Bombs, Explosions and Preparedness: A New Role for Public Health and First Responders
Satellite Conference and Live Webcast
Tuesday, March 27, 2007
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Faculty
Ziad N. Kazzi, MD, FAAEM
Assistant Professor
Co-Director
Center for Emergency Infections & Emergency Preparedness
Department of Emergency Medicine
University of Alabama at Birmingham

Program Objectives
- Describe important historical events involving explosions.
- Discuss different clinical aspects of blast injuries.
- Describe public health and first responder activities in reaction to explosions and blasts.

FBI Reported Bombings, 1988-1997

FBI Bombing Database 1988-1997
- 17,579 bombings
- Numbers doubled over the 10 year period
- Number of bombing peaked in 1992
- 78% were explosives and 22% were incendiaries
FBI Bombing Database 1988-1997

- 427 deaths with a peak in 1995 (Oklahoma City bombing)
- 4,063 bomb-related injuries
- Incendiary bombs caused more injuries than explosives

Special Characteristics of Bombing Victims

- Victims of terrorist bombings (906) were compared with 55,033 casualties of non-terror related trauma.

Special Characteristics of Bombing Victims

- Bombing resulted in significantly different:
  - Injury complexity
  - Increased severity
  - More body regions involved
  - Enhanced use of intensive care
  - Prolonged hospital stay
  - More surgical interventions
  - Increased hospital mortality

Discovery

- A Mongol bomb thrown against a charging Japanese samurai during the Mongol invasions of Japan, 1281.

Discovery

- Believed to be discovered in China in the 10th century
- Called black powder or gun powder
  - Charcoal
  - Potassium nitrate
  - Sulfur
- Used for signals and fireworks
- Then used in warfare
Spread
• Brought to Europe by an English monk named Roger Bacon who published the formula.
• Developed further by a German Franciscan monk, Berthold Schwarts.

Nitroglycerin
• Invented by Italian chemist Ascanio Sobrero in 1846
• Liquid form
• Ignites and explodes spontaneously

Dynamite
• Invented by Alfred Noble
• Added silica to liquid nitroglycerine making the more malleable dynamite
• Also invented blasting caps that were made with a fuse and gunpowder

Ammonium Nitrate/Fuel Oil (ANFO)
• Fuel oil (diesel but can be kerosene or molasses)
• 80% of explosives used in the USA
• High explosive
  – Requires a booster

Texas City Disaster 1947
• Seven KiloT of ANFO exploded on board of SS Grandcamp in the port killing 581 people.

1983 - US Marine Barracks and Embassy Bombings, Beirut
• At 6:20 a.m. a yellow truck drove into the US Marine headquarters.
• Truck carried explosives equivalent to 12,000 pounds of TNT.
• This initial explosion was coupled with another explosion 20 seconds later at the French Marine barracks.
• 307 people died and 75 were injured.
1995 - Oklahoma City Bombing
• Ryder truck detonated in front of building containing 2,300 kg of explosive material.
• Blast destroyed or damaged 324 buildings within radius of sixteen-blocks.
• 168 confirmed dead.
• 153 victims had been treated at St. Anthony Hospital, eight blocks from the blast.

U.S. Embassy Bombings
Dar es Salaam, Tanzania and Nairobi, Kenya
August 7, 1998
• Car bombs in vehicles, each adjacent to the embassies, were detonated simultaneously at 10:45 a.m.
• Total of 257 people were killed and 7,000 wounded.

World Trade Center
September 11, 2001
• Both Twin Towers of the World Trade Center were destroyed.
• 25 surrounding buildings were damaged.
• 2749 people were killed in WTC and on board both American Flight 11 and United Flight 175.

Iraq 2003 - Present
• Bombing tactics have largely been composed of military bombings, suicide bombings, and car bombings.

Iraq 2003 - Present
• As of late 2003, 40 to 60 percent of all attacks began with an IED.
  – Some of these attacks included direct fire attacks immediately following the detonation of the device.
  – More and more IEDs were subsequently being used as a stand-alone means to engage a convoy.

Madrid Commuter Train
March 11, 2004
• Using 13 IEDs in backpacks, ten explosions occurred aboard four commuter trains over 3 minutes.
• All trains were traveling on the same line and in the same direction.
• 191 people were killed and 2050 were injured.
London Underground and Double Decker Bus, July 7, 2005

- Three suicide bombs exploded within 30 seconds of each other on the underground system.
- Almost one hour after the underground explosions, a suicide bomb was detonated on a double decker bus.
- 52 people were killed and around 700 were injured.

Explosives

- Chemical compound that is able to release stored energy in the form of rapidly expanding gases.

High Explosives

- Stored energy is released rapidly
- Detonation
- Examples: TNT and dynamite

Idealized Blast Overpressure Waveform Seen Only in High-order Explosives (HE)
Low Explosives
• Stored energy is released slowly
• Combustion or deflagration
• Examples: gun powder, fuel
• No blast wave or over pressurization
• Injury results from:
  – Thermal burns,
  – Ballistic (shrapnel)
  – Suffocation (fumes and toxins)

Host
• Age
• Sex
• Height
• Medical history
• Access to care

Environment
• Open space
• Enclosed or confined space
• Structural collapse

Open Space
• Potential for shrapnel to travel a large distance (>100 m)
• Less primary blast injuries

Enclosed Space
• Increased mortality
• Increased blast pressure
• Complicated rescue

Structural Collapse
• Increased mortality:
  – Primary blast wave
  – Tertiary and quaternary injuries
• Crush syndrome
Impact of Building Collapse on Outcome In Oklahoma City Terrorist Bombing, 1995

<table>
<thead>
<tr>
<th>Casualty Location</th>
<th>No. of Casualties</th>
<th>No. of Dead(%)</th>
<th>No. of Survivors</th>
<th>No. of Survivors Hospitalized (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collapsed</td>
<td>175</td>
<td>153 (87)</td>
<td>22</td>
<td>18 (82)</td>
</tr>
<tr>
<td>Uncollapsed</td>
<td>186</td>
<td>10 (5)</td>
<td>176</td>
<td>32 (18)</td>
</tr>
<tr>
<td>Total</td>
<td>361</td>
<td>163 (45)</td>
<td>198</td>
<td>50 (25)</td>
</tr>
</tbody>
</table>

Madrid Bombing
- Rupture of the tympanic membranes occurred in 99 of 243 victims
- Chest injuries in 97/243 victims
- Shrapnel wounds in 89/243
- Fracture in 44
- Burns in 45
- Eye injuries in 41
- Abdominal injuries in 12
- Traumatic amputations in 5

Immediate Effects of Blast and Explosions
- Primary - direct effects (e.g., overpressurization and underpressurization)
  - Rupture of tympanic membranes
  - Pulmonary damage
  - Rupture of hollow viscera
- Secondary
  - Penetrating trauma
  - Fragmentation injuries

Immediate Effects of Blast and Explosions
- Tertiary - effects of structural collapse and of persons being thrown by the blast wind
  - Crush injuries and blunt trauma
  - Penetrating or blunt trauma
  - Fractures and traumatic amputations
  - Open or closed brain injuries
- Quaternary - burn, asphyxia, and exposure to toxic inhalants

Primary Blast Injuries
- Result from overpressurization or underpressurization relative to atmospheric pressure
- Result from the interaction of high frequency stress waves and low frequency shear forces
Primary Blast Injuries
- Affect air-filled organs or air-fluid interfaces
- Rupture of tympanic membranes, pulmonary injury, air embolization and rupture of hollow viscera are the most common patterns

Tympanic Membrane Rupture
- Occurs at the lowest pressure (5 psi)
- May be bilateral
- May be the earliest sign to look for
  - Deafness, tinnitus and vertigo
- If more severe, may cause dislocation of the oval, round window or the ossicles
  - Permanent hearing loss
- Other organs need higher pressures (56-76 psi) so if the TM is intact, they are unlikely

Tympanic Membrane Rupture
- Normal and Perforated Right Tympanic Membranes

The drawing of a traumatic perforation shows an irregular margin or rim with blood or a blood clot, and the drawing of a permanent central perforation shows a tympanocele.

Pulmonary Injuries
- Second most common primary blast injury
- Hemorrhage
  - Pulmonary contusion (appearing as a bihilar "butterfly" pattern on chest radiographs)
  - Pneumothorax
  - Hemothorax
  - Pneumomediastinum
  - Subcutaneous emphysema

Pulmonary Injuries
- Onset of symptoms is commonly within minutes.
- Body armor protects from penetrating (secondary) but not primary blast injuries.
- Early onset pulmonary edema carries a grave prognosis.
TM Perforation - Pulmonary Injury

- Among 17 critically ill victims with pulmonary injuries from the blast:
  - 13 had ruptured tympanic membranes and 4 did not
  - Rupture of tympanic membranes occurred in 18 of 27 critically injured victims
    - 17 of these were bilateral

  *Data from Madrid*

Screening

- 647 survivors of explosions on buses used immediate radiography of the chest to screen for pulmonary injuries from the blasts.
- Primary injuries, in some form, were found in 193 persons:
  - 142 had isolated perforation of the eardrum.

Screening

- 51 had other forms of primary blast injuries:
  - 18 with isolated pulmonary injuries
  - 31 with combined otic and pulmonary injuries
  - Two with intestinal injuries

Visceral Injury

- Visceral injury is third most common primary blast injury.
- Rupture of the colon and, less frequently, the small intestine may occur as an immediate result of a blast.
- Mesenteric ischemia or infarct can cause delayed rupture of the large or small intestine; these injuries are difficult to detect initially.

Other Injuries

- Ruptured globe or serous retinitis
- Concussion
- Air embolism may be seen and can present as stroke, MI, acute abdomen, blindness, deafness, spinal cord injury, or claudication

Secondary Injuries

- Penetrating injuries from:
  - Primary fragments (fragments that are part of the weapon)
  - Secondary fragments (those that result from the explosion)

Ocular war injuries in Iraq are common.
Tertiary Injuries

- Caused by trauma from falling objects or from bodies being thrown against other objects
  - Blunt and penetrating injuries
  - Crush syndrome and secondary rhabdomyolysis
  - Open or closed head injuries

Crush Syndrome

- Entrapment increases mortality
- Rhabdomyolysis: Myoglobinuric renal failure and hyperkalemia

Crush Syndrome

Statistics Related to Major Earthquakes in the Past 18 Years

<table>
<thead>
<tr>
<th>Location and Year</th>
<th>Death</th>
<th>Crush Victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spitak, Armenia, 1988</td>
<td>25,000</td>
<td>600</td>
</tr>
<tr>
<td>Northern Iran, 1990</td>
<td>&gt;40,000</td>
<td>?</td>
</tr>
<tr>
<td>Kobe, Japan, 1995</td>
<td>5,000</td>
<td>372</td>
</tr>
<tr>
<td>Marmara, Turkey, 1999</td>
<td>&gt;17,000</td>
<td>639</td>
</tr>
<tr>
<td>Chi-Chi, Taiwan, 1999</td>
<td>2,405</td>
<td>52</td>
</tr>
<tr>
<td>Gujarat, India, 2001</td>
<td>20,023</td>
<td>35</td>
</tr>
<tr>
<td>Boumerdes, Algeria, 2003</td>
<td>2,266</td>
<td>20?</td>
</tr>
<tr>
<td>Bam, Iran, 2003</td>
<td>26,000</td>
<td>124</td>
</tr>
<tr>
<td>Kashmir, Pakistan, 2005</td>
<td>&gt;80,000</td>
<td>118</td>
</tr>
</tbody>
</table>

Total       >217,000       >1900

Rhabdomyolysis

- Secondary complication of crush syndrome
- Myoglobinurea and CK elevation
- Treatment is IV hydration, urinary alkalization (with mannitol)

Quaternary Injuries

- Burns (chemical or thermal)
- Toxic inhalation of carbon monoxide or hydrogen cyanide gas
- Exposure to radiation
- Inhalation of dust containing coal or asbestos
- Exacerbation of chronic illnesses

Carbon Monoxide - Mechanism

- Binds hemoglobin to form carboxyhemoglobin that is unable to carry oxygen
- Uncouples oxidative phosphorylation
<table>
<thead>
<tr>
<th>Carbon Monoxide - Clinical</th>
<th>Carbon Monoxide - Labs</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Neurological manifestations</td>
<td>• Carboxyhemoglobin level</td>
</tr>
<tr>
<td>• Cardiovascular manifestations</td>
<td>• Creatine kinase</td>
</tr>
<tr>
<td>• Gastrointestinal manifestations</td>
<td>• EKG, CXR</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hydrogen Cyanide - Mechanism</th>
<th>Hydrogen Cyanide</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Inhibits cytochrome oxidase and uncouples oxidative phosphorylation</td>
<td>• Clinical:</td>
</tr>
<tr>
<td>• Cells are unable to use oxygen</td>
<td>– Neurological</td>
</tr>
<tr>
<td>• Anaerobic metabolism prevails</td>
<td>– Cardiovascular</td>
</tr>
<tr>
<td></td>
<td>– Bitter almond: only 60% of population can detect</td>
</tr>
<tr>
<td></td>
<td>– Cherry red skin, fundoscopic exam</td>
</tr>
<tr>
<td></td>
<td>• Labs:</td>
</tr>
<tr>
<td></td>
<td>– Lactic acid</td>
</tr>
<tr>
<td></td>
<td>– O$_2$ extraction and venous O$_2$ saturation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Exacerbation of Chronic Illnesses</th>
<th>Prehospital</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Asthma and COPD</td>
<td>• Airway</td>
</tr>
<tr>
<td>• Diabetes Mellitus</td>
<td>• Breathing</td>
</tr>
<tr>
<td>• Hypertension</td>
<td>• Circulation</td>
</tr>
<tr>
<td>• Coronary artery disease</td>
<td>• Triage categorization</td>
</tr>
<tr>
<td>• Peptic ulcer disease</td>
<td>• Did the blast occur in an enclosed setting?</td>
</tr>
<tr>
<td>• Alcohol and substance abuse</td>
<td>• Regular trauma/burn protocols</td>
</tr>
<tr>
<td>• Mental health</td>
<td>• Radiation survey</td>
</tr>
<tr>
<td></td>
<td>• Secondary device survey</td>
</tr>
<tr>
<td></td>
<td>• Survey for chemical contamination</td>
</tr>
</tbody>
</table>
Prehospital

- Incident command
- Securing the area
- Judicious use of IV fluids:
  - Overzealous fluid administration may worsen primary pulmonary injury or even bleeding.
- Cautious mechanical ventilation:
  - Mechanical ventilation and positive pressure may increase the risk of alveolar rupture and air embolism.

Prehospital Special Considerations

- Cautious air transport
- Air embolization:
  - Place patient in a prone left lateral position

Triage Categorization

- Red — Immediate
- Yellow — Delayed
- Black — Dead or expectant
- Green — Minimal

Transport

- Transport to the nearest facility of red patients.
- Green patients should be directed to other hospitals that are further away and that are not necessarily level I trauma centers.

Blast Lung Injury

- Should not rely on TM rupture to predict lung injury:
  - TM perforations are found in only 60% of patients with clinically significant injuries.
  - Clinically significant injuries are present in less than 30% of patients with TM perforations.

Blast Lung Injury

- Patients with normal CXR and ABGs, who have no complaints that would suggest BLI, may be discharge after 4-6 hours of observation.
**Blast Lung Injury**
- Management similar to pulmonary contusions
- Complex fluid management
- Mechanical ventilation will increase the risk of air embolization

**Management of Secondary Injuries**
- As per protocol
- Watch for unusual shrapnel such as nails and bolts

**Management of Tertiary Injuries**
- As per trauma protocols
- Look for crush syndrome especially in structural collapse:
  - Myoglobinurea
  - Renal failure
  - Hyperkalemia

**Major Steps in Treating Patients With The Crush Syndrome**
- Consider the importance of early fluid administration in the field.
  - Initiate an infusion of isotonic saline at the earliest convenience, followed by hypotonic saline-alkaline solution.
  - In patients with adequate urinary flow, add mannitol to the solution.
  - Avoid empirical administration of potassium-containing fluids.

**Major Steps in Treating Patients With The Crush Syndrome**
- Closely monitor each patient's fluid intake and urinary output.
  - Administer up to 6 to 12 liters of appropriate fluids per day.
  - Remember that urinary output may be substantially lower than the amount of administered fluid.
  - Amount of fluid defined by the basis of the clinical course or central venous pressure measurements.

**Major Steps in Treating Patients With The Crush Syndrome**
- Correct electrolyte abnormalities.
  - Hyperkalemia is often fatal and should be corrected vigorously.
  - Hypocalcemia should be corrected only if it causes symptoms.
  - Remember that virtually any other electrolyte disturbance may occur as well and should be treated.
**Major Steps in Treating Patients With The Crush Syndrome**

- Consider dialysis as a lifesaving procedure.
- Begin dialysis when indicated by the presence of any of the following: oliguria or anuria, volume overload, or biochemical abnormalities such as severe uremia, hyperkalemia, and acidemia.

**Management of Crush Syndrome**

- IVF: Start in the field
- Urinary alkalinization:
  - Myoglobinurea, Urine pH>7
- Mannitol
- Hemodialysis:
  - Anuric patients, acidemic patients
  - Correction of electrolyte abnormalities
  - Advanced surge capacity planning

**Management of Quaternary Injuries**

- Inhalational injuries
- Carbon monoxide
- Hydrogen cyanide
- Contamination with radionuclides

**Carbon Monoxide**

- 100% oxygen therapy
- Hyperbaric oxygen therapy

**Cyanide Antidotes**

- The Lilly kit
  - Amyl nitrite pearls
  - Sodium nitrite
  - Sodium thiosulfate
- Hydroxocobalamin
  - Bind cyanide to form cyanocobalamin or Vitamin B12
  - Recently FDA approved
Dirty Bombs
• Scene decontamination:
  – Removal of clothes
  – Soap and water
  – Life saving procedure should precede decontamination

Radiopharmaceuticals
<table>
<thead>
<tr>
<th>Radionuclide</th>
<th>Medication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iodine</td>
<td>KI (potassium iodide)</td>
</tr>
<tr>
<td>Transuranics such as Plutonium &amp; Americium</td>
<td>Ca-DTPA</td>
</tr>
<tr>
<td>Uranium</td>
<td>Bicarbonate</td>
</tr>
<tr>
<td>Cesium, Rubidium, Thallium</td>
<td>Prussian Blue</td>
</tr>
<tr>
<td>Tritium</td>
<td>Water</td>
</tr>
</tbody>
</table>

Mental Health Background
• Mental illness is common after disasters in victims and first responders.

• Psychopathology similar in different cultures.

• Responses and coping mechanisms may be different amongst different people or cultures.

Long-term Effects After the Tokyo Sarin Attack
Residual symptoms after 1 year (n=303)

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Prevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye symptoms</td>
<td>56 (18.5%)</td>
</tr>
<tr>
<td>Fear of the subway</td>
<td>39 (12.9%)</td>
</tr>
<tr>
<td>Easy fatigability</td>
<td>36 (11.9%)</td>
</tr>
<tr>
<td>Fear concerning escape from the attack</td>
<td>35 (11.6%)</td>
</tr>
<tr>
<td>Flashbacks</td>
<td>32 (10.6%)</td>
</tr>
<tr>
<td>Headache</td>
<td>26 (8.6%)</td>
</tr>
<tr>
<td>Depressive feelings</td>
<td>24 (7.9%)</td>
</tr>
<tr>
<td>Lack of concentration</td>
<td>23 (7.6%)</td>
</tr>
</tbody>
</table>

Reactions to Stress
• Occur in stages, each one characterized by a specific psychological mechanism.

• Symptoms include:
  – Flashbacks
  – Difficulties in remembering
  – Avoidance of stimuli
  – Blunting of responses
  – High arousal level
  – Obsessive ruminations

Clinical Illnesses
• Post Traumatic Stress Disorder (PTSD)
• Depression
• Anxiety
• Alcohol abuse
Special Aspects - Victims
- Events are unexpected
- Often affect civilians
- Bombing victims sustain traumatic disfiguring injuries

Special Aspects - Responders
- Bombing victims sustain traumatic disfiguring injuries
- Scene may be hazardous
  - Structural collapse
  - Secondary devices
  - Inhalational injuries from potential toxins
- Distress from inability to save entrapped victims

World Trade Center
- After Sept. 11, at least three New York men involved in rescue and recovery efforts have committed suicide:
  - James Kay Jr., an emergency medical technician, shot himself early last year.
  - Six months later, Daniel Stewart, another EMT, hanged himself.

Interventions
- Increased awareness
- Debriefing
- Mental health specialist
  - Screening
  - Psychotherapy
  - Pharmacologic therapies
  - Other methods

Physical Rehabilitation for Head Injury
- Constrain-induced therapy
- Optimal at 3 months after what injury
- University of Alabama at Birmingham
  - Taub Therapy Clinic

Upcoming Programs
Pandemic Influenza:
Alabama Schools Need to Plan Now
Monday, April 2, 2007
3:30 - 5:00 p.m. (Central Time)

For complete list of upcoming programs visit our website
www.adph.org/alphtn