Bombings:
Injury Patterns & Care

Version 2.0
About the project

- This project was funded by the Centers for Disease Control & Prevention (CDC) under Cooperative Agreement, U17/CE001238-02, Terrorism Injuries: Information, Dissemination, & Exchange (TIIDE)
TIIDE partners

- American College of Emergency Physicians
- American College of Surgeons
- American Medical Association
- American Trauma Society
- National Association of County & City Health Officials
- National Association of EMS Physicians
TIIDE partners

- National Association of EMTs
- National Association of State EMS Officials
- National Native American EMS Association
- Southern Nevada Health District
- State & Territorial Injury Prevention Directors Association
Objectives

- Discuss the current global context of bombings
- Describe the four categories of blast injury
- Discuss the management & care of blast casualties
Bombings: 

Context, 

Injury Patterns, 

& Care
Explosions are by far the most common cause of casualties associated with terrorism.
Use of a conventional explosive continues to be the most probable al-Qa’ida attack scenario

John Negroponte

Director of National Intelligence

Annual Threat Assessment of the Intelligence Community

Senate Select Committee on Intelligence

11 January 2007
We judge use of a conventional explosive to be the most probable al-Qa’ida attack scenario because the group is proficient with … improvised explosive devices & is innovative in creating capabilities & overcoming security obstacles

J Michael McConnell
Director of National Intelligence
Annual Threat Assessment of the Intelligence Community
Senate Select Committee on Intelligence
5 February 2008
Conventional weapons & explosives will continue to be the most often used instruments of destruction in terrorist attacks

Dennis C. Blair
Director of National Intelligence

Annual Threat Assessment of the Intelligence Community

Senate Select Committee on Intelligence

12 February 2009
Global perspective

- India, 2008
- Pakistan, 2008
- Peru, 2008
- Israel, 2006
- United Kingdom, 2005
- Spain, 2004

Reuters/Prashanth Vishwanathan

- >36,000 bombing incidents
- >5,900 injured, 699 dead

Photo courtesy of the City of Oklahoma City
“Predictable surprise”

- Tendency to maintain the status quo
- Problem exists that will not solve itself
- Problem is getting worse
- Solving the problem incurs present costs with delayed benefits

Bazerman and Watkins, Predictable Surprises, 2004
How prepared are we?

None of the hospitals surveyed in the 7 cities had sufficient emergency care capacity to respond to an attack generating the number of casualties that occurred in Madrid.

*Hospital Emergency Surge Capacity: Not Ready for the “Predictable Surprise”*
Committee on Oversight & Government Reform
US House of Representatives, May 2008
How sick are bombing injured?

<table>
<thead>
<tr>
<th>Variable</th>
<th>Terrorist Bombings (%)</th>
<th>Other Trauma (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISS &gt;15</td>
<td>28.7</td>
<td>10.0</td>
</tr>
<tr>
<td>GCS &lt;6</td>
<td>9.5</td>
<td>2.9</td>
</tr>
<tr>
<td>Admission BP&lt;90mmHg</td>
<td>6.2</td>
<td>2.5</td>
</tr>
<tr>
<td>ICU admission</td>
<td>26.0</td>
<td>7.1</td>
</tr>
<tr>
<td>Body regions injured ≥3</td>
<td>28.3</td>
<td>6.2</td>
</tr>
<tr>
<td>Surgical procedure</td>
<td>50.8</td>
<td>36.6</td>
</tr>
<tr>
<td>In-hospital mortality</td>
<td>6.1</td>
<td>2.0</td>
</tr>
</tbody>
</table>


This table was published in “Explosion & Blast Related Injuries,” Elsayed & Atkins, 2008, ©Elsevier
Bombings: Context, Injury Patterns, & Care
Explosives

- High-order explosives (HE)
  - Ammonium nitrate/fuel oil (ANFO)
  - Nitroglycerin (NTG)
  - Trinitrotoluene (TNT)
  - C4

- Low-order explosives (LE)
  - Gunpowder/black powder
High energy explosions

- Sudden release of energy
- Solid to gas transformation
- Expands outward at supersonic speeds
- Compresses surrounding medium
Ideal blast waveform

- Peak overpressure
- Negative phase

<table>
<thead>
<tr>
<th>Pressure</th>
<th>Atm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Time (milliseconds)
Waves & surfaces

- Surfaces amplify waves
- Reflected > incident wave strength
United Kingdom, 2005

With permission of Directorate of Public Affairs, Metropolitan Police Service, London
Blast injury categories

- Primary
- Secondary
- Tertiary
- Quaternary
- Quinary (?)
Primary blast

- Unique to high-order explosives
- Tissue injury from overpressure wave
- Major effect at air-fluid interfaces
  - Gas containing structures at risk
Blast overpressure wave

Primary blast injuries

- Pulmonary injury
  - Tearing, hemorrhage, edema
- Auditory injury
  - Tympanic membrane rupture
- Abdominal injury
  - Perforation, hemorrhage
- Traumatic brain injury (TBI)
Secondary blast injury

- Most common injury
- Penetrating fragments
  - Explosive debris
  - Implanted screws & nails
  - Human remains
  - Environment made airborne

Photo courtesy of US Army
Tertiary blast injury

- Displacement of casualty against blunt or sharp objects
  - Blunt injuries
  - Impalement
- Traumatic amputations
Quaternary blast injuries

- Burns
- Crush
- Eye irritation
- Exacerbations
  - Asthma
  - COPD
  - Angina

DeshGujarat.Com/Japan K Pathak
Quinary blast injury (?)

- Contamination
  - Additives
  - Industrial

https://blastinjuryresearch.amedd.army.mil/about.cfm
Blast injury severity

- Type & amount of explosive
  - Characteristics of pressure wave
- Casualty location in relation to blast
  - $1 / r^3$
- Environment
  - Open vs. closed space, barriers
  - Structural collapse
Murrah Federal Building injuries
Bombings: Context, Injury Patterns, & Care
Blast lung injury

- Respiratory distress & hypoxia
- Severe pulmonary contusion
  - Direct alveolar & vascular injury
  - Hemorrhage & edema
- Associations
  - Pneumo/hemothorax
  - Bronchopleural fistula
  - Air embolism
Blast lung injury

- Occurs at 50-80 PSI
- Incidence
  - <10% casualties seen
  - 30-60% admitted casualties
- ↑ with enclosed space events
Blast lung injury

Used with permission of CHEST, December 1999; 116(6): 1683-1688
Blast lung injury

- Manage as major pulmonary contusion
  - High flow oxygen
  - Chest decompression for PTX/HTX
  - Balanced fluid resuscitation
  - Intubation/mechanical ventilation

- Disposition: monitored/ICU setting
Blast lung injury

- Significant scene mortality
- Critically injured survival >70%
- Near-normal lung function at 1 year
Blast auditory injury

- External ear amputation = death
- Middle ear
  - Ruptured tympanic membrane most common blast injury
- Inner ear
  - Stunned receptors & sensorineural hearing loss
Tympanic membrane rupture

- $\geq 5$ PSI
- Acute hearing loss, tinnitus, otalgia
- Marker for primary blast exposure
- Imperfect correlation with more significant blast injuries

Blast Injuries: Ear Blast Injuries.  [www.emergency.cdc.gov/masscasualties/blastinjury-ear.asp](http://www.emergency.cdc.gov/masscasualties/blastinjury-ear.asp)
TM rupture

With permission of NEJM, April 2005; 352: 1335–1342
TM rupture management

- Keep clean and dry
- Refer to ENT
  - Careful suctioning of debris, blood, & cerumen
  - Antibiotic eardrops
  - Follow-up for resolution
Blast gastrointestinal injury

- Colon most commonly injured
  - Acute perforation
  - Mesenteric avulsion with delayed perforation
- Risk of delayed clinical presentation
- Manage as acute abdomen

Blast (traumatic) brain injury

- Concussive injury without direct blow to head
- Headache, fatigue, & poor concentration
  - May have delayed presentation
  - ? link to post-traumatic stress disorder

Explosions & Blast Injuries: A primer for clinicians. [http://emergency.cdc.gov/masscasualties/explosions.asp](http://emergency.cdc.gov/masscasualties/explosions.asp)
Secondary & tertiary injuries

- Fragments follow unpredictable paths through body
- All wounds dirty
  - No primary closure
  - Consider broad spectrum antibiotics
- External signs may be tip of iceberg: follow-on radiographic survey
Multi-dimensional injury

- Combined mechanisms of blast injury
  - Each casualty may have primary + secondary + tertiary + quaternary injuries
- Complex management & exponential increase in care resources

Multi-dimensional injury
Lessons from war

- Aggressive hemorrhage control
  - Tourniquets
  - Hemostatic dressings
- Avoid hypothermia
- Controlled resuscitation
- Damage control procedures
Special considerations

- Pregnancy
- Children
- Older adults
- Communication barriers
- Mental health consequences
- Postexposure prophylaxis
Pregnancy

- Placental abruption with primary blast
- 2\textsuperscript{nd}/3\textsuperscript{rd} trimester
  - Continuous fetal monitoring
  - Screen for fetal-maternal hemorrhage
- OB/GYN consultation

DePalma, et. al., *NEJM*, 2005; 352:1335-1342
Children

- Communication & separation
- Anatomic & physiologic differences
- Head, fractures, & amputations
  - Mortality from trunk injuries
- Resource intensive/sicker
  - Regional pediatric trauma centers

Older adults

- ↑ orthopedic injuries
- Poor tolerance of blunt chest trauma
- Mobility limitations
- Quaternary injuries

Blast Injuries: Older Adults. www.emergency.cdc.gov/masscasualties/blastinjury-olderadults.asp
Communication barriers

- Multiple languages in multi-cultural population
- Antecedent deaf & chronic hearing loss
- Hearing impairment from blast
Mental health consequences

- Risk factors
  - Little or no warning/unknown duration
  - Potential threat to personal safety
  - Unknown health risks

- Responders & receivers at risk

- Acute stress reactions

HBV, HCV, & HIV postexposure?

<table>
<thead>
<tr>
<th>Risk category</th>
<th>HBV</th>
<th>HCV</th>
<th>HIV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 1. Penetrating injuries or nonintact skin exposures</td>
<td>Intervene</td>
<td>Consider testing</td>
<td>Generally no action</td>
</tr>
<tr>
<td>Category 2. Mucous membrane exposures</td>
<td>Intervene</td>
<td>Generally no action</td>
<td>Generally no action</td>
</tr>
<tr>
<td>Category 3. Superficial exposure of intact skin</td>
<td>No action</td>
<td>No action</td>
<td>No action</td>
</tr>
</tbody>
</table>

Chapman LE, Sullivent EE, et al. Recommendations for Postexposure Interventions to Prevent Infection with Hepatitis B Virus, Hepatitis C Virus, or Human Immunodeficiency Virus, & Tetanus in Persons Wounded During Bombings and Other Mass-Casualty Events --- United States, 2008, Centers for Disease Control & Prevention, MMWR, August 1, 2008, 57(RR06);1-19
Bombings: Context Redux, Injury Patterns, & Care
Oklahoma City, 1995

- 169 dead, >800 injured
- >65% not transported by EMS
- >60% went to hospitals within 1.5 miles of event
- Significant bystander rescue efforts

Photo courtesy of the City of Oklahoma City

Madrid, 2004

- 10 detonations on 4 trains
- 177 dead at scene
- >2000 injured
  - >50% went to 2 hospitals
    - 15 hospitals available
    - 312 casualties at GMUGH
    - 272 in 2.5 hours

Scene principles

- Protect responders
  - Anticipate secondary events
  - Appropriate PPE
  - Activate incident command
- Protect the public
- Protect casualties
- Protect crime scene

Photo courtesy of the Oklahoma City National Memorial & Museum
ED as scene

DeshGujarat.Com/Japan K Pathak
Mass casualty triage

- Significant initial bystander involvement

- Casualties self-triage to closest facility
  - Surge of non-critical followed by critical
  - Limited EMS triage

Mass casualty triage

- Greatest good for greatest number
- Repeated across casualty settings
- Majority not critically injured
  - Critically injured have complex, multidimensional injuries
Are there patterns?

**Table 1-3**
Patterns of Death, Hospitalizations, and Outpatient Treatment following a Bombing Event

<table>
<thead>
<tr>
<th>Author</th>
<th>Total Injured No.</th>
<th>Deaths No. (%)</th>
<th>Admitted No. (%)</th>
<th>Outpatient No. (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mallonée et al., 1996</td>
<td>759</td>
<td>167 (22)</td>
<td>83 (11)</td>
<td>509 (67)</td>
</tr>
<tr>
<td>Thompson, Brown, Mallonée &amp; Sunshine, 2004</td>
<td>420</td>
<td>19 (5)</td>
<td>66 (16)</td>
<td>335 (80)</td>
</tr>
<tr>
<td>Cooper, Maynard, Cross &amp; Hill, 1983</td>
<td>385</td>
<td>28 (7)</td>
<td>104 (27)</td>
<td>253 (66)</td>
</tr>
<tr>
<td>Frykberg &amp; Tepas, 1988</td>
<td>3357</td>
<td>423 (13)</td>
<td>881 (26)</td>
<td>2053 (61)</td>
</tr>
<tr>
<td>Biancolini, Del Bosco &amp; Jorge, 1999</td>
<td>286</td>
<td>84 (29)</td>
<td>41 (14)</td>
<td>161 (56)</td>
</tr>
</tbody>
</table>

This table was published in “Explosion and Blast Related Injuries”, Elsayed & Atkins, 2008, ©Elsevier.
Simplified casualty predictor

http://emergency.cdc.gov/masscasualties/predictor.asp
Overtriage & critical mortality

Critical Mortality (%) vs. Overtriage (%)

Real world challenges

- Lack of training for personnel
- Closed vs. open doors
- TM rupture = difficult communication
- Blood donations > requirements
- Equipment issues (e.g., external fixators)
- Casualty tracking
Model uniform core criteria for mass casualty triage

Summary

- Terrorists prefer conventional bombs
- Explosions combine four main blast mechanisms of injury
- Multidimensional & complex injuries
- System challenges require innovative and multidisciplinary approach

http://www.bt.cdc.gov/masscasualties/blastinjuryfacts.asp