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Author(s): Jim Holliman (Uniformed Services University), MD 2012

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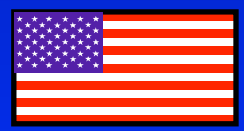
Crush Injury and Crush Syndrome

Jim Holliman, M.D., F.A.C.E.P.
Program Manager
Afghanistan Healthcare Sector Reconstruction Project
Center for Disaster and Humanitarian Assistance Medicine
Professor of Military and Emergency Medicine
Uniformed Services University
Bethesda, Maryland, U.S.A.



Crush Injury and Crush Syndrome Lecture Outline

- Epidemiology
- Pathophysiology
- Treatment
- Controversies in management
- Prognosis

Causes of Crush Syndrome

- Immobility against firm surface for > one hour :
  - Drug or alcohol intoxication
  - Carbon monoxide poisoning
  - Cerebrovascular accident
  - Head trauma with coma
  - Elderly with hip fracture
  - Improper positioning of surgical patient
  - Assault with beating
  - Pneumatic Antishock Garment (PASG or MAST)

Causes of Mass Casualties with Crush Syndrome

- Building collapse
  - Earthquakes
  - Landslides
  - Bombings
  - Construction accidents
  - Heavy snow on roof
- Mine or trench collapse

Crush Syndrome
Official Definitions

- From recent consensus meeting :
  - "A crush injury is a direct injury resulting from crush. Crush syndrome is the systemic manifestation of muscle cell damage resulting from pressure or crushing."
- Better (mine) :
  - Crush syndrome is the clinical condition caused by compression of muscle with subsequent rhabdomyolysis which can then cause the complications of electrolyte disturbances, fluid sequestration, & myoglobinuria.
- Another :
  - "A form of traumatic rhabdomyolysis that occurs after prolonged continuous pressure & is characterized by systemic involvement".

Historical Reports of Crush Syndrome

- Old Testament Book of Numbers
  - Deaths from illness involving muscle pain & weakness (rhabdomyolysis)
    - Due to eating quail which had consumed hemlock seeds
- Larrey (Napoleon's army surgeon) in 1812 described limb gangrene in carbon monoxide victims
- Bywaters & Beal in 1941 reported 5 patients from the London Blitz who died of renal failure
  - Later reports (both clinical & animal studies) by Bywaters identified myoglobinuria as the cause for the renal failure

Major Mass Casualty Events with Reports of Crush Syndrome

- Earthquakes :
  - Tangshan, China 1976
  - Armenia 1988
  - Iran 1990 and 2003
  - Northridge, California 1994
  - Kobe, Japan 1995 ("Hanshin-Awaji")
  - Turkey 1992 (Izmit, "Marmara" 1999)
- Terrorist bombings :
  - Israel
  - Lebanon
  - Saudi Arabia

Buildings damaged in the 1999 Marmara earthquake

Source undetermined

Incidence of Crush Syndrome in Mass Casualty Events

- 10 to 60 % of survivors extricated from collapsed buildings
  - Up to half may develop renal failure
    - At least half of these require dialysis
- Typically about 20 % of injured are hospitalized, and 5 to 20 % of these have crush injury, and 0.5 to 1 % end up needing dialysis
- Incidence less in quakes where most residences are adobe or one story (Central America for example)

Pathophysiology of Crush Syndrome

- Not usually directly due to ischemia
- Main cause is stretch of the muscle sarcolemma
  - Sarcolemma permeability increases
  - Influx of sodium, water, & extracellular calcium into the sarcoplasm
    - Results in cellular swelling, increased intracellular calcium, disrupted cellular function & respiration, decreased ATP production, & subsequent myocytic death
- Muscle swelling can then cause early or even days delayed compartment syndrome

Systemic Sequelae of Crush Injury

- Result from death of muscle cells and leak of intracellular metabolites into the systemic circulation ("reperfusion injury"
  - Superoxide anions (free radicals) then cause further membrane injury
- May not manifest until just after entrapped part of body is extricated

Metabolic Derangements from Crush Syndrome

- Hypovolemia (fluid sequestration in damaged muscle)
- Hyperkalemia
- Hypocalcemia (due to calcium deposition in muscle)
- Hyperphosphatemia
- Metabolic acidosis
- Myoglobinemia / myoglobinuria

Effects of Myoglobinuria in Crush Syndrome

- Myoglobin can precipitate (particularly with hypovolemia and acidosis) and directly obstruct renal tubular flow
- Myoglobin is also directly toxic to the renal tubular cells

Renal Toxicity of Myoglobin

- Bywaters' studies showed acid urine is required for myoglobin to cause renal injury
- At pH < 5.6, myoglobin dissociates into its 2 components :
  - Globin (shown nontoxic if infused)
  - Ferrihemate (probably the toxic component)

Other Clinical Syndromes with Similar Effects as Crush Syndrome

- Tumor lysis syndrome
- Heatstroke
- Exertional rhabdomyolysis
- High voltage (> 1000 volts) electrical injury

Field Rescue Considerations for Patients with Crush Syndrome

- Apply facemask to protect from dust inhalation
- Oxygen (if no risk of fire at the scene)
- If building unstable, then equipment stabilization may be needed before medical treatment can be given
- Start IV normal saline early if possible
- Ventilate well near gas or diesel powered generators to avoid CO poisoning

Hyperkalemia in Crush Syndrome

- Can occur soon after extrication
- Can be quickly fatal
- May occur before manifestations of renal failure
- May occur without obvious signs of compartment syndrome
- May require emergent prehospital treatment

Emergent Treatment of Hyperkalemia from Crush Syndrome

- Normal saline IV fluid bolus
- IV $NaHCO_3$ 50 to 100 meq
- Aerosolized albuterol (2.5 mg in 3 cc)
- Less effective or practical :
  - IV dextrose (25 grams) & insulin (5 units IV)
  - PO or PR kayexalate
- Note that IV calcium is controversial (as it may just worsen intramuscular hypercalcemia)
- Emergent hemodialysis may be needed

Main Treatment for Crush Syndrome : IV Fluid Resuscitation

- Normal saline (0.9 %) preferred
  - (lactated Ringers contains 4 meq / liter of potassium, & so may worsen hyperkalemia, & also has calcium)
- If started early, may prevent later development of renal failure
- Best if IV fluids can be started even prior to extrication

Recommended IV Fluid Infusion Rates for Crush Syndrome

- 1 to 1.5 liters per hour for young adults
- 20 cc per kg per hour for children
- 10 cc per kg per hour for elderly
- Insert foley catheter as early as possible
  - Target urine output should be > 50 cc per hour for adults, and > 2 cc per kg per hour for children
  - Some references advocate 150 to 200 cc per hour target in early phase

Use of IV Bicarbonate for Crush Syndrome

- Goal is to have alkaline urine (check with pH paper)
- Can bolus supplement the normal saline with 50 meq (1 amp) doses
  - Up to 300 meq per 24 hours may be needed
- Or add 3 amps (150 meq) to one liter D5W and infuse as first or second IV bolus

Use of Mannitol for Crush Syndrome

- May help eliminate myoglobin from the kidney & prevent renal failure
- May be useful to initiate diuresis in a patient who has adequate normal saline on board but whose urine output is still < 2 cc per kg per hour, or if adequate urine output is still not achieved 4 hours after treatment started

Mannitol Dosage for Crush Syndrome

- Mannitol 20 % solution 0.25 grams per kg IV over 10 to 30 minutes
  - Diuresis should start in 15 to 30 minutes
  - If urine output thereafter drops again, hypovolemia should be assumed, and only after aggressive rehydration should a second dose of mannitol be given
- Maximum dose : 2 grams per kg per day (or 200 grams per day)

Contraindications to Mannitol

- Established anuric renal failure
- Severe congestive heart failure
  - These patients may require pressors such as dopamine in order to tolerate the fluid load required for treatment, or may need early dialysis

Other Advantages of Mannitol for Treating Crush Syndrome

- May scavenge free radicals in muscle thus limiting necrosis
- Positive inotropic effect on the heart
- Most important : may help decompress compartment syndrome by mobilizing fluid from damaged muscle (thereby preventing need for fasciotomy)

Compartment Syndrome in Crush Injury

- Normal muscle compartment pressure is < 15 mm Hg
- Pressure > 30 mm Hg produces muscle ischemia, so fasciotomy indicated if pressure is persistent above this
- Irreversible muscle damage occurs after 6 hours, & irreversible nerve damage may occur after 4 hours of ischemia
- Patients with higher diastolic pressure can tolerate higher tissue pressure without ischemia, so fasciotomy recommended when compartment pressure approaches 20 mm Hg below diastolic pressure
- However, if patient is hypotensive, they can have significant ischemia at lower compartment pressures

When Should Fasciotomy be Done for Crush Injury ?

- In most reports of mass casualties from earthquakes, most of the fasciotomies were done more than 12 hours after the time of trauma
  - Reviews of these cases showed high infection rates with increased mortality and amputations, and poor long term function
- Israeli experience has shown better results with not routinely performing delayed fasciotomies
- So fasciotomy would be indicated if the victim can be extricated and receive definitive medical care within 6 hours of injury, but not later
- If initial compartment pressures are normal, and delayed compartment syndrome develops, fasciotomy may be needed

Additional Treatments for Crush Injury

- Don't forget oxygen suplementation (even if the patient is not hypoxemic, O2 may help ischemic muscle)
- Don't forget pain medications
- Address tetanus immunization status
- Acetazolamide (250 mg PO tid) may help excrete bicarbonate in the urine
- Furosemide may initiate diuresis but not favored since it makes acid urine

Diagnostic Testing in Patients with Crush Injury

- EKG as early as possible to look for signs of hyperkalemia
- Handheld fingerstick blood analyzer may be useful in the field to identify hyperkalemia early
- Routine labwork to obtain :
  - CBC, platelets, type and screen, electrolyte panel, BUN, creatinine, CPK, liver panel, urinalysis
- Optional labwork : ABG, myoglobin, PT, PTT
- Chest X-ray
- Other radiographs, computed tomography, etc. to evaluate for other injuries

Monitoring the Crush Syndrome Patient

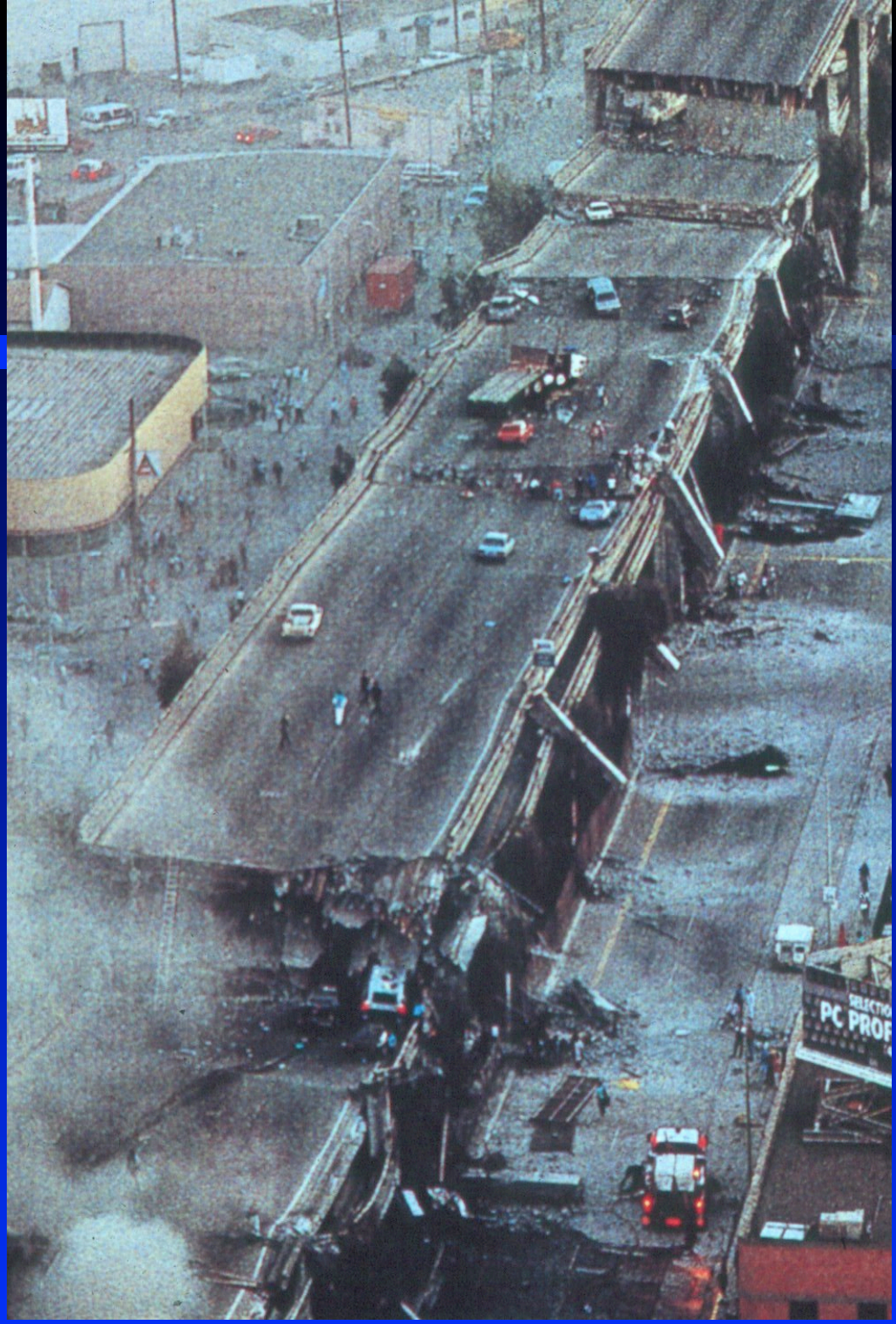
- Urine output and urine pH (hourly)
- Serial electrolytes (particularly potassium) : every 6 hours initially
- CPK, BUN, creatinine : every 8 to 12 hours
- ABG (if initially acidotic or on ventilator) : every 4 hours
- May need central IV line or Swan Ganz catheter for patients with cardiac or pulmonary disease
- Compartment pressures : every 4 hours initially

Other Injuries in the Crush Syndrome Patient

- High incidence of associated injuries
  - Extremity fractures and lacerations are most common
  - With crush injury to trunk, can have internal abdominal injuries in addition to abdominal wall muscle compression injury
  - May have "traumatic asphyxia" if chest compressed
  - Dust inhalation common in concrete building collapse
  - Fires common with earthquakes, so may have burns, smoke inhalation, and CO poisoning
  - Hypothermia or hyperthermia

Mortality Related to Crush Syndrome

- In earthquakes, most of on scene deaths are due to direct head and trunk trauma
- Of those extricated, mortality reports vary widely (zero to 60 %)
- Mortality increases with :
  - Age > 50, prior chronic illness
  - Duration of entrapment (almost no survivors after 5 days)



Nimitz Freeway (Interstate highway I-880) collapse in Oakland California from October 1989 earthquake, causing 42 deaths

Car crushed by 1989 Nimitz Freeway collapse ; one patient rescued here on the fifth day later died from complications of crush syndrome

Prognosis Related to Crush Syndrome

- Major risk factors for renal failure :
  - 2 or more limbs crushed
  - Insufficient early IV fluid
  - Delayed in presentation to hospital
- Children at lesser risk to need dialysis
- 50 % or more may have severe long term limb disability if fasciotomy done
- Patients often need long term physical therapy and may need counseling

Disaster Planning Aspects Related to Crush Syndrome

- Need to have access to increased number of hemodialysis machines
  - The Renal Disaster Relief Task Force of the International Society of Nephrology has been organized to bring multiple machines to a disaster region
- Prehospital personnel need to be supplied with extra facemasks and respirators
- Prehospital personnel will need access to large amounts of IV fluid and amps of bicarbonate

Crush Syndrome Lecture Summary

- Start IV fluids prior to extrication if possible
- Assess quickly for hyperkalemia and associated injuries
- If extrication > 6 hours after injury, do not perform fasciotomy for compartment syndrome
- Perform careful monitoring after admission to hospital