	-	-	2	-	-	-	-	-	-	-
1974[15–17]	London	5	0	0	32	-	54	11	3	3	-	35	-	-	5	3	27	-	-
1974[15,16]	Guildford	-	-	-	18	-	-	-	-	-	-	14	-	-	-	-	20	-	-
1974[15,16,18]	Birmingham	-	-	1	20	-	55	1	1	1	4	8	6	-	1	1	23	-	-
1980[21]	Bologna	2	2	2	-	-	-	1	1	1	-	-	-	1	3	-	-	-	-
1983[22–24]	Beirut	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	-
1985[4]	Paris	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	94	-	-
1986[25]	Berlin	1	-	-	53	-	14	1	-	-	1	-	-	-	-	-	20	-	-
1987[26,27]*	Barcelona	-	-	7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1987[28]	Djibouti	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1987[29,30]	Enniskillen	0	2	0	-	0	-	-	0	0	2	24	5	0	4	0	-	-	2
1988[31]	Jerusalem	-	7	20	-	4	-	-	-	-	-	-	-	2	-	-	-	-	-
1991[32]	London	-	-	-	0	-	100	3	3	7	3	40	40	7	3	-	0	-	-
1992[13]*	London	-	-	-	10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1993[33,34]	New York City	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	93	-
1994[35]*	Buenos Aires	2	4	-	-	1	-	-	-	-	4	12	12	2	6	2	-	1	6
1995[37–41]	OK City	2	1	1	3	-	66	12	2	1	2	13	-	-	2	1	2	3	1
1995[42]	Tel Aviv	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-
1996[44]**	Jerusalem	-	19	44	-	4	-	-	-	-	-	-	-	-	-	10	-	-	-
1996[44]**	Jerusalem	-	3	5	-	0	-	-	-	-	-	-	-	-	-	1	-	-	-
1996[45–46]	Manchester	0	0	0	3	0	61	3	0	0	0	1	0	0	0	0	0	0	0
1996[47]	Atlanta	0	0	0	0	0	100	-	0	2	2	6	3	0	1	1	0	0	0
1996[51]*	Ulster	0	0	3	0	0	-	3	0	3	3	9	9	0	6	0	3	0	0
1999[55]	London	-	-	-	-	2	-	2	-	-	-	-	-	3	-	-	-	-	-
2001[57,58]***	New York City	-	-	-	-	-	17	19	-	-	-	6	-	-	-	-	6	52	1

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Table 5—Emergency department injury frequency in mass-casualty, terrorist bombings (- = Not reported; *Data from one hospital; **Data from two events; ***Data from 5 hospitals; TM = tympanic membrane)

the rates of crush injuries were 1% for those bombings associated with vehicle delivery and structural collapse.

Injury Severity Scores (ISS)

The dichotomized frequencies for injury severity scores for the victims who were hospitalized (no eligible study reported ISS data in ED populations) are provided in Table 7. The highest injury severity scores were reported from the two suicide, bus bombings that occurred in Jerusalem in 1996 (63% of hospitalized victims had an ISS of >16).[44]

Emergency Department Patient Loads

The four mass-casualty events that reported the highest numbers of injured survivors seeking emergency care at a single hospital are listed in Table 8. During the first 24 hours after the 2001 World Trade Center attack, >500 victims

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Subgroup	Median (IQR)																	
	Pulmonary contusion (%)	Pneumothorax (%)	Blast lung syndrome (%)	TM rupture (%)	Intestinal perforation (%)	Penetrating soft tissue (%)	Eye (%)	Penetrating eye (%)	Penetrating abdomen (%)	Penetrating vascular (%)	Fracture (%)	Open fracture (%)	Amputation (%)	Intracranial (%)	Liver or spleen (%)	Burn (%)	Inhalation (%)	Crush (%)
Vehicle delivery	1 (0–2)	1 (0–2)	2 (1–4)	3 (2–3)	0 (0–1)	66 (61–72)	8 (3–14)	0 (0–1)	1 (1–2)	3 (2–3)	6 (2–11)	11 (10–11)	0 (0–1)	6 (2–6)	1 (0–1)	3 (2–4)	2 (0–40)	1 (0–1)
Terrorist suicide	-	11 (3–19)	25 (5–44)	4*	2 (0–4)	17*	19*	-	-	-	6*	-	-	12*	6 (1-10)	6*	52*	1*
Confined-space	3 (2–4)	13 (5–19)	11 (1–38)	32 (20–53)	4 (4–4)	54 (34–55)	2 (2–7)	2 (2–3)	2 (2–3)	3 (2–3)	14 (11–25)	6*	3 (3–5)	3 (2–4)	7 (3–10)	23 (20–27)	-	-
Open-air	0 (0–0)	2 (0–3)	3 (0–5)	2 (0–5)	0 (0–0)	91 (72–100)	3 (3–3)	0 (0–2)	2 (1–3)	2 (1–3)	2 (2–6)	3 (2–22)	0 (0–4)	1 (1–2)	1 (1–1)	0 (0–0)	0 (0–0)	0 (0–0)
Structural collapse	2 (0–2)	2 (1–2)	2 (1–2)	2 (1–2)	0 (0–1)	42 (29–54)	8 (3–14)	1 (0–1)	1 (1–2)	3 (2–3)	12 (9–13)	9 (7–11)	1 (0–1)	5 (3–6)	1 (0–1)	3 (3-5)	2 (1–15)	1 (1–2)
Structural fire	-	-	7*	-	-	17*	19*	-	-	-	6*	-	-	-	-	50 (28–72)	73 (62–83)	1*
All	1 (0–2)	2 (0–4)	2 (0–6)	7 (2–23)	0 (0–3)	64 (54–86)	3 (2–12)	1 (0–3)	1 (1–3)	3 (2–4)	9 (6–14)	7 (5–10)	1 (0–3)	4 (2–6)	1 (0–2)	5 (0–21)	1 (0–15)	1 (0–1)

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Table 6—Emergency department injury frequency in bombing subgroups and overall (TM = tympanic membrane; - = Not reported; *Data from one bombing only; IQR = inter-quartile range)

sought emergency care at Beekman Hospital (four blocks from Ground Zero), and >300 victims sought emergency care at St. Vincent's Hospital (approximately one mile from Ground Zero).[64] The events listed in Table 8 either were associated with open-air settings, structural collapse sequela, or structural collapse and structural fire sequelae.

The time until arrival of the first victims at an ED following detonation as well as how long patients continued to arrive following the event have relevance for planning. Such key time intervals for those events that resulted in mass casualties are listed in Table 9. The shortest time interval from detonation to the arrival to the ED of the first patients was five minutes following the 1973 Old Bailey bombing in London[11] and a "few" minutes in the 2001 World Trade Center attacks.[14–16,57] The shortest time interval from detonation to the arrival of all of the patients to the ED was 15 minutes following the 1966 Cu Chi bombing.[6] The longest time interval for the last live victim to be extricated from a structural-collapse bombing was 36 hours following the AMIA bombing in Buenos Aires in 1994.[35] A live victim reportedly was discovered in the Ufundi House collapse at the 1998 Nairobi bombing site between 24 and 48 hours, but the victim died at the scene.[53]

Discussion

Bombing Characteristics

Terrorist bombings have posed an ongoing threat for decades to a variety of populations in a variety of locations throughout the world. As the data listed in Table 1 suggests, targeted sites often are highly visible and play an important operational or symbolic role in the community targeted, including commercial, government, military, and transportation assets.

Terrorists have used a number of strategies to maximize the impact of bombings, including the use of more than one bomb, the use of highly explosive materials (i.e., Semtex), the use of metallic or incendiary additives, the use of explosive material of greater magnitude, the use of vehicle delivery systems, the use of suicide to direct bombings against specific targets, and the direct targeting of concentrated populations within confined-spaces or collapsible structures.

Mortality Rates

Mortality rates help characterize the magnitude of the events and their overall burden on communities. Several factors are likely to influence mortality rates in mass-casualty, terrorist bombings, including the bombing characteristics (which in turn affect injury type and severity), and the quality, capacity, and timeliness of medical care during the immediate, early, and late phases.

In mass-casualty, terrorist bombings, the vast majority of the number of deaths was immediate, with relatively few deaths occurring early or late (Tables 3 and 5). This biphasic pattern of mortality—a higher immediate mortality rate followed by very low early and late mortality rates—occurred in virtually every individual bombing and subgroup, and differs from the classic triphasic pattern of mortality reported in general trauma populations.[87]

The highest immediate mortality rates occurred from bombings associated with terrorist suicide bombings that occurred in buses, and bombings associated with structural collapse. Terrorist suicides tend to focus explosions much

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Year	City	Type of Attack	Type of Setting or Sequela	Number of Patients	Percentage	
					ISS 1–15	ISS 16–75
1980[21]	Bologna	-	SC	107	77	23
1983[22]	Beirut	VD, TS	SC	85	78	22
1996[44*]	Jerusalem	TS	OA	73	73	27
1996[44*]	Jerusalem	TS	CS	40	37	63

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Table 7—Injury severity scores (ISS) in hospitalized patients in mass-casualty, terrorist bombings (CS = confined-space; OA = open-air; SC = structural collapse; TS = terrorist suicide; VD = vehicular delivery *Two events, reported as ISS 1–16, 17–75)

Year	City	Type of Attack	Type of Setting or Sequelae	Number of Victims Seeking Emergency Care
1966[5]	Saigon	VD	OA	123
1973[14]	London	VD	OA	160
1994[35]	Buenos Aires	VD	SC	84
2001[64]	New York City	VD, TS	SC, SF	>500*

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Table 8—Maximum number of injured survivors seeking emergency care at a single hospital in mass-casualty terrorist bombings (CS = confined-space; OA = open-air; SC = structural collapse; SF = structure fire; TS = terrorist suicide; VD = vehicular delivery *A second hospital reported >300)

closer to potential victims. Buses constitute particularly lethal bombing settings, since they concentrate the potential victims closer to the detonation point and potentiate barotrauma via blast waves reflected off of the surrounding walls. Structural collapse sequela—especially pancake type structural collapses—leave little space in which victims might survive.[35,37,58,88] For example, occupant mapping in the 1995 Oklahoma City bombing showed that 98% of all deaths occurred inside the Murrah Federal Building, with 87% occurring within collapsed regions of the building.[38] Higher immediate mortality rates tend to reduce the demand for ED and hospital capacity, since fewer casualties survive to reach these facilities.

Low early mortality rates occurred across virtually all bombings (individual, subgroup, and overall), suggesting that relatively few casualties died in EDs or operating rooms (≤1%). Low early mortality rates reduce the need to re-distribute emergency resources away from the more injured and toward the less injured according to the principle of the "greatest good for the greatest number". Instead, these low rates suggest that in most situations, critically injured survivors who reach EDs should be given the full benefit of aggressive modern trauma care.

Injury Frequency

Injury rates or frequencies influence the demand for medical resources in mass-casualty incidents (MCIs) and disasters. The determinants of injury in explosions are complex and involve multiple factors related to the bomb, environment, and victims (Table 9). In general, explosions cause injury via rapidly expanding spherical waves of atmospheric overpressure (blast wave), air displacement (blast wind), and heat.[89–96]

The distribution of primary blast injuries (Table 6) suggests that barotrauma affects the auditory system (tympanic membrane rupture), lungs (pulmonary contusion, pneumothorax, and blast lung syndrome), and intestinal tract (intestinal perforation)—in order of decreasing susceptibility. Primary blast injuries were most common in the confined-space subgroup, since confined-spaces tend to concentrate victims around the detonation point and augment barotrauma via blast waves reflected off surrounding surfaces. Blast lung syndrome was reported most frequently in the terrorist suicide subgroup, in which explosions were detonated in small confined-spaces or amidst dense crowds, and EMS transport were relatively short.[31,44]

Intestinal perforation, the most common type of abdominal blast injury, also occurred most frequently in bombings associated with terrorist suicide and confined-space settings (especially buses).[42,44] Incompressible solid organs also are highly susceptible to barotrauma, accounting for the relatively higher frequency of liver or spleen injuries observed in the terrorist-suicide and confined-space subgroups.

Secondary blast injury constituted the most common category of injuries in the subgroups and overall. Penetrating injury is a common consequence of explosions, because shrapnel is generated by both the bomb and the environment surrounding the detonation point (e.g., glass, wood, stone, and masonry). Penetrating soft tissue injuries, the single most common type of injuries across all subgroups, was most common in the open-air subgroup. This probably occurs because relatively more victims are injured by flying shrapnel at much greater distances from the detonation point in open-air bombings than in other bombing subgroups. While eye injuries are caused by shrapnel, they also may be due to aerosolized dust and debris, accounting for the increased frequency of eye injuries in the structural-collapse subgroup. It also is noteworthy that serious secondary blast

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injuries requiring operative therapy occurred in all subgroups, including penetrating ocular, abdominal, and vascular injuries.

Tertiary blast injuries also occurred in all subgroups and ranged from fractures to solid organ injuries. Many so-called tertiary blast injuries are difficult to categorize, since they may be attributable to more than one mechanism. For example, fractures, amputations, intracranial injuries, and solid organ injuries all may be primary, secondary, or tertiary in origin. Accordingly, fractures, intracranial injuries, and liver or spleen injuries tended to occur less frequently in the open-air subgroup, in which barotrauma and blunt trauma mechanisms were likely to play a smaller role. Amputations were relatively uncommon in injured survivors seeking emergency care from any type of bombing, presumably because they correlate with exposure to higher blast energy and immediate death. On the other hand, the exposed cranium is susceptible particularly to injury in explosions, accounting for the occurrence of intracranial injuries in all bombing subgroups.

A greater frequency of burns was reported in the confined-space subgroup in which victims were more likely to be concentrated around the detonation point. These injuries were most likely flash burns—superficial burns of unprotected skin on the head, neck, and skin—due to the brief intense heat of explosion near the detonation point (up to 3,000C).[36] Burns also were reported more frequently in the structural-fire subgroup. These injuries most likely were thermal burns that occur when the blast heat is sufficiently intense to ignite the surrounding structure.[4]

Inhalational injury only was reported in bombings associated with structural fire or structural collapse. In the 1993 World Trade Center bombing, 93% of injured survivors sought emergency care for smoke inhalation due to the associated fires and prolonged evacuation times.[34] In the 2001 World Trade Center attack, 52% of immediately surviving injured sought emergency care for inhalation injury due to either smoke from the high rise fires or respirable dust from the collapse.[58] Crush injury only was reported in the structural-collapse subgroup.

Injury Severity Rates

Injury severity rates influence the demand for medical resources in disasters. Factors likely to affect injury severity rates in mass-casualty, terrorist bombings include the explosive composition and magnitude, the bombing environment (space in which the explosion occurs, materials upon which blast waves act, and secondary environmental effects), and the victim distance from the detonation point.

The greatest injury severity rates in hospitalized patients in mass-casualty bombings were reported in two confined-space bombings on buses in Israel in 1996, in which 63% of hospitalized patients had ISS of >16. In contrast, <27% of hospitalized patients in four open-air-and structural collapse bombings had ISS of >16 (Table 6).

No study has reported the pattern of injury severity in ED patients from a mass-casualty, terrorist bombing. However, three large studies not included here, which pooled data from multiple bombings of various types and magnitudes, reported that <15% of ED patients had ISS of >16.[36,66,81] These three studies and the injury severity patterns in hospitalized patients indirectly suggest that the majority of injuries in ED patients from mass-casualty, terrorist bombings are relatively minor.

ED Utilization Rates

Emergency Department utilization rates affect the demand for ED capacity during MCIs and disasters. Emergency Department utilization rates in mass-casualty, terrorist bombings are likely to be influenced by the rate of immediately surviving injured, the number of immediately surviving injured, and the availability of EDs.

In general, ED utilization rates in mass-casualty, terrorist bombings are complementary to immediate mortality rates. Bombings with the highest ED utilization rates usually have the lowest rates of immediate mortality, because bombings that kill fewer victims on-scene generate more immediately surviving injured (and vice versa).

The relationship between ED utilization rates and the number of injured survivors may be more complex. In several mass-casualty bombing events that produced large numbers of injured survivors, the ED utilization rate appeared to diminish (Table 3). In addition, the structural-collapse and vehicle-delivery subgroups, with the highest median numbers of injured also had lower rates of ED utilization (Table 4). One reason for this observation may be that bombings producing large numbers of injured survivors also produce large numbers of injured survivors with minor injuries, who then seek emergency care at venues other than the EDs (i.e., at the scene, clinics, private doctor's offices).[38] It also is conceivable that the number of injured victims utilizing the EDs were not as well-documented in bombings producing very large numbers of injured versus those that produced smaller numbers of injured victims.[58]

Maximum Number of Injured Survivors Seeking Emergency Care

The maximum numbers of injured survivors seeking emergency care at the EDs helps define the upper limits of the demand for ED capacity during MCIs and disasters. Several factors are likely to influence the maximum number of injured survivors utilizing a single ED in a mass-casualty, terrorist bombing, including the number of immediately surviving injured (which in turn is related to the bombing characteristics), as well as hospital proximity to the bombing site, primary distribution of casualties by prehospital EMS to hospitals, and the number of available EDs. In this study, the maximum number of injured survivors reported to seek emergency care at a single hospital was "greater than 500" in the 2001 World Trade Center attack.[64] As the data in Table 8 suggest, the four reported maxima occurred in bombings associated with vehicle-delivery systems. This is consistent with the observation that vehicles are used to carry much larger amounts of explosive material, which, when detonated, injure more persons. In three of the bombings, the receiving ED was very close to the blast site.[14,35,64] The greatest number of injured survivors alleged to seek emergency care at a single hospital in any mass casualty terrorist bombings was 1,857 at Kenyatta National Hospital in the 1998 Nairobi bombing (excluded from this

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study because the data were obtained from a media report).[3]

Hospital Admission Rates

Hospital admission rates influence the demand for hospital capacity in MCIs and disasters. A number of factors are likely to influence hospital admission rates due to terrorist bombings including the pattern of injury severity, the practice of over-triage, and the demand for specific hospital services, such as operative therapy or observation.[37,44,19] Hospital admission rates were greatest from the confined-space and terrorist-suicide subgroups, presumably because the overall injury severity tended to be greater from these events. Greater hospitalization rates also may reflect the over-triage of ED patients to beds inside the hospital, which, in turn, may be influenced by institutional policy or the inexperience of responding physicians.[19]

Time of Arrival of First Injured Survivor at the ED

The time interval from the onset of an event to the arrival of the first injured survivor at the ED helps to define the immediacy with which such events impact the EDs. Factors likely to affect this time interval include the ability of injured victims to transport themselves (or be transported) to hospitals by modes of transportation other than using prehospital EMS vehicles, hospital proximity, and ambient traffic conditions.[6,14,17,29,26,36] In eight of the bombings, this time interval ranged from 5–30 minutes (Table 9). In general, victims with relatively minor injuries, who are not entrapped or incapacitated, tend to bypass the prehospital EMS system and go rapidly by other means to the nearest hospital.[26,36] For example, in the 1996 Oklahoma City bombing, a first wave of injured survivors with relatively minor injuries began arriving at the EDs 15 minutes after the blast, while victims with injuries requiring hospitalization tended to arrive later in a second wave via prehospital EMS.[37]

Time of Arrival of the Last Injured Survivor at the ED

The time interval from detonation to the arrival of the last injured survivor at the ED helps to define the duration of the impact on the EDs. Factors likely to influence this time interval are complex and include those bombing characteristics that affect the timeliness of evacuation or search and rescue, the number of victims with minor injuries, the capacity and timeliness of prehospital EMS response, and hospital proximity.

In five mass-casualty, terrorist bombings, all injured survivors arrived at hospitals within 30–60 minutes of the blast, placing an acute demand on ED resources (Table 9). The ED arrival times are delayed when evacuation is prolonged or victims are distributed to hospitals farther away from the site of the event. In the 1993 World Trade Center bombing, only 50% of injured survivors arrived at the EDs within 3.5 hours of the blast.[34] In the 2001 World Trade Center attack, injured survivors with minor injuries continued to arrive at EDs more than 24 hours after the attack.[58]

Time of Extrication of Last Entrapped Survivor

The time interval from detonation to the extrication of the last entrapped survivor helps to define the prehospital duration of a bombing involving structural collapse and may provide insight into the upper limit of survivability. Factors likely to influence this time interval are complex and include bombing, structure, and victim characteristics that lead to the prolonged entrapment of live victims, and the quality, capacity, and timeliness of search and rescue resources. Most injured survivors extricate themselves or are assisted by bystanders. In the 1995 Oklahoma City bombing, only 38 (10%) of 388 injured survivors were extricated by EMS personnel.[37] Seventy-five percent of all of the EMS extrications occurred within the first 45 minutes, and only three victims were extricated alive after the first five hours.[37,39] Early extrication is critical because delays are associated with higher in-hospital mortality, presumably due to delays in receiving life-saving medical care. In Beirut, six of the seven late deaths were associated with delayed extrication (5–9 hours).[22]

Late extrications often are futile. In the 1994 Buenos Aires bombing, one victim was extricated 36 hours after the blast, but died in the hospital.[35] In the 1998 Nairobi bombing, an American search and rescue team arrived 41 hours after the blast and found no live victims.[52] A local media account of the 1998 Nairobi bombing reported that an Israeli search and rescue team arrived 22 hours after the blast and extricated one live victim at 36 hours and two more at 50 hours (although their outcomes were not reported).[97] This mirrors the 2001 World Trade Center experience, in which only five victims originally inside the towers were extricated after the collapse, with the last being rescued at 32 hours.[56]

Limitations

This study may be limited by the definition of "mass-casualty bombing" as one that produces ≥30 casualties. The impact of excluding bombings with fewer casualties on the results is unknown. Nevertheless, this threshold seems reasonable, since ≥30 casualties is likely to tax virtually all modern emergency care systems, and result in external response systems being placed on alert.[4]

In several mass-casualty bombings, epidemiological outcomes or resource utilization data were unavailable as shown in Tables 1–3. In some cases, this in turn limited the subgroup analysis as shown in Table 6. In addition, data regarding certain injury types were unavailable for comparison in injured victims seeking emergency care, including hearing loss, vertigo, abrasions, contusions, sprains, strains, dislocations, spine fractures, closed head injuries, concussions, and acute psychiatric conditions. Data were collected from retrospective sources, potentially limiting their accuracy. In a few cases, data were reported in articles published many years after the occurrence of the precipitating event.[5,6,24]

A number of confounding variables may affect the subgroup comparisons, such as the other bombing characteristics listed in Table 1 (i.e., explosive composition or magnitude) or Table 9 (i.e., materials within the blast environment, design and construction of collapsed structures, victim density around or distance from the detonation site), as well as differences in the quality, capacity, and timeliness of medical care in the various phases after detonation. The three bombings in which pre-evacuation or pre-explosion evacuation

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Year	City	Type of attack	Type of setting or sequela	Time for first ED patient to arrive (min)	Time for last ED patient to arrive (min)	Time for last live victim to be extricated (hr)
1965[5]	Saigon	VD	OA	-	180	-
1966[6]	Cu Chi	-	-	15	15	-
1973[14]	London	VD	OA	5	60	-
1974[17]	London	-	CS	20	140	-
1980[21]	Bologna	-	SC	-	90	-
1983[22]	Beirut	VD, TS	SC	-	-	9
1987[29]	Enniskellen	-	SC	23	120	-
1987[26]	Barcelona	VD	SF	30	-	-
1991[32]	London	-	OA	16	45	-
1993[34]	New York City	VD	SF	-	840	-
1994–1998[36]	Tel Aviv	TS	-	-	50	-
1994[35]	Buenos Aires	VD	SC	-	-	36
1995[37,39]	Oklahoma City	VD	SC	15	-	13
1995[42]	Tel Aviv	TS	OA	15	-	-
1996[47]	Atlanta	-	OA	-	32	-
1996[51]	Ulster	VD	SC	-	240	-
1998[53]	Nairobi	VD, TS	SC	-	-	24–48**
1999[55]	London	-	CS	38	143	-
2001[56–59]	New York City	VD, TS	SC, SF	"Minutes"	*	32

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Table 9—Time intervals in mass-casualty, terrorist bombings (CS = confined-space; OA = open-air; SC = structural collapse; SF = structure fire; TS = terrorist suicide; VD = vehicular delivery - = Not reported; * >48 hours; **Died at scene during rescue (two live victims extricated at 50 hours in media report))

occurred were not excluded, because >100 victims were injured in each of these events. Finally, our MEDLINE search strategy was likely to have missed some mass-casualty, terrorist bombings reported in other databases (i.e., media or social sciences). The impact of these exclusions may be to overestimate or underestimate the various outcome rates.

Conclusion

Epidemiological outcomes and resource utilization vary with the characteristics of the bombing. Understanding how bombing characteristics affect the number, types, frequency, and severity of injuries may help hospital emergency managers to respond more effectively. A rational approach to the emergency management of acts of terrorism requires that the lessons learned from previous mass-casualty, terrorist bombings be incorporated into current planning and preparedness.

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Determinant		Mechanism	Effect	Category
Bomb	Magnitude and type of blast	Barotrauma from blast overpressure, including spalling, implosion, inertial, and pressure differential mechanisms	Pulmonary blast injuy — pulmonary contusion, pneumothorax, pneumomediastinum, subcutaneous emphysema, blast lung syndrome, air embolism Auditory blast injury — hearing loss, ruptured tympanic membrane, ossicle injury, vertigo Abdominal blast injury — subserosal hemorrhage, intestinal perforation, solid organ injury CNS blast injury — brain and spinal cord injury Traumatic amputations	Primary
		Primary shrapnel from bomb contents or casing	Penetrating injuries — usually from metal	Secondary
		Blast wind accelerates victims against fixed objects	Blunt deceleration injuries	Tertiary
		Blast wind differentially accelerates exposed body parts	Traumatic amputations	Tertiary
		Blast heat (instantaneous)	Flash burns on exposed skin	Quaternary
Environment	Space in which blast wave occurs	Amplitude of reflected blast waves increase geometrically in confined-space	Primary blast injuries increase in confined-space	Primary
		Duration of exposure to blast overpressure increases in smaller confined-space	Pulmonary blast injuries increase disproportionately in smaller confined-space	Primary
		Duration of exposure to blast heat increases in smaller confined-space	Percentage body surface area of flash burns increase in smaller confined-space	Quaternary
	Material upon which blast wave acts	Secondary shrapnel from environmental destruction	Penetrating injuries from glass, wood, structural material	Secondary
	Environmental effects of blast	Structural collapse	Blunt injuries, crush syndrome, compartment syndrome, inhalation injury, hypothermia	Quaternary
		Fire	Thermal burns, inhalation injury	Quaternary
Victim	Distance from detonation point	Blast wave and heat exponentially decays with distance	Primary blast injuries, traumatic amputations, flash burns occur near detonation point Penetrating injuries occur farthest away from detonation point Injury severity decreases with distance from detonation point	
	Protective barriers	Clothing, shoes protect against minor blast effects	Minor penetrating injuries and flash burns primarily affect exposed body areas	

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Table 10—Injury determinants and effects in explosions (CNS = central nervous system)

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