HAPPY HUMP DAY!

Woop Woop!!
KINETIC ENERGY

- $K_e = \frac{1}{2} MV^2$
- Energy is transferred from the missile to the tissue
- Speed Kills!
• Tissue is stretched by a temporary cavity
• Higher velocity missiles cause greater cavitations
• Higher velocity missiles produce greater energy waves
\[ K_E = \frac{1}{2}MV^2 \]
Larger solid organs, less musculature, compact torso, elastic ribcage, liver & spleen anterior
  - ↑ Potential internal injury
  - Spleen>liver>kidney>
    pancreas>intestine
Bladder intra-abdominal
  - 10% have GU injury
HIGH VELOCITY GSW INJURY
• 740 patients (ages 0-16) at University of Miami between 1991 to 2011
• 82% male; African American (72%)
• Most frequently were shot in the abdomen, back or pelvis
• Patients with head or neck injuries experienced the highest mortality rate (35%)
• The mortality rate overall was 12.7%

**Twenty years of pediatric gunshot wounds: an urban trauma center’s experience**

<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdomen/bac/k/pelvis</td>
<td>71 (29%)</td>
<td>54 (30%)</td>
<td>33 (38%)</td>
<td>20 (21%)</td>
<td>19 (14%)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Chest</td>
<td>42 (17%)</td>
<td>28 (16%)</td>
<td>18 (21%)</td>
<td>14 (15%)</td>
<td>6 (4%)</td>
<td>0.003</td>
</tr>
<tr>
<td>Extremities</td>
<td>28 (11%)</td>
<td>25 (14%)</td>
<td>13 (15%)</td>
<td>21 (22%)</td>
<td>52 (37%)</td>
<td>&lt; 0.001</td>
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<tr>
<td>Face/head/neck</td>
<td>79 (32%)</td>
<td>43 (25%)</td>
<td>16 (18%)</td>
<td>21 (22%)</td>
<td>12 (9%)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Multiple</td>
<td>24 (10%)</td>
<td>25 (14%)</td>
<td>7 (8%)</td>
<td>19 (20%)</td>
<td>32 (23%)</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>
• Data indicate a decrease in total number of firearm injuries from 1991 through 2003.
  – Youth drug and violence prevention programs
  – Improved gun control, gun safety educational programs,
  – More austere prison sentences
  – Decline in the cocaine trade

• The gradual increase include deteriorating police effectiveness, greater access to guns, and decreasing investment in educational and deterrent programs
• ABI’s should be performed
• Evaluate for hard signs of vascular injury (bleeding, expanding hematoma, bruit, etc.)
• In absence of hard signs
  – Duplex ultrasound
  – CTA
  – On-table angiogram
• Equivocal findings or abnormal findings warrant surgical exploration
• Smaller arteries prone to vasospasm
• Small intravascular volume
• Low intravascular volume can contribute to vessel thrombosis
• 12% of femoral vessels in children aged 0 to 9 are partially or completely overlapping
• Two thirds of injuries are noniatrogenic in children older than 6 years
• Half or more are caused by penetrating injuries
• Femoral artery disruption can be associated with limb length discrepancy which may not manifest until several years after the vascular insult
Historically injured vessels were managed with ligation
  – Stunted limb growth
  – High amputation rates

Severe persistent vasospasm (lasting hours)
  – Once series found a 26% incident of peripheral arterial vasospasm that ultimately resolved without vascular reconstruction*
  – ABI of 0.88 can be “normal” in children younger than 2 years of age

Prospective study; children 15 years or younger from 1987 to 2013
There were 222 operative procedures
Anatomic locations were primarily upper extremity
- Upper extremity (n = 134, 60%); brachial artery most dominant
- Lower extremity (n = 29%); Popliteal second most common
- Abdomen (n = 16, 7.2%)

• Interposition graft (n = 54, 24%)
• Patch (n = 43, 19%)
• Lateral suture/direct anastomosis (n = 27, 12%)
• Bypass (n = 21, 9.5%)
• Endovascular techniques (n = 8, 3.7%)
  – 4 patients (ages 2-6) had stents placed in axillary, subclavian, external iliac and thoracic aorta
• No vascular reconstructions performed in patients less than 2 years of age
• Arterial occlusion/thrombosis most common complication (n= 12)
• 30-day follow-up; one BKA and one AKA
• Mechanism of injury dominant with injuries located primarily in the upper and lower extremities
• Vascular injuries in children associated with high limb salvage

(DoDTR) (2002-2011) identified patients (1-17 years old) treated at US military hospitals in Iraq and Afghanistan for vascular injury

- U.S. military hospitals treated 4,402 pediatric patients; 150 pts (3.5%) had a vascular injury
- Vascular injuries were primarily from penetrating mechanisms (95.6%; 58.0% blast injury)
- Anatomic locations: Extremity (65.9%), torso (25.4%), and neck (8.6%)

Penetrating (secondary)

Unprotected torso
Extremity
Eye
Head/neck

Penetrating (fragments and debris)

Unprotected torso
Extremity
Eye
Head/neck

Responsible for wounding
IEDS

Oil Can

Tank Buster
Vascular injury rate of 3.5% higher than 0.6% in civilian injuries
Extremity injuries most common wounding pattern
Torso vascular injuries primary source of mortality
Injuries were reconstructed (63%), ligated (31%) or observed (2%)
Traditional vascular repair no different than civilian and military adult populations
TVS used in children were reported with no acute complications

• Both military and civilian experience show patency rates between 85% and 95%
• TVS do not negatively affect limb salvage rates when used in proximal vessels
• Distal TVS have poor patency rates and do not improve limb salvage
• Should be used a bridge to definitive repair in injuries requiring ongoing resuscitation
• Similar approaches appropriate in pediatric population

Limb salvage rates was 95% combining both theaters of operation consistent with civilian pediatric trauma.

Mortality rate was 9%.

Torso vascular injury in children is four times lethal relative to other injury patterns.

<table>
<thead>
<tr>
<th>Known Cause of Injury</th>
<th>Age</th>
<th>Location</th>
<th>Injury</th>
<th>Procedure</th>
<th>Second Procedure</th>
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<tbody>
<tr>
<td>IED</td>
<td>8</td>
<td>Head</td>
<td>Brain</td>
<td>Debridement</td>
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<tr>
<td>IED</td>
<td>12</td>
<td>Extremity</td>
<td>Femoral A</td>
<td>Shunt, SFA Repair</td>
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<tr>
<td>IDF</td>
<td>7</td>
<td>Abdomen/Chest</td>
<td>Liver</td>
<td>Liver Resection</td>
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<td>IDF</td>
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<td>Bladder</td>
<td>Bladder Repair</td>
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<td>IDF</td>
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<td>Abdomen</td>
<td>IVC/Iliac V</td>
<td>Ex Lap</td>
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<tr>
<td>IED</td>
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<td>Chest</td>
<td>Pulmonary Hilum</td>
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<td>VBIED</td>
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<td>Renal</td>
<td>Nephrectomy</td>
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<td>VBIED</td>
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<td>IED</td>
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<td>Abdomen/Chest</td>
<td>Lung/colon</td>
<td>Colectomy</td>
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</tbody>
</table>
INTRACRANIAL GUNSHOT WOUNDS
• Likely to know the perpetrator
• Likely to be killed in the home by an unsecured firearm
• Likely to die of a severe head injury
INTRACRANIAL GUNSHOT WOUNDS

- Pediatric population 1.31 deaths per 100,000 in 2004-2008
- 1.42 deaths per 100,000 in 2004-2010
- Adult mortality ranges between 50% and 90% in most series
- Children typically have a lower overall mortality when compared to adults
- A greater propensity for neurological recovery
INJURY PATTERN PREDICTIVE OF DEATH

- GCS < 5 and dilated pupils
- Laboratory (initial hematocrit < 30%, base deficit < -5 mEq/L)
- Imaging (deep nuclear/3rd ventricular injury, bi-hemispheric injury, intraventricular injury)
- At age less than 9 years, initial ICP > 30 cm H20, both supra-infratentorial injury and midline shift were not predictive
- Coagulation (INR > 1.5) was not significantly associated with death

MEDICAL AND SURGICAL MANAGEMENT

- ICP less than 20 cm H20
- Maintain CPP above 40-60 mm Hg
- Utilize fluids or vasopressors to adjust MAP and CPP
- Barbiturate coma
- Decompressive laparotomy
DECOMPRESSIVE LAPAROTOMY

- Basic science and limited clinical evidence suggests a close relationship between intracranial and intra-abdominal pressures.
- Proposed mechanism is decreased jugular venous outflow from increased central venous pressure.
- TBI with refractory intracranial hypertension following a massive transfusion might be improved after laparotomy for abdominal compartment syndrome.

*Effects of increased intra-abdominal pressure upon intracranial and cerebral perfusion. J Trauma. 1996*
INTRACTABLE INTRACRANIAL HYPERTENSION

- 17 patients with severe TBI and elevated IAP had successful lowering of ICP by decompressive laparotomy
  - Decompression completed after aggressive medical management
  - 13 patients treated with barbiturate coma
- None of the patients had extracerebral organ dysfunction to suspect IAH/ACS
- Mean decompression IAP of 27.5 mmHG
- 11 of the 17 patients survived to hospital discharge

Joseph DK et al et al. J Trauma. 2004
DECOMPRESSIVE LAPAROTOMY FOR REDUCTION OF INCESSANT INCREASED INTRACRANIAL PRESSURE IN THE ABSENCE OF ABDOMINAL COMPARTMENT SYNDROME

ARMANIOUS, M, WILSON KL ET AL.
NEUROLOGIC RECOVERY

ABBIE’S ROAD TO RECOVERY AFTER BEING SHOT IN THE HEAD
PENETRATING NECK INJURIES
Fig. 1. Algorithm for the modern management of penetrating neck trauma.
• CT scan/CT angiogram is the an accurate primary test
• CT scan is extremely accurate in determining missile trajectory and depth of penetration
  – Determines if other subsequent studies are required
• Inaba et al. demonstrated in an adult population 100% sensitivity and 93.5% specificity.
• NTDB queried from 2008-2012 (pts < 15 years of age)
• 1,238 pts with penetrating neck injuries; incidence of 0.28%
• Majority male (70.6% n= 874); mean age 7.87 years
• Most common mechanism of injury was stabbing (44%, n = 546)
• Second most common gunshot/firearm (24%, n = 301)
• Only 243 operative neck procedures
• 69 patients died (mortality rate of 5.6%)

*Penetrating neck trauma: an uncommon entity, J Trauma Acute Care Surg, 2016.*
CT Scan most frequent study performed (42.2%)
Aerodigestive injuries were the most common and occurred more frequently in the youngest age group (0-5 years)
Operative procedure for aerodigestive group most common
Vascular injury and hypotension independently associated with mortality
Overall mortality was 5.6%
ED THORACOTOMY

• Rarely life-saving for patients in extremis
• Associated with significant blood loss
  – Increased prevalence of exposures for providers
• Associated with excessively high healthcare costs
  – $100,000 or more per patient
• Significant portion of survivors have significant neurologic impairment
1691 pts evaluated for age ≤ 18 years; included 179 pts (11%)
  – Pediatric (age ≤15 years)
  – Adolescents (16-18 years)
Pediatric patients more likely to sustain blunt injury (72% vs 32%)
The youngest survivor of EDT was 16 years old
All survivors had cardiac activity in the field
  – Most common injury pattern was penetrating stab wound to the chest

• There were no survivors in the pediatric age group

• Adolescent patients more frequently undergo EDT per year compared to pediatric patient

• The rate of pediatric EDT was 1.3 per year

• A 10 year experience in the state of Illinois the rate was 2.3 EDT/year
ILLINOIS THORACOTOMY DATA

- Resuscitative thoracotomy was most frequent use for penetrating trauma
  - \( n = 19, 76\% \)
- Males > Females \( n = 19 \text{ boys}; n = 6 \text{ girls} \)
- 83\% of pediatric patients who received resuscitative thoracotomies were in extremis presenting with zero SBP
- 6 patients (24\%) undergoing the initial resuscitative thoracotomy survived
- Only 2 patients (8\%) survived to discharge

CONSIDERATIONS FOR PEDS EDT

- ED resuscitative thoracotomies rarely performed in the pediatric population
- EDT for patients under the age of 15 is a futile procedure
- Not enough patients survived to draw a conclusion about which patients are most likely to benefit from the procedure
- Dismal survival for blunt trauma pediatric patients
- Cautious not to over utilize resuscitative thoracotomy when unlikely to benefit the patient
WHAT'S OLD IS NEW AGAIN

• Whole Blood use
  – Effectively restore circulating volume
  – Provides oxygen carrying capacity
  – Carries vitally important clotting factors
  – Has buffering capabilities

• OIF/OEF balanced resuscitation with platelets, plasma and packed red blood cells used effectively resembling whole blood

Glassberg E et al. J trauma Acute Care Surg. 2013
• Borgman, MA et al. The ratio of blood products transfused affects mortality in patients receiving massive transfusion at a combat support hospital (J Trauma. 2007)

• Perkins JG et al. An evaluation of apheresis platelets used in the setting of massively transfused trauma patients (J Trauma. 2009)

• Both studied demonstrated a significant survival benefit for massively transfused patients when the RBC:FFP:Platelet ratio is close to 1:1:1
The Armed Services Blood Program: Blood support to combat
Rentas, Francisco; Lincoln, David; Harding, Aaron; Maas, Peter; Giglio, Joseph; Fryar, Ronny; Elder, Kathleen; Fahie, Roland; Whitlock, Kathleen; Vinluan, Jerome; Gonzales, Richard

Journal of Trauma and Acute Care Surgery. 73(6) Ten Years

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<table>
<thead>
<tr>
<th>Year</th>
<th>RBC Transfused</th>
<th>FFP Transfused</th>
<th>Whole Blood Transfused</th>
<th>RBC:FFP Ratio</th>
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<td>2001</td>
<td>48</td>
<td>4</td>
<td>0</td>
<td>12.0</td>
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<tr>
<td>2002</td>
<td>1163</td>
<td>77</td>
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<td>2003</td>
<td>5469</td>
<td>879</td>
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<td>2004</td>
<td>12748</td>
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<td>11741</td>
<td>11741</td>
<td>333</td>
<td>1.5</td>
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<td>2010</td>
<td>15626</td>
<td>8242</td>
<td>513</td>
<td>1.4</td>
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<td>2011</td>
<td>15656</td>
<td>13156</td>
<td>1041</td>
<td>1.2</td>
</tr>
</tbody>
</table>

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• DOD Trauma Data Base 1,311 injured children < 14 years requiring transfusion
• All patients were treated in Afghanistan or Iraq 2002-2012
• Purpose of the study: Effect of crystalloid volume and balanced component resuscitation

The effects of balance blood component resuscitation and crystalloid administration in pediatric trauma patients requiring transfusion in Afghanistan and Iraq 2002 to 2012. J Trauma Acute Care Surg. 2015
• High Volume (>40 mL/kg)
• 224 pts
• Higher mortality (19%)
• Crystalloid resuscitation
  – (+) association with increased ICU and ventilator days
• Age less than 4, penetrating mechanism, ISS >15

• Massive Transfusion (>70 mL/kg)
• 77 pts
• Mortality (25%)
• Crystalloid resuscitation
  – (+) association with increased ICU and ventilator days
• ISS >15, severe abdominal and severe extremities
Effect of crystalloid administration on mortality

The effects of balanced blood component resuscitation and crystalloid administration in pediatric trauma patients requiring transfusion in Afghanistan and Iraq 2002 to 2012.

Edwards, Mary; Lustik, Michael; Clark, Margaret; Creamer, Kevin; Tuggle, David

Effects of Blood Transfusion ratio on mortality

The effects of balanced blood component resuscitation and crystalloid administration in pediatric trauma patients requiring transfusion in Afghanistan and Iraq 2002 to 2012. Edwards, Mary; Lustik, Michael; Clark, Margaret; Creamer, Kevin; Tuggle, David

Journal of Trauma and Acute Care Surgery, February 2015.
• Heavy reliance on crystalloid has an adverse effect on outcomes
• Balanced component resuscitation was actually associated with higher mortality when all transfused patients were considered
• Clear trend toward increased mortality in both groups when crystalloid > 150 mL/Kg

TRANEXAMIC ACID

- **(TXA)**
  - Antifibrinolytic agent (synthetic lysine)
  - Prevents activation of plasminogen to plasmin
- **Ongoing research needed in Peds**
- **Dosing recommendations exist**
  - 15-mg/kg (loading dose)
  - 2 mg/kg (8 hours or until bleeding stops)
The only predictor of TXA use were severe abdominal or extremity injury.

No significant thromboembolic complication.

Suggested improvement in neurologic status and decreased ventilator dependence.

TXA administration was independently associated with reduced mortality.

Military experience using pediatric data from 2001 to 2013 seeking to find a data-driven MT protocol for Peds casualties

- Crystalloid resuscitation had adverse outcome
- No benefit from PRBC/FFP 1:1 ratio
- 40ml/kg of blood products during MTP gave best results
- TXA given early
SUMMARY

- A survival benefit is not always seen in plasma-first resuscitation, but adherence to damage control resuscitation in the prehospital setting will lead to an eventual mortality benefit.
- Limited Volume resuscitation achieves best result; high volume less good, and no-fluid resuscitation is worst option.
- TXA appears to be the best pharmacologic agent for hemostasis in a prehospital setting.