Blast Injuries

Physics and Physical Consequences

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Blast Injuries

• Why should we worry about explosions?
  • Rhode Island is not a war zone, but…
  • Not all blast injuries occur in Iraq
  • Not all blast injuries are war-related
Blast Injuries

• **Presentation**
  • Acts of war or terrorism
  • Occupational hazard
  • Isolated injuries
  • Unsafe behavior
  • Children: victims
    • Of war
    • Of lack of judgement
    • Of curiosity
Blast Injuries

• Definitions
  • Explosion: rapid release of energy
  • Radial expansion of the energy
    • “Ideal Shock Wave”
    • Reflecting and absorptive forces
  Buildings and objects
  People
Blast Injuries

(Distances in 10's of Ft, Contours in Psi)

3D Overpressure Contour Plot

bldng.bpe 04/17/97 11:31  Yld=75.0 Lbs  HoB=3.00 Ft  Ah=NONE  Av=NONE

Engineering Analysis, Inc., Huntsville, AL
Blast Injuries

Engineering Analysis, Inc., Huntsville, AL
Blast Injuries

• Definitions
  • Explosion: rapid release of energy
  • Radial expansion of the energy
  • Direct and indirect effects
    • Primary blast injuries
    • Secondary blast injuries
    • Tertiary blast injuries
    • Quaternary blast injuries
Blast Injuries

Classification

- Primary:
  - Direct effect of blast energy on the body
- Secondary:
  - Projectiles set in motion by blast
- Tertiary:
  - Displacement of body (parts), crush
- Quaternary:
  - Burns, inhalation, toxins
Blast Injuries

All you’ll ever need to know about trauma

- Mass casualties/disaster planning
- Triage
- Burns
- Inhalation injury
- Pressurization injury
- Blunt trauma
- Penetrating trauma
Blast Injuries

Classification

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Blast Injuries

Friedlander wave

Pressure

Baseline

Peak overpressure

Positive phase (Blast wave)

Negative phase (vacuum)
Blast Injuries

Primary blast effect

- Negative phase (Blast wind)
  - Lasts 10x longer than positive phase
  - Causes vacuum
  - “Sucks” objects into area
- Windows pulled out of buildings
- Flying debris
Blast Injuries

Primary blast effect

Oklahoma City - April 1995 - 18 years ago
Blast Injuries

Primary blast effect

- 19 children in 2nd floor day-care
- First comprehensive study of blast injuries in children

Blast Injuries

Primary blast effect

- …but not the first pediatric blast disaster
- 1927 Bath school bombing

Kim D et al, J Surg Res 2010
Blast Injuries

Primary blast effect

- Maximal impact within blast perimeter
Blast Injuries

Primary blast effect

- Immediate proximity:
- Head trauma
  - Major cause of death in children

Non-survivable head injuries 90%

Blast Injuries

Primary blast effect

- Immediate proximity:
  - Head trauma
  - Cause of death in 41.6% of victims

Blast Injuries

Primary blast effect

- Blast wave = sound wave
- Travels readily through air
  - = 500 m/sec
Blast Injuries

Primary blast effect

- Blast wave = sound wave
- Travels readily through air, *but*
  - Rapid dissipation
  - Energy decreases rapidly
    - …in open space
Blast Injuries

Primary blast effect

• Blast wave = sound wave
• Travels readily through air, *but*
  • Rapid dissipation
  • Energy decreases rapidly
    • …but not if enclosed
Blast Injuries

Primary blast effect

- Madrid train bombings (March 2004)
  - 191 dead, 1,800 wounded
- Boston marathon bombings (April 2013)
  - 3 dead, 264 wounded
Blast Injuries

Mass Casualty Incident (MCI)

- Mortality:
  - Structural collapse 25% (6-44%)
  - Confined space 4% (0-9%)
  - Open space 2% (0-4%)

- Rationing care rarely needed in open explosions
Blast Injuries

Primary blast effect

- Travels more slowly in solids/liquids
- Maximal effect at interfaces
Primary Blast Injuries

- **Mechanisms**
  - Shock wave converted into:
    - Stress wave
    - Shear wave
Primary Blast Injuries

• **Shear waves:**
  - Occurs at points of attachment
    • Ligament of Treitz
    • Aortic arch (ductus)
Primary Blast Injuries

- **Stress waves:**
  - Mostly at interfaces:
    - Solid/Air
    - Solid/Liquid
    - Air/Liquid
Blast Wave Velocity

Air-solid interface
Blast Wave Velocity

Solid-air interface
Primary Blast Injuries

- **Stress waves:**
  - Mostly affect air-containing organs:
    - Lung
    - Intestines
    - (Middle) ear
Primary Blast Injuries

- **Lung:**
  - Prime target:
    - Large volume
    - Complex air-fluid-solid structure
    - (Massive) alveolar disruption:
      - Emphysema-like pattern
    - Simultaneous capillary rupture:
      - Pulmonary contusion
Primary Blast Injuries

• **Lung:**
  - Tracheal rupture
  - Bronchial rupture
  - Pulmonary contusion
  - Tension pneumothorax
  - Rarely: rib fractures
Primary Blast Injuries

- Blast lung:
  - “Butterfly” contusion
Primary Blast Injuries

- **Lung trauma management:**
  - Positive pressure ventilation:
    - May worsen barotrauma
    - May cause systemic air emboli
  - Without intubation:
    - Hypoxia
    - Hypercapnia may worsen brain insult
    - Head injury and coma: apnea
Primary Blast Injuries

- **Lung trauma management:**
  - Unconventional therapies:
    - High frequency jet ventilation
    - Nitric oxide
    - One-lung ventilation
Primary Blast Injuries

• **Gastrointestinal tract:**
  • Less common than lung injury
  • More common in underwater blasts
    • Solid objects have more inertia
    • Ligament of Treitz rupture
  • Mechanism:
    • Hemorrhage
    • (Delayed) ischemia
    • Perforation and peritonitis
Primary Blast Injuries

- **Special situations:**
  - Underwater explosions
  - Waves travel slowly, but don’t dissipate
  - Wading injuries:
    - Abdominal and lower lung lobe injuries
    - Upper lobes relatively spared
Primary Blast Injuries

- **Ear:**
  - Ear is designed to sense sound
  - Blast wave = “sound” wave

- **Injuries:**
  - Rupture of tympanic membrane
  - Ossicle injury: 33%
  - Neurosensory deficits
  - Balance problems
Primary Blast Injuries

- **Ear:**
  - Injury depends on head orientation
Primary Blast Injuries

• **Ear:**
  • Injury depends on head orientation
  • Poor correlation with other injuries:
    • Lung
    • Intestines
Primary Blast Injuries

- **Ear:**
  - Retrospective study - Israel
  - Survivors of 11 terrorist attacks
  - 647 patients
    - 193 sustained primary blast injuries
    - 18 lung alone
    - 31 lung + ear
    - 142 ear alone
  - Outcome independent of ear injuries

Primary Blast Injuries

• **Ear:**
  - U.S. military – I.E.D. in Iraq
  - 167 patients in 30 days
  - 16% had TM perforation
  - 7% had *other* primary blast injuries
    - 3.6% pneumothorax
    - 1.1% pulmonary contusion
  - Sensitivity of TM as marker for other injuries: 50%

Harrison CD et al. J Trauma 2009
Blast Injuries

- Secondary blast injuries:
  - Blast wave sets objects in motion
    - Bomb shrapnels
    - Projectiles
  - Objects travel further than the blast wave
Blast Injuries

- **Secondary blast injuries:**
  - Blast wave sets objects in motion
    - Bomb shrapnels
    - Projectiles

Guermazi A et al, Arthritis Care Res 2013
Blast Injuries

• Oklahoma City bombing
  • Eye injuries (Mines M, Ophthalmology 2000)
Blast Injuries

- Secondary blast injuries:
  - Penetrating trauma
    - Trunk (largest surface)
    - Eye (most sensitive)
Blast Injuries

- Secondary blast injuries:
  - Penetrating trauma
    - Trunk (largest surface)
    - Eye (most sensitive)
    - Face (immediately life-threatening)
  - Blunt trauma
Blast Injuries

• Secondary blast injuries:
  • Maxillofacial trauma
    • Airway
    • Breathing
    • Circulation
Blast Injuries

• Secondary blast injuries:
  • Ocular trauma
    • Eye = 0.1% of anterior body surface
    • 10% of survivors have eye trauma
    • Vulnerable to small particles
    • Most often penetrating

(Mines M, Ophthalmology 2000)
Blast Injuries

• Secondary blast injuries:
  • Ocular trauma (Mines M, Ophthalmology 2000)
Blast Injuries

- Secondary blast injuries:
  - Ocular trauma  (Mines M, Ophthalmology 2000)
    - Corneal abrasion  21%
    - Eyelid/eyebrow laceration  20%
    - Open globe injury  10%
    - Orbital fracture  5%
    - Retinal detachment  4%
    - Corneal burn  3%
    - Globe blow-out  0%
Blast Injuries

- Tertiary blast injuries:
  - Whole body in motion
  - Part of the body in motion
  - Example: landmines
## Blast Injuries

### Where in the world?

<table>
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<tr>
<th>Country</th>
<th>Population</th>
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<td>Zimbabwe</td>
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Blast Injuries

- **Landmines:**
  - 70 countries worldwide
  - 2,000 injuries/deaths *a month!*
Blast Injuries

• **Landmines:**
  - 70 countries worldwide
  - 2,000 injuries/deaths *a month*
  - Often children
Blast Injuries

- **Landmines:**
  - 70 countries worldwide
  - 2,000 injuries/deaths *a month!*
    - 50% fatal
      - From blast
      - From delay in treatment
  - Contaminated amputations
  - Projectiles to face/trunk
• **Landmines:**
  - Injuries long after the conflict is over
  - Children are injured later (after the war)

Blast Injuries

- Unexploded Ordnances (UXO):
  - Injure more children than landmines
  - 42% when playing/tampering with UXO
  - Children injured: UXO 3x more than mines
  - Good news: easier to clean up (visible)
  - Bad news: curiosity factor (visible)
Blast Injuries

• Unexploded Ordnances (UXO):
  • Injure more children than landmines

Afghanistan 2002-2006

Bilukha OO et al. Prehosp Disaster Med 2008
Blast Injuries

• Types of explosions:
  • Acts of terrorism
  • Acts of Wars
Blast Injuries

• Types of explosions:
  • Acts of stupidity
Blast Injuries

• Types of explosions:
  • Acts of stupidity
    • 95% between June 22 and July 21
    • Burns (most common)
    • Hand injuries (most severe)
    • Eyes (30%)
    • Legs (15%)
    • Individual trauma
Blast Injuries

• **Fireworks injuries:**
  - 8,500 injuries/year (1999)
  - 45% children (>4,000)
    - 40% hand injuries
    - 20% eye injuries
    - 20% head/face injuries
  - 275 permanently blind
  - 16 deaths

Committee on Injury and Poison Prevention, AAP, Pediatrics 2001
Blast Injuries

- Types of explosions:
  - Fireworks *factory* explosion
    (Enschede, Netherlands 2001)
Blast Injuries…

Come in all forms

- Primary blast
  - Occult trauma in survivors
  - Lung injuries!
- Secondary/tertiary injuries
  - Penetrating, blunt, burns…
- Triage!
- Decontamination/radiation
www.hasbro-surgery.org