Halifax, Nova Scotia December 6, 1917

- Belgian ship Imo collides with French munitions ship Mont Blanc
- 35 tons of benzene ignite on top deck of the Mont Blanc
- 15 minutes later the fire ignites 2300 tons of picric acid, 10 tons of gun cotton, 300 rounds of ammunition and 200 tons of TNT
- 2.5 km of city leveled, 150 tidal wave, 2000 dead, 9000 injured, 20,000 homeless (in a city of 50,000), entire fire department lost
April 16, 1947, Texas City, Texas

- The ship Grand Camp catches fire
- 20 minutes later cargo of ammonium nitrate fertilizer explodes
- A second more powerful blast shortly later followed by a 150 foot tidal wave
- 600 deaths in a city of 16,000—loss of entire fire department
1970’s-80’s Ireland

- 1532 bombing victims, 9 hospital deaths*
  - 10 chest and abdominal injuries - 5 deaths
  - 16 major limb amputations, 4 deaths
  - 50 superficial burns - none required skin grafts
- 828 British servicemen killed or injured in bombings 1979-84**
  - 216 deaths (26%). Most died at the scene


Sha’arei Zedek Medical Center 1975-79

- 24 terrorist explosions – 511 casualties
  - 340 casualties a SZMC
    - 26 (7.6%) DOA or died in ER
  - 272 required admission
    - 3 (1.1%) died in hospital
  - 13 open air explosions
  - 6 indoor explosions
  - 5 bus explosions
  - Overall mortality 8.5%

Classification of Explosives

- High Order Explosives
  - TNT
  - C-4
  - Semtex
  - Nitroglycerin
  - Dynamite
  - Ammonium Nitrate Fuel Oil

- Low Order Explosives
  - Pipe Bombs
    - Gunpowder
    - Petroleum based bombs (Molotov Cocktails)
    - Aircraft used as guided missiles (Sept. 11)

http://www.cdc.gov/masstrauma/preparedness/primer.htm
Physics of Blast Wave

Pressure Wave in Air

- Pressure Wave close to explosion moves at supersonic speed
- Speed of wave progression in water greater than in air and force maintained with distance
Physics of Blast Wave

- If pressure wave in close apposition to a solid barrier, the pressure wave reflected off the solid barrier may be many times greater than the initial pressure wave.

- A low grade pressure wave in an out of doors explosion maybe a lethal pressure wave in a closed space.

http://www.vnh.org/EWSurg/ch05/05PathologyBI.html
<table>
<thead>
<tr>
<th>Category</th>
<th>Potential Injuries</th>
</tr>
</thead>
</table>
| Primary       | Lung  
               Tympanic Membrane  
               Intestine  
               Ruptured Globe  
               Cerebral Concussion |
| Secondary     | Penetrating Trauma  
               High risk of penetrating eye injury |
| Tertiary      | Closed and Open head Injury  
               Fractures  
               Traumatic Amputations |
| Quaternary    | Burns  
               Crush Injuries  
               Bloodborne Infections  
               Smoke/dust inhalation  
               Exposure to Nonconventional Weapons |
## Terrorist Bombing Victims at SZMC Jan 1995-Jan 2004

<table>
<thead>
<tr>
<th>Injury</th>
<th>N (%)</th>
<th>Closed Space N(%)</th>
<th>Open Space N(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blast Lung</td>
<td>23 (50)</td>
<td>18 (72)</td>
<td>5 (24)</td>
</tr>
<tr>
<td>Burns</td>
<td>14 (30)</td>
<td>10 (40)</td>
<td>4 (19)</td>
</tr>
<tr>
<td>Abd solid organ</td>
<td>7 (15)</td>
<td>2 (9)</td>
<td>5 (24)</td>
</tr>
<tr>
<td>Penetrating GI Injury</td>
<td>3 (6.5)</td>
<td>1 (4)</td>
<td>2 (9.5)</td>
</tr>
<tr>
<td>Intest Blast Injury</td>
<td>1 (2)</td>
<td>1 (4)</td>
<td>0</td>
</tr>
<tr>
<td>Vasc Injury</td>
<td>5 (11)</td>
<td>1 (4)</td>
<td>4 (19)</td>
</tr>
<tr>
<td>Rupt Tymp Membrane</td>
<td>26 (56)</td>
<td>19 (76)</td>
<td>4 (19)</td>
</tr>
</tbody>
</table>
BLAST LUNG INJURY FOLLOWING TERRORIST BOMB ATTACKS

Vered Avidan\textsuperscript{1}, Moshe Hersch\textsuperscript{2}, William Schecter\textsuperscript{1,3}

Departments of Surgery\textsuperscript{1} and ICU\textsuperscript{2}, Shaare-Zedek Medical center,
Department of Surgery University of California, San Francisco
SanFrancisco General Hospital\textsuperscript{3}.
Introduction
# Introduction

<table>
<thead>
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<th>Date</th>
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<td>30/07/2002</td>
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<tr>
<td>21/08/1995</td>
<td>27/01/2002</td>
<td>31/07/2002</td>
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<td>09/08/2001</td>
<td>19/06/2002</td>
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</tbody>
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Blast Lung Injury
Objective

• Review our experience in order to characterize clinical presentation, treatment and outcome.
Setting
Location

[Map with locations marked: CITY CENTER and SZMC]
Methods

• Retrospective review of patient files
  – Victims of terrorist bomb attacks
  – Blast lung injury
  – ICU admission

• Telephone interview.
Results

- 916 ED admissions following 31 TBAs.
- 41 ICU admissions.
- 29 BLI.
- Age: 4-75 years.
- Male: 15, Female: 14.
24/29 (83%) - Closed Space Explosions
Clinical presentation

• Hypoxia in all patients
  – dyspnea \ tachypnea
  – cyanosis
  – convulsion, lateralization signs
  – disturbed consciousness, coma

• Hemoptysis \ bloody-frothy tracheal secretions \ bloody NGT aspirate.

• Short deterioration.
Severity of hypoxia - PaO$_2$/FiO$_2$ (Ventilated Patients, n=22)

<table>
<thead>
<tr>
<th>Range</th>
<th>Patients</th>
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<tbody>
<tr>
<td>&lt; 60</td>
<td>7 patients</td>
</tr>
<tr>
<td>60-100</td>
<td>4 patients</td>
</tr>
<tr>
<td>100-200</td>
<td>5 patients</td>
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<tr>
<td>&gt; 200</td>
<td>4 patients</td>
</tr>
<tr>
<td>no data</td>
<td>2 patients</td>
</tr>
</tbody>
</table>
1. Pulmonary infiltrates:
   • Present in all patients.
     – Bilateral - 20
     – unilateral - 9
   • May worsen over time and fluid replacement.
   • Typical - Butterfly (bat wings) infiltrates.
Butterfly infiltrates
Bat-wing infiltrate
Chest X-ray

2. Pneumothorax:
   - unilateral: 7 patients
   - bilateral: 5 patients

3. Pneumomediastinum:
   - 3 patients
Mechanical Ventilation

- 22/29 (76%) - mechanical ventilation.
- Median length - 4 days (range 1-78).
- Intubation and ventilation:
  - on scene\ in ED 17
  - within 2 hours 4
### Mechanical Ventilation - PEEP

<table>
<thead>
<tr>
<th>Maximal PEEP</th>
<th>n</th>
<th>Aids\special modes</th>
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</thead>
<tbody>
<tr>
<td>15</td>
<td>1</td>
<td>NO inhalations</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>HFV</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>-</td>
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<tr>
<td>12</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>HFV</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>9</td>
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<tr>
<td>0</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td><strong>Missing data</strong></td>
<td><strong>2</strong></td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>22</strong></td>
<td></td>
</tr>
</tbody>
</table>

- Lowest possible PEEP should be used to avoid air emboli.
Fluid replacement

• Keep to a minimum
• Crystalloids \ colloids as needed.
Additional Injuries

• Primary blast injuries:
  ruptured tympanic membranes 25 (86%)
  intestinal blast injury 3 (10%)

• Others:
  abdominal solid organs 3 (10%)
  vascular injuries 2 (7%)
  limb fracture 8 (28%)
  limb amputation 2 (7%)
  burns 15 (52%)
Intestinal Blast Injury

- Jerusalem Bus Bombing reported in 1989
- 3 dead at the scene and 55 survivors
- 29 patients hospitalized
- 2 patients with perforated intestine with late presentation (delayed dx vs delayed perforation)

Intestinal Blast Injury
Length of stay

- ICU: median 6 days (range 1-81).
- Hospital LOS: median 14 days (range 1-250).
Complications

• 2 patients had suspected air embolus:
  – 1 patient developed VT-VF and acute injury pattern in EKG.
  – 1 patient developed Lt. Hemiparesis which gradually resolved.
Mortality

• 1 patient (3.4%) died of sepsis and MOF.
Long term follow-up

- 21/28 survivors responded.
- Follow up: 6 mo - 21 y (median 3y).
- 16 (76%) - no respiratory sequelae.
- 3 (14%) patients - use inhalers
- 1 (5%) patient - respiratory symptoms
- 1 (5%) patient - abnormal PFT
Case 1 Primary Blast Injury

- 12 yo girl involved in bus bombing Jan 23, 2004
- Admitted with sob but hemodynamically stable
- CT scan ordered 40 minutes after arrival
- Intubated in CT Scan
- Fresh blood suctioned from ET tube
Case 1

- Infiltrates worsen
- CXR deteriorates
- Hemodynamic instability requires large infusion of crystalloid
- Gas exchange deteriorates, requires FiO2 100% and HFPPV
Case 1

- Patient improves with HFPPV and diuresis
- Develops diplopia for unclear reasons which improves over 2 month period
- Returns to school
Case 2 Primary and Tertiary Blast Injury

- 73 yo former Pediatric Head Nurse
- Bus explosion Jan 29, 2003
- Admitted with sob, chest pain
- Injuries:
  - Flail chest
  - Pulmonary contusion
  - Fracture right humerus
  - Traumatic bilateral finger amputations
  - Partial thickness facial burns
Case 2

- 10 days of mechanical ventilation
- 1 month of in hospital rehabilitation
- Prolonged recovery at home
Significant Risk of Left Sided Air Embolism

- Caused by alveolar-pulmonary venous fistula due to disruption of alveoli due to primary blast injury
- Possible Patent Foramen Ovale
- Risk increased with positive pressure ventilation
- Clinical manifestations
  - Blindness
  - “Hemiparesis
  - Paraplegia
  - Acute obstruction of other vascular beds
Evaluation of Patient for Air Embolism

• Fundoscopic Exam – bubbles in retinal artery?
• Echocardiogram
• CT Head
• Most examinations are non-diagnostic
Treatment of Patient with Air Embolus

- Left Decubitus Position, Head Down, Feet Up
- Keep Peak Inspiratory Pressure Low if Patient Requires Mechanical Ventilation
- Hyperbaric Chamber
Case 3 Primary Blast Injury with Air Embolism and ? Intestinal injury

- 14 yo boy admitted in shock, unconscious with pH 7.0 and pO2 70
- Intubated in ER and moved immediately to RR (secondary triage)
- Resp Status improves
- CT Chest and Abd ok except for pulm blast injury
- CT head ? Air embolus
Case 3 Hospital Course

- Resp Status remains stable
- Mental status begins to improve
- Dense left hemiparesis becomes evident
BP becomes labile
Vomits a small nail
Abdominal rigidity develops
KUB in the middle of the night suggests free air
Dx of delayed intestinal perf due to blast injury or shrapnel injury
Exp lap: NORMAL
Case 3

- Condition at discharge:
  - Left hemiparesis
  - Extremely labile

- 2 months later Hemiparesis almost completely resolved, playing soccer
Conclusions - 1

- BLI is a common serious injury among severely injured victims of closed space suicide explosions.
Conclusions - 2

- BLI often requires early mechanical ventilation.
- Clinically significant decompensation is unlikely after the first few hours.
Conclusions - 3

• Other blast injuries may occur and should be considered.
Conclusions - 4

• Death due to BLI is rare in patients who survive the initial explosion.