Blast Injuries

- An Overview of the Effects of Blast Injuries at the Medical Level

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Objectives

- Describe the basic physics, mechanisms of injury, and pathophysiology of blast injury
- List the four types or categories of blast injuries
- List the factors associated with increased risk of primary blast injury

Objectives...cont.

- Recognize the key diagnostic indicators of serious primary blast injury
- State the most common cause of death following an explosion

Why?

- Combat
- Terrorism
- Accidents

Combat: Iraq & Afghanistan

Terrorism: USS Cole
Terrorism: ???

Bombings are clearly the most common cause of casualties in terrorist incidents.
Recent terrorism has shown increasing numbers of suicidal bombers wearing or driving the explosive device
- A poor man’s guided missile!

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Boston Marathon April 15, 2013

- Pressure cooker device (2), form of an IED
- Same type of device used in Mumbai train bombings in 2006 and Time Square car bomb attempt in 2010
- Often packed with nails, ball bearings and other small metal objects

Pressure cooker device

- "Inspire" magazine Summer 2010, "Make a Bomb in the Kitchen of your Mom", by "The AQ chef"
- Al-Qaeda publication article on the step by step process for making a Pressure cooker bomb.

Boston Marathon Results

- Three killed, 264 wounded – many with amputations, scene described as a war zone
- One Police officer killed in shoot out with bomber suspect Dzhokhar Tsarnaev
Not in Wisconsin?

- Steve Preisler - aka "Uncle Fester", from Green Bay, graduated from Marquette University in 1981 with a degree in Chemistry and Biology.
- Many books, including "Secrets of Methamphetamine Manufacture" and "Home Workshop Explosives"
- Has a website

MacGyver Bombs

- Park High school – October 2, 2012
- Plastic bottle – soda or water (different sizes)
- Use combination of a strong acid or base and things like aluminum foil to create a gas that causes the container to explode

MacGyver Bombs cont.

- Chemicals used include Drain or Toilet bowl cleaners, Calcium Hypochlorite or such items as Dry Ice
- Injury from blast effects and chemical that may cause burns or respiratory injury
- Felony in many states

New Threats

- ISIS – Islamic State of Iraq and Syria
- Estimated 100 US citizens belong to ISIS
- 6000 missing foreign nationals on student visas in the US
- Times Square and Las Vegas

September 11, 2014

- ?
Accidents

Grain elevator

Accidents

Fireworks Plant Explosion

First... A Little Theory

...What Is An Explosive?

- There are four types...
  - High explosive
  - Low explosives
  - Fuel-Air explosives
  - Nuclear Explosives

We won’t talk about nuclear explosions...

Morton Thiokol

Destroyed in Seconds – Chemical Plant Explosion

- http://youtu.be/_KuGizBjDXo

Explosives

- High order
  - Detonation
  - Blast wave formation (supersonic)
- Low order
  - Deflagration
  - No blast wave formation (always subsonic)

High Order Explosives

“HE”

- Nitroglycerine
  - Dynamite
- TNT – “classic”
- PETN – “det” cord.
- C-4 – familiar to all military
- Semtex (Warsaw pact version of C-4)
- ANFO
  - Ammonium nitrate, fuel oil mixture
High Order Explosives

"HE"

- When a high explosive detonates, it is converted instantaneously into a gas at high pressure and temperature.
- The expansion of these gases creates the blast wave.
  - Brisance is the shattering effect of the blast wave

Low Order Explosives

(Propellants)

- Gunpowder
- Nitrocellulose
  - Smokeless powder
  - (This is also a high explosive under certain conditions)
- Match heads
- Multiple other compounds
  - Abnormal explosion of a high order explosive may occur

Deflagration

Low-Order Explosive Combustion

Deflagration is very rapid burning...
The speed is increased by confinement

Fuel-Air Explosives

(Thermobaric Weapons)

- Neither a high explosive nor a low order explosive
- Has features of both
- Most often has deflagration
- May have supersonic detonation
  - May have much longer, broader blast wave than high explosive

Thermobaric Weapons

Fuel-Air Mixtures

- Particularly effective in enclosed spaces
  - Fireball and blast can travel around corners
  - Blast waves are intensified when reflected by walls and other surfaces.
- Optimized to produce heat and blast
  - Secondary effects through flying fragments
  - Toxic detonation gases
  - Anoxia

Fuel-Air Mixtures

(not just military explosives)

- Grain/dust explosions
- BLEVE
  - Boiling Liquid Expanding Vapor Explosion
- Slow escape of natural or LP gas
IED (A very, very bad terminology)

- Improvised Explosive Device
- ANY device that doesn’t have a military issue number somewhere
- Ranges from
  - crude match-head pipe bombs
  - Low explosive
  - Experimental professional munitions that don’t yet have issue numbers
  - Often high explosives

Issued Munitions
...can be part of an IED

Roadside IED...
155 mm Artillery shells
Linked with detonation cord

Injuries From Blast
Definitions

- Primary
  - The direct effect of the blast
- Secondary
  - Due to projectiles from the blast
- Tertiary
  - The victim is thrown by the blast wind
- Quaternary
  - All other effects – burns, building collapse, etc.

Blast Effects

Primary Blast Injury (Injury due to shock wave)
Secondary Blast Injury (Injury due to missiles being propelled by blast force)
Primary Blast Injury

- Primary Blast Injury (PBI) is caused directly by the sudden increase in air pressure after an explosion
  - Blast wave or shock front that travels faster than the speed of sound
  - How will this injure tissue???

Variables Affecting Severity

Primary Blast Injury

- Distance is the most important
  - Intensity varies by the third power of the distance...
  - Double the distance from the explosion and reduce the injury by a factor of 8
  - The most effective way to minimize injury from primary blast injury is to increase the distance from the center of the explosion (stand-off distance)

Variables Affecting Severity

Primary Blast Injury

- "Blast Environment" is a very important factor determining the extent of injuries.
  - Nearby structures may either act as a shield or may reflect the blast wave onto a casualty.
  - Confined environment increases damage
  - Foxhole or shelter is a confined environment
  - Inside the bus is bad...
  - Orientation of body relative to blast wave – end-on orientation minimizes injury

Variables Affecting Severity

Primary Blast Injury

- Peak of the initial positive wave
  - Overpressure >60-80 PSI potentially lethal
  - Duration of the overpressure
    - Longer is bad – See thermobaric weapons
  - Medium in which it travels
    - Water is a special case

Blast Inside of a Closed Space

Reflected Blast Waves

- A blast wave that is reflected can create a peak pressure 10X greater than that of the incident wave.
  - Blast waves inside buildings are repeatedly reflected creating a "complex blast wave"
  - Marked increase in injuries related to primary blast effects when explosion occurs in a closed space

9/4/2014
Primary Blast Injury
- Direct trauma
  - Amputations
  - Death
- Hollow organ damage
  - Ear
  - Lung
  - GI tract

Primary Blast Injury
- Organs most sensitive to blast effects are air-filled (damage is produced at the interface between air and water)
  - middle ear; ear drum rupture @ 5 psi
  - the respiratory system
    - lungs and bronchi: lung damage at 15 psi
    - upper airways (trachea, pharynx, and larynx)
    - nasal passages and sinuses
  - the bowels
- LD₅₀ is around 50 psi.
- Air embolism is the cause of sudden death due to blast.

Primary Blast Injury
Death
Amputation

Primary Blast Injury
Traumatic Amputation
- Blast wave creates stress wave through skin and muscles
- Stress wave shatters solid bone
- Landmines
  - Expanding gases enter and expand tissues while ripping off distal part

Primary Blast Injury
Pulmonary Injury
- Hemorrhage:
  - Pulmonary contusion
  - Hemothysis
  - Hemothorax
- Escape of Air:
  - Pneumothorax
  - Pneumomediastinum
  - Pulmonary pseudocyst
  - Arterial gas embolism (AGE)
- Apnea

Primary Blast Injury
Pulmonary Injury
- Blood vessels stretched and torn causing pulmonary contusion
- Interstitial hemorrhage with oxygen diffusion problems

Bruises on lungs produced when primary blast wave rapidly accelerates ribs into underlying lung tissue
Primary Blast Injury

Pulmonary Injury

- Respiratory difficulty
  - With exertion
  - At rest !!
- Asymmetrically or patchy decreased breath sounds or inspiratory crackles
- Decreased $S_aO_2$ on ambient air or 100% oxygen therapy
- Pulmonary infiltrates on chest radiograph

Blood & Fluids in lungs

- Signs of blast lung are usually present at the time of the initial evaluation.
- Presentation may be delayed by 48 hours.
  - In one series, all patients with blast lung required ventilation support within 6 hours of presentation
  - All were in enclosed space (bus bomb)
- Wheezing or SOB on arrival should be presumed to be blast lung

Primary Blast Injury

Pulmonary Injury

- Alveoli disrupted
  - Pneumothorax
  - Tension pneumothorax
- Asymmetrically decreased breath sounds
- Tracheal deviation
- JVD
- Shock if enough pressure in hemithorax to cause mediastinal shift (tension pneumothorax)

Primary Blast Injury

Brain Injury

- Concussion
- TBI
- Arterial gas embolism
- Signs and symptoms include headache, fatigue, poor concentration, lethargy, anxiety, and insomnia

Primary Blast Injury

Arterial Gas Embolism

- Arterial gas embolism (AGE) – air bubbles enter blood stream and travel to brain and/or heart causing stroke and/or heart attack
- Cerebral circulation
  - Stroke
  - Seizures
  - Altered mental status
- Coronary circulation
  - Dysrhythmias
  - Ischemia or infarction
  - Cardiogenic shock
- Arterial gas embolism in liver

Primary Blast Injury

Ear Injury

- Middle ear:
  - Ruptured tympanic membrane (TM)
  - Temporary conductive hearing loss
- Inner ear:
  - Temporary sensory hearing loss
  - Permanent sensory hearing loss
Primary Blast Injury

Ear Injury

- TM rupture thought to be marker for pulmonary injury?
  - Good study showed that this is NOT true
  - Earplugs/hearing protection
  - In water?
  - Ruptures at 5 psi

Primary Blast Injury

Gastrointestinal Injury

- More common in underwater blasts
- Acute/Delayed perforation of the bowel
  - No obvious external wound – easily missed
  - Early hemorrhage
  - Delayed sepsis
  - Pathology
    - Mesenteric tears
    - Hematomata in bowel wall
    - Intraluminal hemorrhage
  - Delayed perforation up to 8 days after injury

Primary Blast Injury Identifying Abdominal Injury

- Serial abdominal examinations
- Serial hematocrit determinations
- Diagnostic studies
  - Ultrasonography
  - Peritoneal lavage
  - Computed tomography

Underwater Blast Injury

- More devastating at a greater distance
  - Pressure wave travels much faster in water
  - Force does not dissipate as quickly
    - Underwater exposure to the explosion of a 1 lb. charge causes death at 23 ft. This is 3X better than the lethal range in air
  - If vertically oriented in the water at/near the surface
    - Significantly greater amount of blast energy imparted on the abdomen than on the lungs.

Primary blast injury is lethal….

But SECONDARY blast injuries are the real killer of explosions.

Bomb Fragment Damage

Terrorist Bomb

Parts of the bomber can be fragments that strike victims
Secondary Blast Injury
#1 source of injury/death from explosions
- Fragments from munitions (design)
- Fragments from "spiked" terrorist bomb (Nails, Glass, Unique IED’s…)
- Fragments from blast environment
- Glass fragments are a common cause of injury/death related to blast in civilian settings
- From the bomber...
- At least one paper reports infections from bomber fragments...

Fragments are often (erroneously) called shrapnel...

Fragments Can Travel...
...a long distance....

They travel at HTOH velocity
Conventional military explosives create fragments with initial velocity > 8000 fps.
M16 round travels at 2800 fps!

Fragments Kill!

Normally, if the victim is close enough to be seriously injured by blast wave ... victim is killed by fragments (Not true for enhanced blast weapons)

Fragments...
Come from many sources
- Munitions (design)
- The real shrapnel...
- Terrorist devices
- Munitions (design)

Fragments...
Eye Injuries
- 10% of blast victims will have significant eye injuries.

Fragments
- Glass causes up to 50% of secondary blast injuries
- 88% of Khobar Towers patients were injured by flying glass
- Occur most often in exposed areas such as head, neck and extremities
EFP Vehicle Damage

The results of the fragment

Tertiary Blast Injuries

- The blast wind pushes/throws the victim onto something else.
- The trauma is due to the impact.
- Blast wind occurs with both HE and LE explosions.

Quaternary Blast Injury

- The building collapses
- The products of the blast are poisonous
  - Nitrogen oxides (NOx) are poison
  - Depleted uranium
- The patient is burned
  - White phosphorous
- Exacerbation of underlying COPD, CAD, etc.

Medical Management Issues In Blast Injury

EMS Providers...

- BE WARY OF SECONDARY DEVICES
  - Device command detonated or timed to occur 30-100 minutes after the first device
Management of secondary, tertiary, and quaternary blast injuries is unchanged from usual principles of care.

- There may be LOTS of casualties....
- They may have LOTS of injuries...

**Triage**

- Dead...stays dead
  - CPR has no place in the MASCAL
- Confined space explosions will have FAR more injuries and higher incidence of primary blast injury.
- Structure collapse markedly increases mortality

**EMS Providers**

- Airway control - minimize airway pressures as much as possible.
- Positive pressure ventilation only when necessary
- Pulse oximetry if possible

**EMS Providers**

- Identify and treat hemorrhage at once
  - Tourniquet is the appropriate treatment
- Good IV access –
  - Monitor fluid administration carefully
  - Avoid overhydration/ARDS!
- Frequent vital signs

**EMS Providers**

- MANDATORY LITTER PATIENT –
  - Left lateral decubitus position w/head lower than feet (AGE position), if possible
  - Don’t allow the patient to assist in own rescue or exert him/her self in any way

**Evacuation**

- Casualties with pneumothorax and AGE will get worse with altitude
  - Consider field chest tube
- Avoid initial evacuation by long-distance high-altitude flights
- Bad oxygenation will get worse with altitude
Evacuation
Civilian/Mass Casualty Variant

- Minor injuries skip EMS and go to hospital
  - Expect LEAST injured to arrive first in hospital
  - Double first hour's count for a rough prediction of the 'first wave' of casualties

History
Important historical questions...

- Can you hear me? Do you have ear pain?
  - Tympanic membrane rupture
  - Hearing loss
- Ear injuries do not need special care in the field

History
Important historical questions...

- Are you short of breath?
  - First subjective complaints of pulmonary contusion, pneumothorax, hemothorax, or shock.
  - The more exertion required to elicit dyspnea... the better your patient is
- Do you have chest pain?

History
Important historical questions...

- Do you have nausea, abdominal pain, urge to defecate, or blood in your stools
  - Early markers for GI injuries
  - May be absent/altered with other trauma

History
Important historical questions...

- Do you have eye pain or problems with your vision?
  - Markers for blunt and penetrating eye trauma
  - 10% of explosion victims will have eye trauma
  - This doesn’t take into account military protective eyewear.

Examination
Important physical findings...

- Respiratory system
  - Ecchymosis or petechiae in hypopharynx
  - This is more sensitive than ear findings
  - Cough
  - Tachypnea
  - Dyspnea
Examination
Important physical findings...

- Respiratory, cont...
  - Hemoptysis
  - Rales or crepitations
  - Wheezes
  - Chest pain
  - Asymmetric chest movement
  - Subcutaneous emphysema

- Cardiovascular
  - Tachycardia
  - Stress, hemorrhage, hypoxia, exertion
  - Bradycardia
  - Vasovagal
  - Delayed capillary refill
  - Hypotension
  - Hemorrhage, AGE, vasovagal reaction
  - Arrhythmias
  - Shock, coronary AGE

- Gastrointestinal
  - Nausea/vomiting
  - Abdominal tenderness
  - Hematochezia
  - Hematemesis

- Neurologic
  - Vertigo
    - Vertigo is NOT usually due to auditory trauma
  - Coma
  - Altered sensorium
  - Focal numbness
  - Paresthesias
  - Seizures
  - Retrograde amnesia

- Eye
  - Difficulty focusing
  - Blindness
  - Fundoscopic findings of retinal artery air embolism
  - Loss of red reflex on fundoscopic examination

- Auditory system
  - Blood oozing from mouth or nose
  - Hyperemia, hemorrhage or rupture of TM
  - Deafness
  - Tinnitus
Diagnostic Studies

- Chest X-ray
  - Should be done on almost all patients
- Pulse oximetry
  - With multiple casualties consider intermittent monitoring
- FAST?
  - CT of head, chest, or abdomen if HX and PE suggest
  - NOT optional in comatose
  - CT is often biggest bottleneck in MASCAL

Diagnostic Studies

- CBC
  - Serial hemoglobin / hematocrit measurements
- Stool occult blood
  - Other labs may be helpful... but order on case-by-case basis

Treatment

- Pulmonary
  - High flow oxygen
  - Consider intubation
  - Respiratory distress
  - Hemoptysis
  - Use lowest airway pressure possible
    - PEEP and high ventilation pressures cause POF
  - If intubated, consider chest tube(s).

Treatment

- Hypotension - CONSIDER
  - Blood loss from wounds
  - Blood loss due to GI hemorrhage
  - Blood loss due to intra-abdominal organ rupture
  - Pneumothorax
  - Air embolism
  - Vagal reflex

Treatment

- Hypotension
  - Volume support
  - ?? Keep dry??
  - Consider blood products – early
  - LOOK for the CAUSE!

Treatment

- Auditory
  - Most resolve spontaneously
  - Avoid irrigating or probing the auditory canal
  - Avoid swimming
  - Refer to ENT if no healing or complications occur
    - Complications include ossicle disruption, cholesteatoma, perilymphatic fistula, and permanent hearing loss (1/3)
  - Steroids may be helpful in sensorineural hearing loss
Treatment

- **Wound management**
  - Avoid primary closure
  - **DO NOT** suture without exploration
  - Use delayed primary closure
  - Consider all wounds to be puncture wounds and have an imbedded FB.
  - Carefully explore every wound.
  - Consider CT, US, or MRI to look for radiolucent foreign bodies

Air Embolism

- **High flow oxygen**
- Position patient
  - Injured lung in dependent position
  - Left lateral recumbent position
  - Head down ???
- **Hyperbaric oxygenation**
  - Navy dive table 6

Air Embolism

- **Aspirin may be helpful in AGE**
  - May reduce inflammation-mediated injury in pulmonary barotrauma
  - Weigh bleeding risk in acute trauma setting

Eye injury

- 28% of blast survivors sustain eye injuries
  - This may not be true with military eyewear
  - Objects penetrating eye (or any other body part) should not be removed in an emergency setting
    - Cover affected eye with a paper cup that will not exert pressure on the globe
    - Remove object in operating room under controlled conditions
    - Refer patient to ophthalmology for definitive treatment

Disposition

- Depends on the injury
- Don’t be hasty to discharge
  - Consider observation for 8-24 hours

Disposition

- Limited data prevent establishing optimal duration of observation
- Low risk and may be discharged with strict precautions after 6-8 hours of observation:
  - Persons exposed to open-space explosions with no apparent significant injury, normal vital signs and unremarkable lung and abdominal examination
Disposition

- Moderate risk and should be observed for longer periods of time for delayed complications:
  - Persons exposed to confined area explosion or in-water explosions
  - Persons with TM rupture
  - Persons with intra-oral petechiae

 CDC BLAST INJURY App

- For the iPhone, iPad and iPod touch
- App store, search for CDC and select Blast Injury
- It’s FREE

Summary

- Explosions cause familiar trauma
  - There may be LOTS of casualties with LOTS of injuries
  - Secondary blast trauma is the biggest killer

Summary

- Primary blast injuries of the lung
  - Leads to pulmonary contusion with possible arterial gas embolism to the brain or heart
  - May rapidly worsen if casualty exercises (including walking)
  - May affect evacuation decisions (air vs. ground) – air evac only at LOW altitude

Summary

- Management of other injuries adjusted
  - Spontaneous breathing or low airway pressures
    - Highest level of oxygen supplementation
    - Just enough fluid or blood to restore perfusion
    - May help to position differently than supine