Pediatric Trauma

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Disclosure

Dr. Moulton, faculty for this session, is a co-founder at Impact Vitals and EZaLife LLC.

All other planners, faculty, and others in control of content (either individually or as a group) have no relevant financial relationships with ineligible companies.

All of the relevant financial relationships listed have been mitigated.

Pediatric Trauma (USA)

- 16 million children/year treated for injuries
- 600,000 children/year hospitalized
  - 2nd leading cause after respiratory illnesses
- 100,000 children/year permanently disabled
- In 2015*:
  - 663 children ≤12 years died as occupants in MVCs and 35% were not buckled up

*National Highway Traffic Safety Administration. Traffic safety facts, 2015 data: occupant protection. Washington, DC: US Department of Transportation, National Highway Traffic Safety Administration, 2017

Pediatric Deaths

- Trauma 48%
- Infectious diseases 14%
- Congenital anomalies 11%
- Cancer 11%
- Other 16%

Trauma is the #1 cause of death between the ages of 1 and 14 years

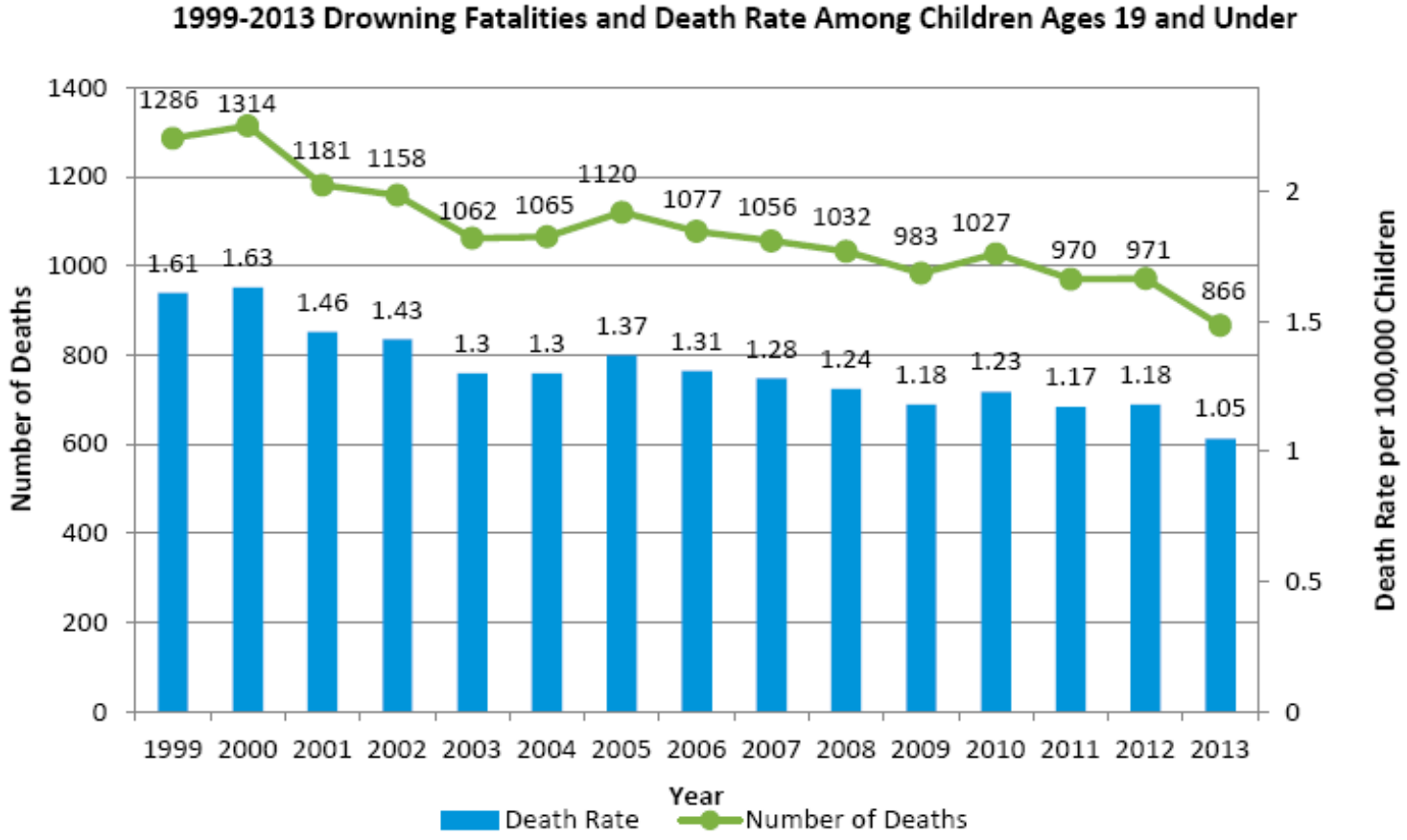
Unintentional Injury

- Blunt Trauma
  - #1 cause of pediatric trauma-related death*
    - Falls
    - Motor vehicle
    - Pedestrian
    - Bicycle/motorcycle

*National Center for Injury Prevention and Control (www.cdc.gov/)

Unintentional Injury

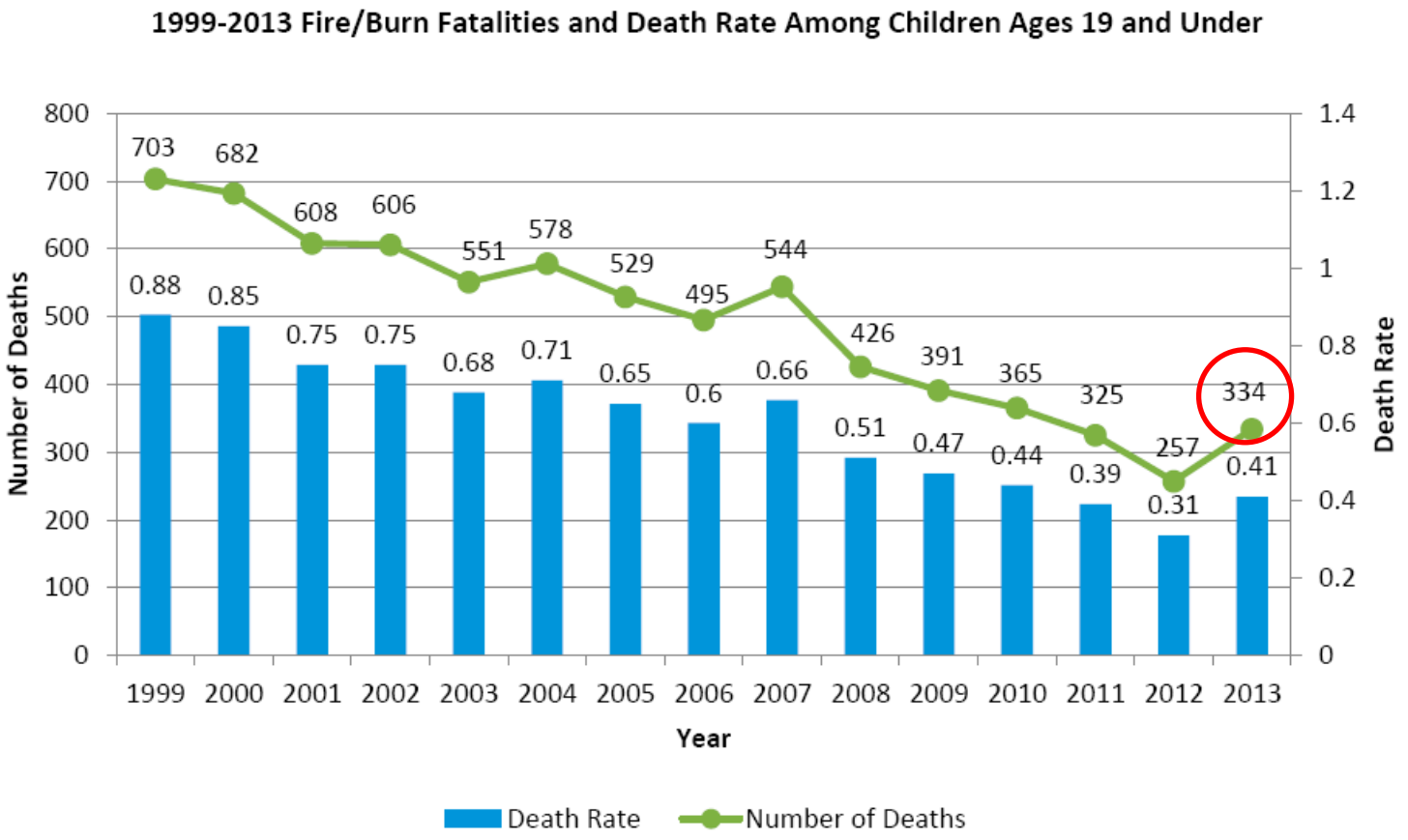
- Drowning
  - #2 cause of pediatric trauma-related death



WISQARS http://www.cdc.gov/injury/wisqars/index.html

Unintentional Injury

- Burns
  - #3 cause of pediatric trauma-related death



WISQARS http://www.cdc.gov/injury/wisqars/index.html

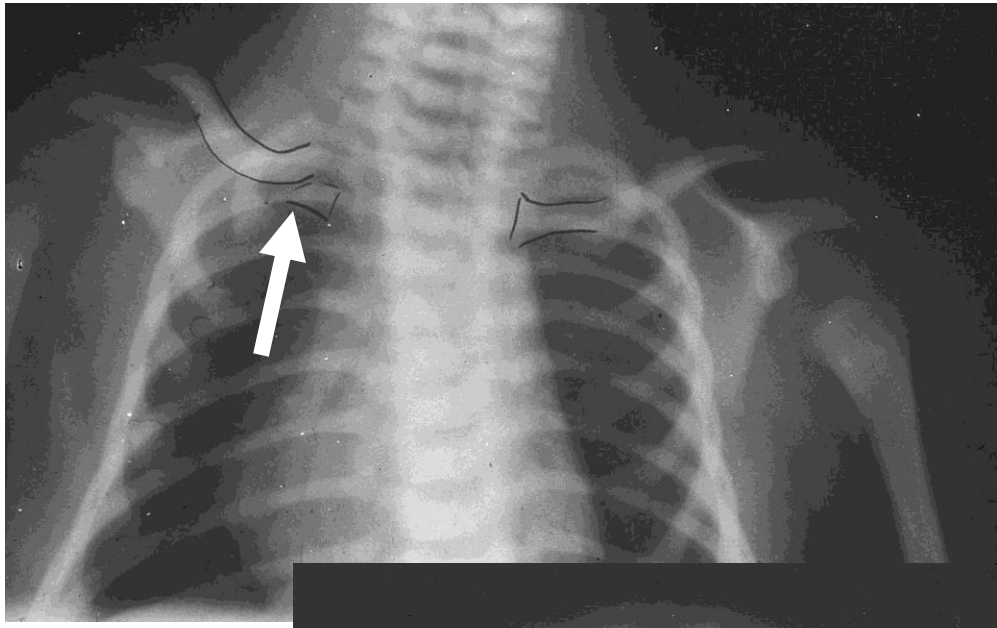
Penetrating Trauma

- Firearms
  - #2 cause fatal injury in the US
  - #1 cause of pediatric trauma-related death in US*

*Stevens J, et al. J Pediatr Surg. 2023 Jan;58(1):130-135

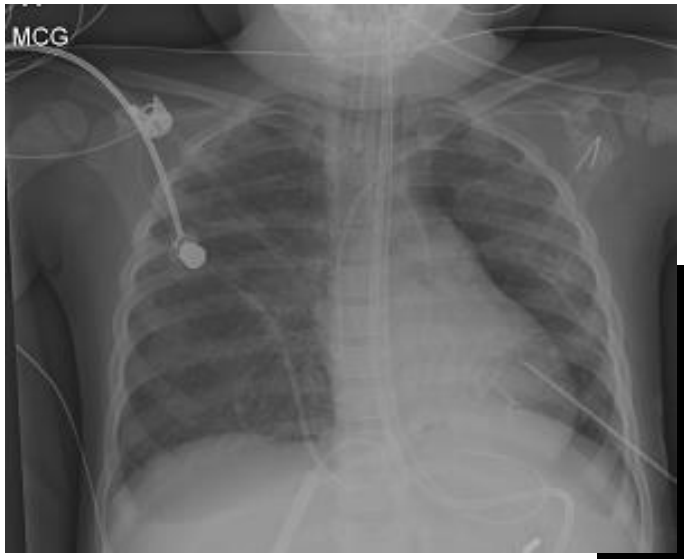
Unintentional Injury

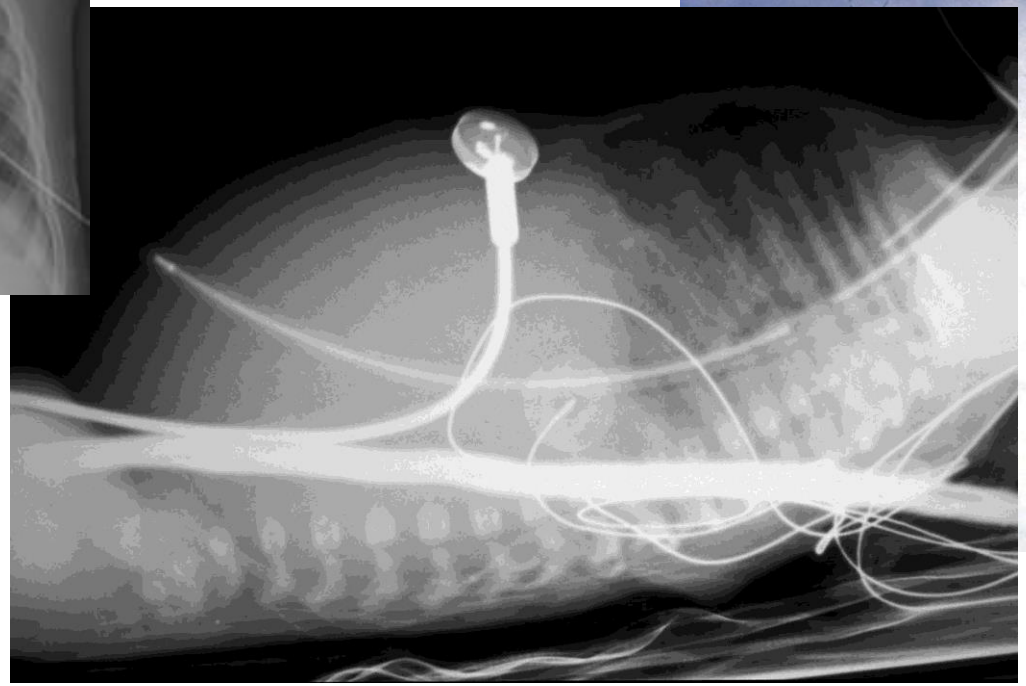
- Birth Trauma
  - Blunt
    - Nerve injuries
    - Fractures
    - Visceral injuries
  - penetrating



Unintentional Injury

- Iatrogenic Injury





Intentional Injury

- Child maltreatment*
  - FFY 2015, CPS agencies received an estimated 4M referrals involving approximately 7.2M children
    - 58.2 percent of referrals were screened in, 41.8% out
  - Children may suffer multiple forms of maltreatment
    - 75.3% of victims are neglected
    - 17.2% of victims are physically abused
    - 8.4% of victims are sexually abused
    - 6.9% of victims are psychologically maltreated

*http://www.acf.hhs.gov/programs/cb/research-data-technology/statistics-research/child-maltreatment

Intentional Injury

- Child maltreatment*
  - Est. 1,670 to 1,740 children die from abuse or neglect each year (about 5/day)
    - 75% of all child fatalities ≤ 3 years old
    - 80% of child fatalities involve at least one parent
    - More than one-half (54.1%) of perpetrators are women
    - **Most common cause of trauma-related death at CH**

Child abuse crosses all socioeconomic and educational levels, religions, ethnic and cultural groups

*http://www.acf.hhs.gov/programs/cb/research-data-technology/statistics-research/child-maltreatment

Intentional Injury

- Consequences of child maltreatment
  - More likely to experience teen pregnancy[1]
  - More likely to engage in sexual risk taking, putting them at greater risk for STDs[1]
  - 30% of abused/neglected children will later abuse their own children[2]
  - Financial cost of child abuse/neglect in US is estimated at $585 billion[3]

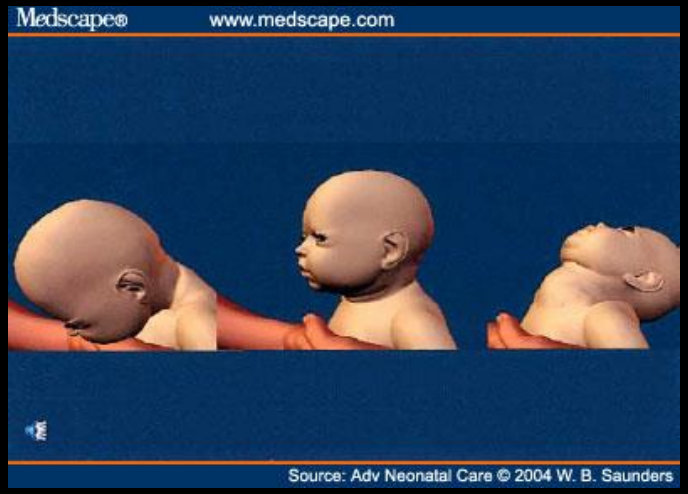
[1]Snyder, Howard, N. (2000, July). http://bjs.ojp.usdoj.gov/content/pub/pdf/saycrle.pdf

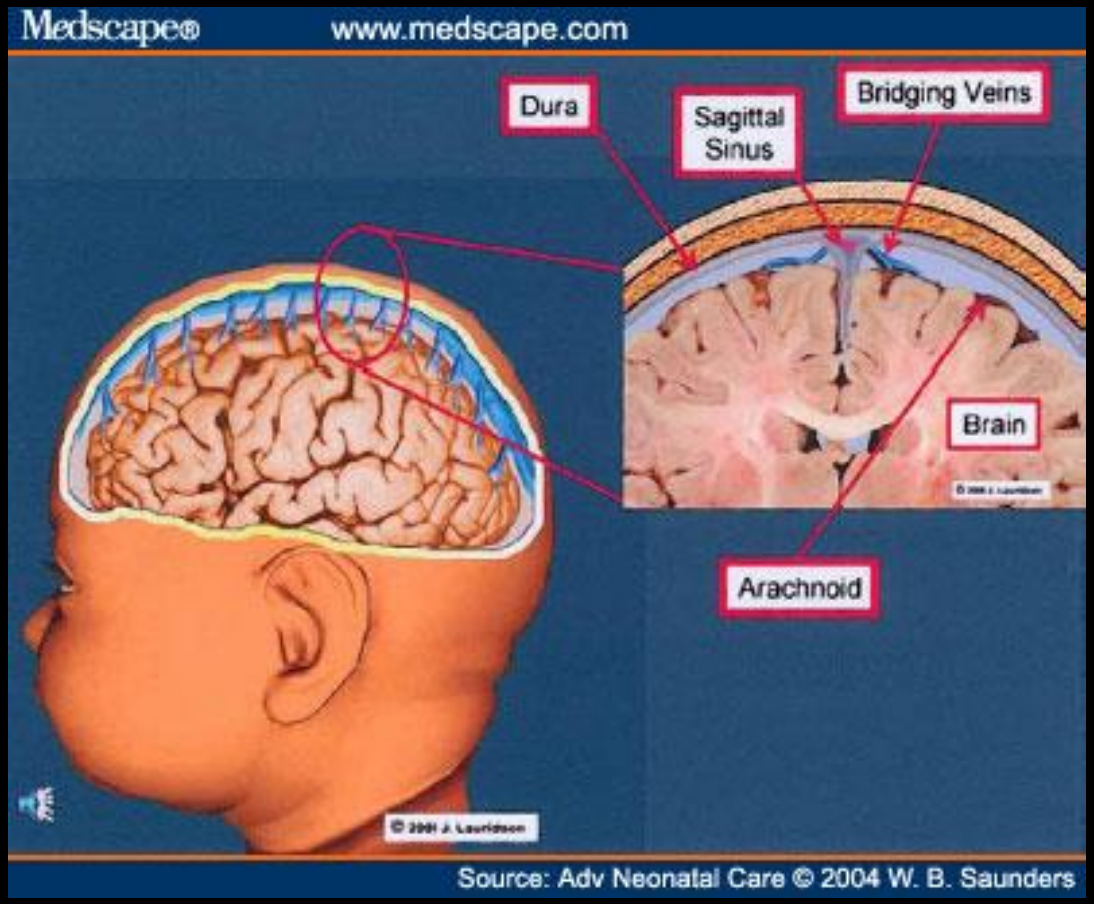
[2]U.S. Department of Health and Human Services, 2013. http://www.childwelfare.gov/pubs/factsheets/long_term_consequences.cfm

[3]Fang, X., et al. Child Abuse & Neglect (2012), http://www.sciencedirect.com/science/article/pii/S0145213411003140

Abusive Head Trauma

- Most common cause of death from child maltreatment
- 10% of head injuries are a result of NAT
- Shake-slam syndrome
- Leading cause of trauma-related death among young children
- Permanent injuries may affect personality, learning and functional skills


Medscape®
www.medscape.com
Source: Adv Neonatal Care © 2004 W. B. Saunders


Medscape®
www.medscape.com
Dura
Sagittal Sinus
Bridging Veins
Brain
Arachnoid
Source: Adv Neonatal Care © 2004 W. B. Saunders

Why Do Woodpeckers Resist Head Impact Injury: A Biomechanical Investigation

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Abstract

Head injury is a leading cause of morbidity and death in bo
injuries account for 15% of the burden of fatalities and dis
Brain injury may be caused by an impact or a sudden char
woodpecker does not experience any head injury at the hi
tree trunk. It is still not known how woodpeckers protec
synchronous high-speed video systems were used to obse
the peck force. The mechanical properties and macro/micr

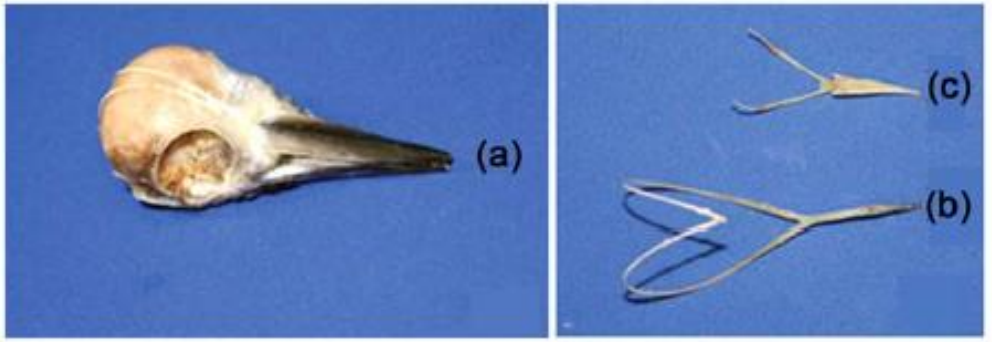


Figure 3. Anatomical structures of head and hyoid bone. (a) Great Spotted woodpecker's head; (b) Great Spotted Woodpecker's hyoid bone; (c) Eurasian hoopoe's hyoid bone.
6490.g003

micro morphology of cranial bone and
l analysis makes it possible to visualize
d treatment of human head injury.

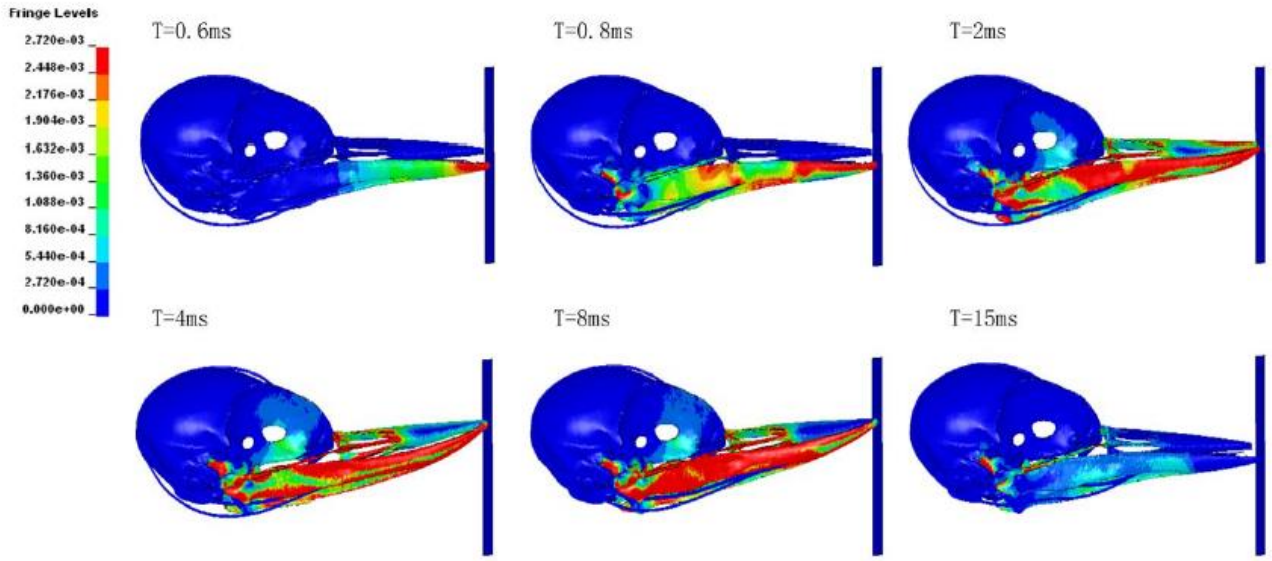
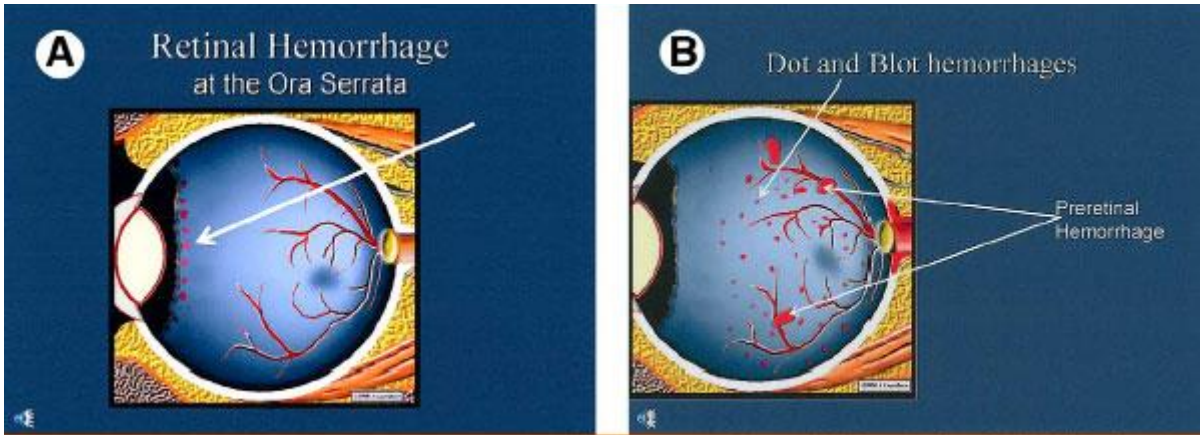
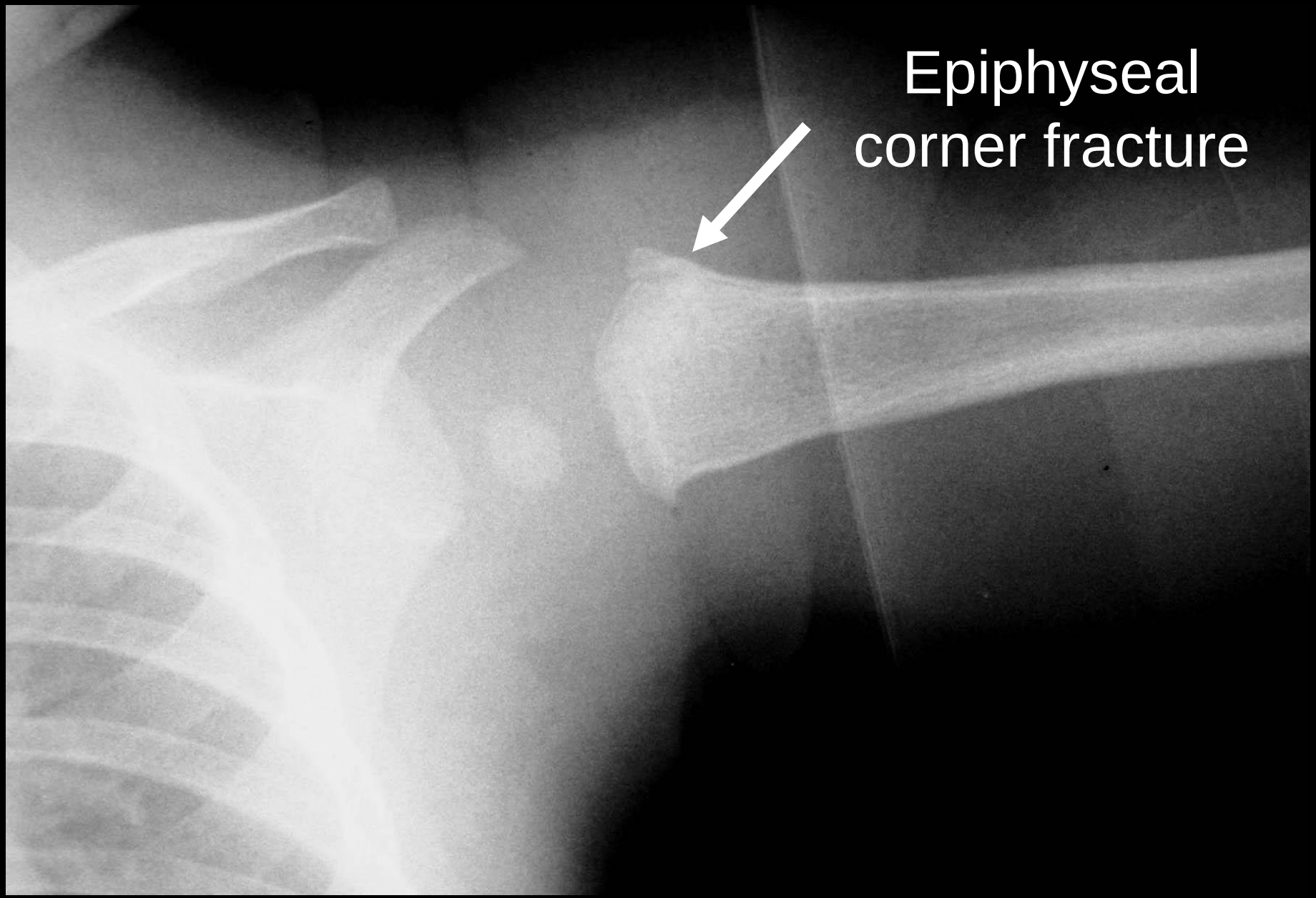


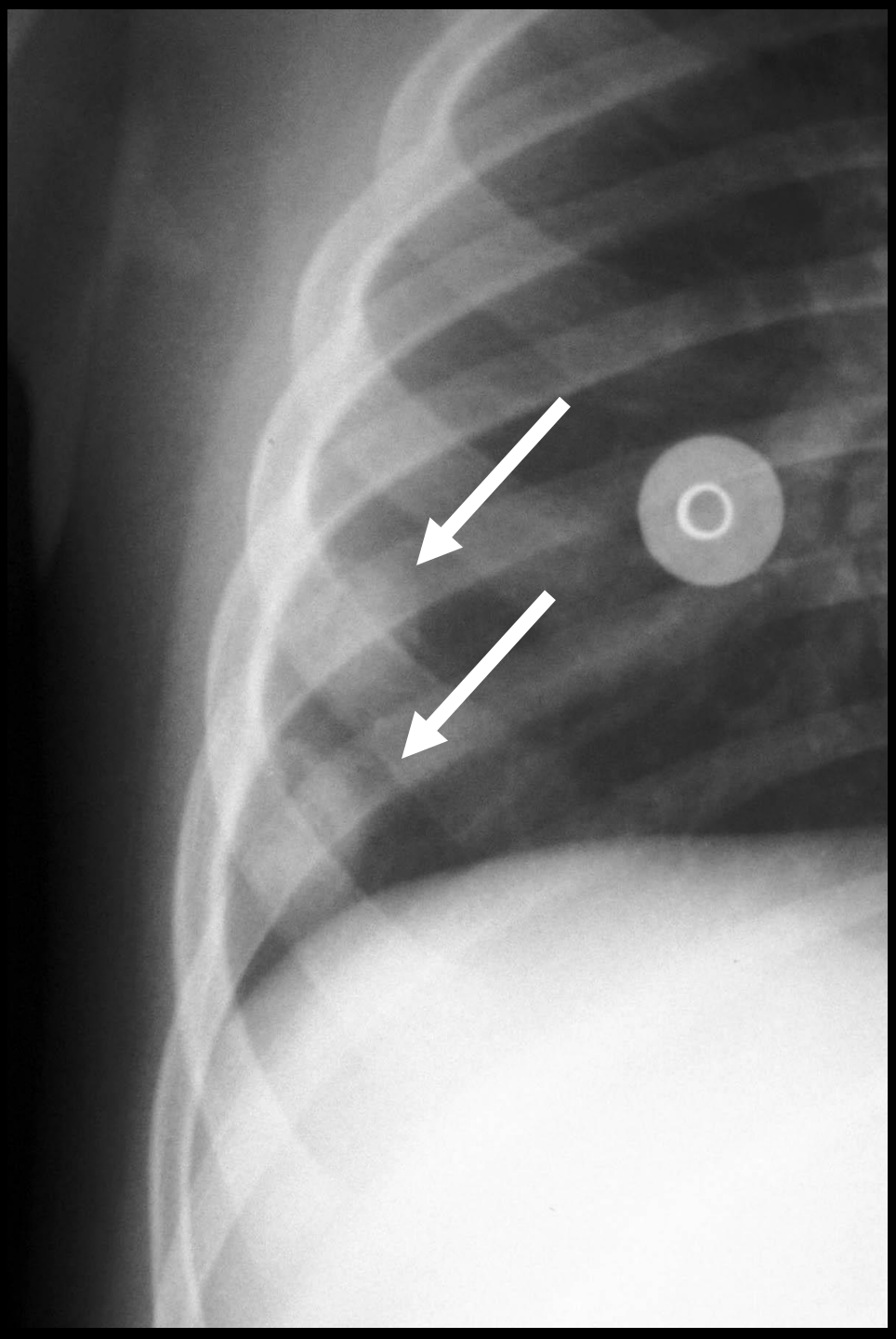
Figure 7. The effective stress distribution of woodpecker's head during pecking.
doi:10.1371/journal.pone.0026490.g007

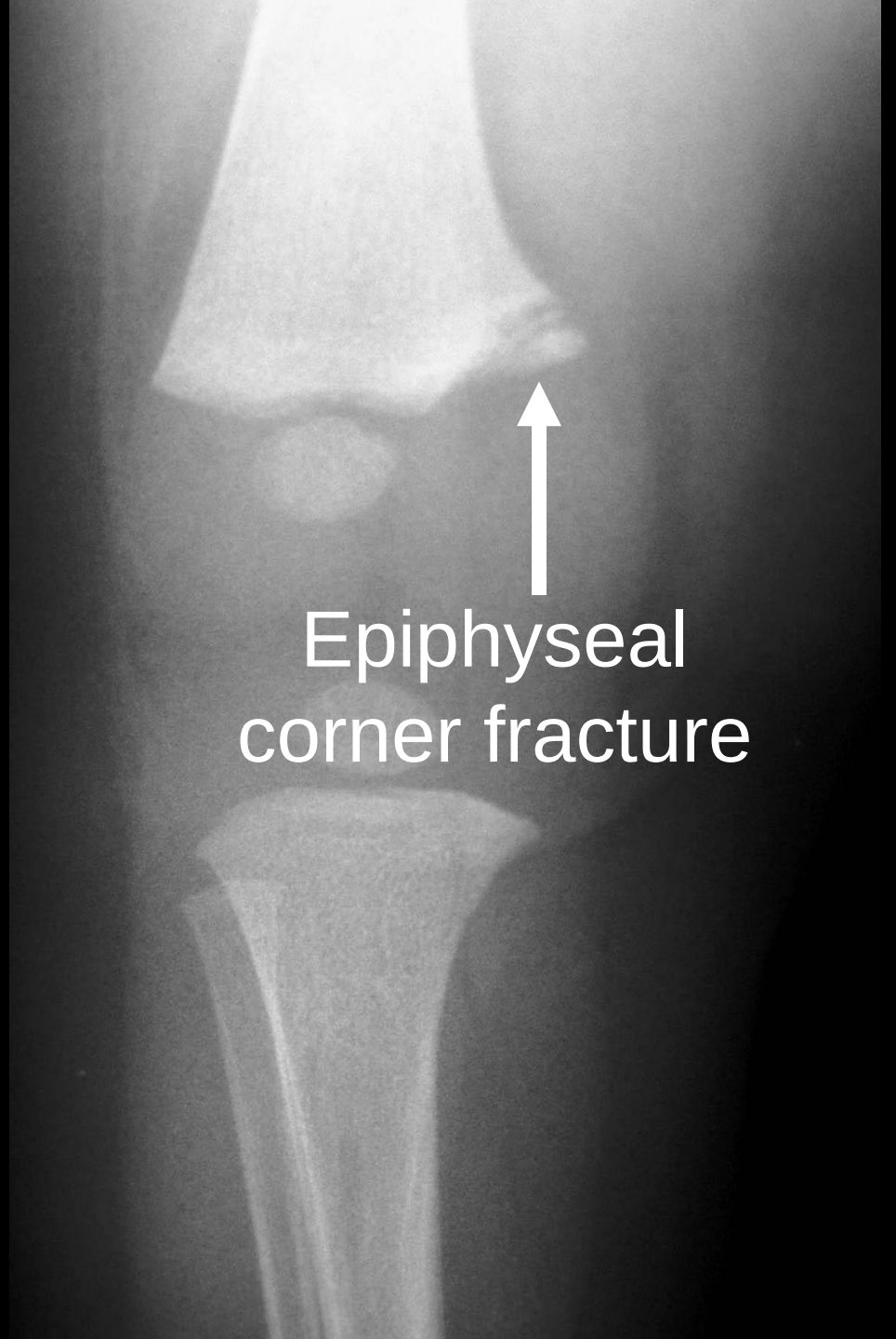
Retinal Hemorrhages

- Hallmark of shaken baby syndrome
- Hemorrhagic lesions in the back of the eyes
  - Usually bilateral
  - Thought due to rapid increases in ICP and/or venous pressure, shearing of retinal vessels
  - Uncommon in other types of CHI




Epiphyseal
corner fracture



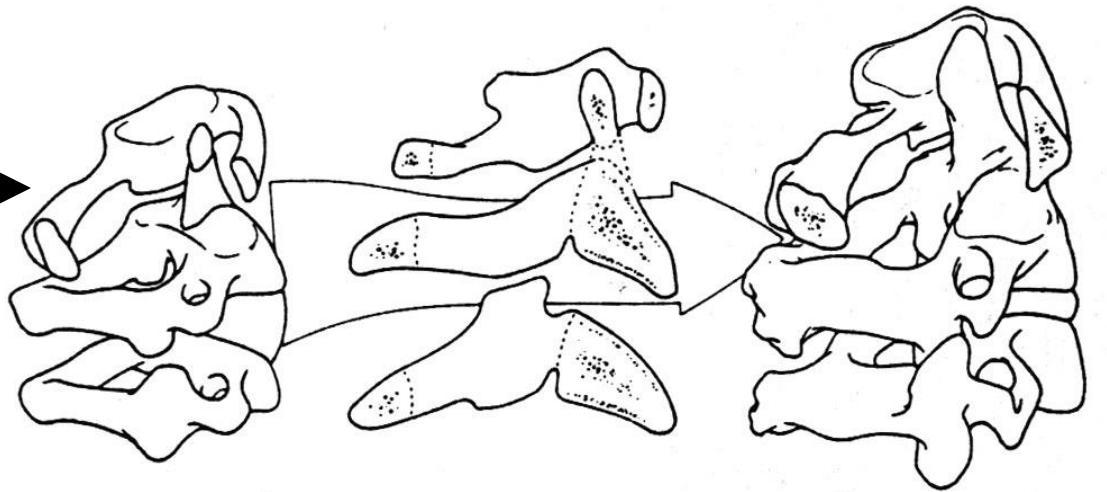

Epiphyseal
corner fracture

Children as Accident Victims

Size and Shape

- Proportionately larger head size
- Underdeveloped musculature and ligaments of the neck
  - Increased risk of head trauma
  - Increased risk of cervical spine injury
    - High (C1-C3) C-spine injuries in young
    - Lower C-spine injures with increasing age

In children, upper 3 facet joints are nearly horizontal



Heat Loss

- Susceptible to hypothermia
  - Large body surface relative to size
  - Thin skin, less insulating fat
  - Tend to equilibrate with the environment
- Complications related to hypothermia
  - Increase in O_2 consumption, to maintain normothermia, promotes lactic acidosis
  - Coagulopathy
  - Decreases myocardial contractility

Patterns of Injury in Children

- Short torso
  - Head, chest and abdomen are at the height of auto fenders and bumpers
  - Force of impact distributed over smaller volume of tissue/greater number of organs
  - Liver, spleen, and kidneys have less abdominal wall/thoracic wall protection
  - The urinary bladder is unprotected in infants

Skeleton

- Child's skeleton incompletely calcified
  - Multiple growth centers, more pliable
  - Internal organ damage frequently noted without overlying bony fracture
  - Rib fractures suggest significant blunt trauma and potentially serious underlying organ injury

Response to Injury

- Blood volume
  - Infant 90 cc/kg
  - Child 80 cc/kg
  - Adult 70 cc/kg

- Hemorrhagic “shock”
  - Infant (3 kg): 30% blood volume = 80 cc
  - Child (10 kg): 30% blood volume = 240 cc
  - Adult (70 kg): 30% blood volume = 1000 cc

Physiologic Response to Injury

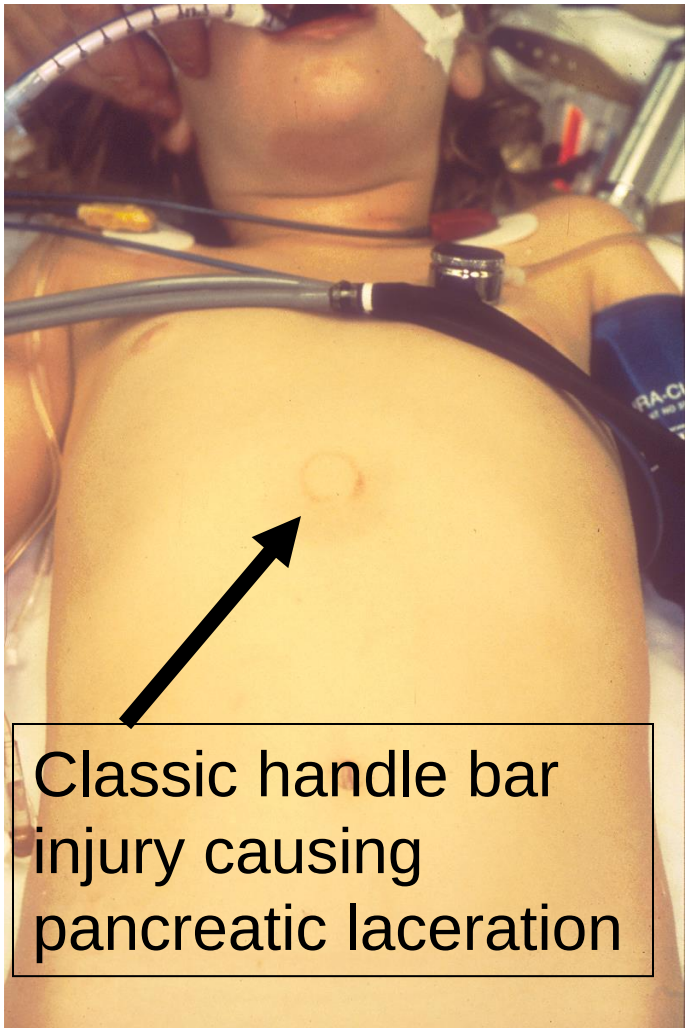
- Pediatric heart has limited capacity to increase stroke volume

$$CO = HR \times SV$$

- Cardiac output in very young children is almost entirely dependent on heart rate
- Tachycardia: think hypovolemia

Non-Operative Management

- Non-invasive evaluation
- Non-operative management
  - Initial period of observation for many injury types
  - Children more likely to stop bleeding
  - Beware of associated injuries:
    - head, facial, chest, pelvic, and extremity injuries
  - High index of suspicion for occult injuries:
    - bowel, bladder, biliary and pancreatic

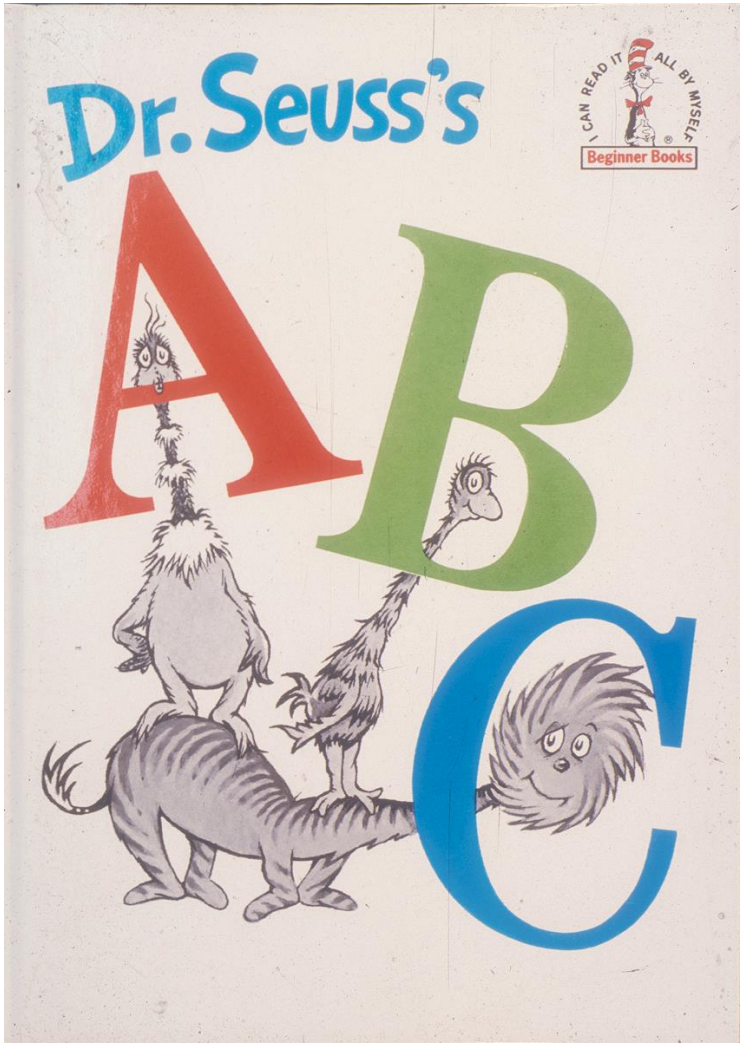


Psychological Status

- Emotional instability
  - Regressive psychological behavior
  - Limited ability to interact with strangers/environment
  - Need to assess psychological and physical injuries

Primary Survey

- Airway
- Breathing
- Circulation
- Disability
- Exposure



Airway Intubation

- Indications:
  - Real or impending respiratory difficulty
  - GCS $\leq$ 8 or agitated patient
  - Plan painful procedures
- Benefits:
  - Controls airway; prevents acute airway obstruction
  - Improves oxygenation and ventilation
  - Decreases risk of aspiration
- Risks:
  - Loss of airway
  - Aspiration

Pediatric Airway Anatomy

- Infant larynx higher (C4) and more anterior than adult larynx (C7)
  - Upper tip of epiglottis behind soft palate
  - Infants are obligate nasal breathers for weeks to months
  - NG tubes partially obstruct the infant airway
- Craniofacial disproportion
- Occipital cervical flexion
- Trachea – short and fragile; easily traumatized and prone to edema formation

Airway Preparation

- C-spine immobilization
- Pre-oxygenation
- Suction airway prn
- Uncuffed endotracheal tubes age $\leq$ 5 yrs

$$\frac{16 + \text{age}}{4} = \text{Int. diameter ETT (mm)}$$

- 3 ETTs readily available

Airway Control

- Oral route
  - Easy, fast, largest ETT
  - C-spine stabilization
- Nasotracheal route
  - If oral route not available
- Needle cricothyroidotomy
  - Large bore IV through cricothyroid membrane
  - Y-connector, high flow oxygen

Airway Secure

- Auscultate
- Check ETT length
- Check end tidal CO_2
- Securely tape ETT
  - Consider wrist restraints
- Check CXR

Breathing

- Rate
  - Infants 40/min.
  - Children 20/min.
  - Adults 12/min.
- Tidal volume
  - 7 - 10 cc/kg
- Low peak inspiratory pressures
  - Upper teens – low 20s
  - Avoid barotrauma

Breathing

- Inadequate ventilation
  - Apnea/decreased LOC
  - Hemopneumothorax
  - Flail or sucking chest wound
- Inadequate oxygenation
  - Pulmonary contusion
  - Aspiration
  - Smoke inhalation

Breathing

- Clinical diagnosis of tension pneumothorax (PTX) difficult in children
  - Breath sounds widely transmitted
  - Tremendous compensatory reserve
  - CXR takes time
- Differentiate PTX from mainstem intubation
  - Check ETT length
- Needle decompression is safe
  - Large bore IV 2nd ICS mid-clavicular line

Circulation

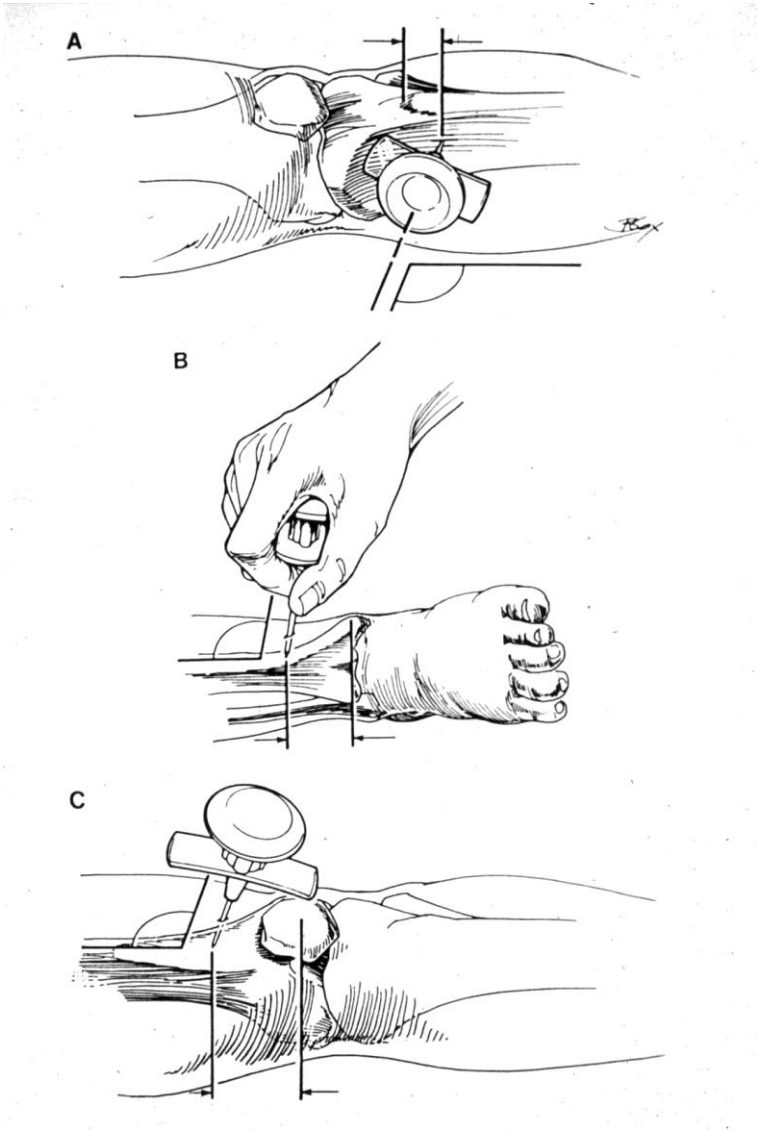
- Shock is usually clinically apparent
  - Mottling of skin, cool and pale extremities, poor capillary refill
  - Rapid and weak pulse, poor heart sounds, collapsed neck veins
  - Diminished neurological response in the absence of head injury

Pediatric Venous Access

- Percutaneous
  - Antecubital
  - (Back of hand if not bleeding)
  - Femoral
  - Internal and external jugular
  - Subclavian
- Cutdown
  - saphenous

Pediatric Venous Access

- If no IV access, use IO
  - Fast
  - Reliable
  - Temporary



Fluid Resuscitation

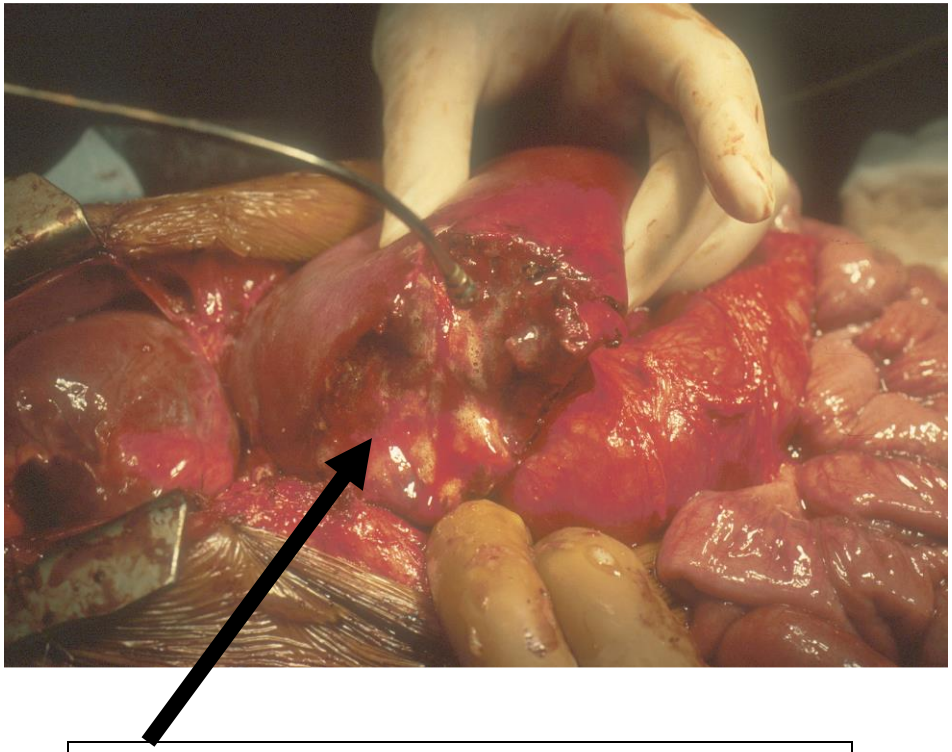
- Blood volume ~ 8% TBW = 80 cc/kg
- 2 X 20 cc/kg LR
  - If inadequate response (~½ total blood volume replaced)….give blood
- 10 cc/kg PRBCs

Fluid Resuscitation

- Access adequacy of fluid resuscitation
  - Heart rate
  - Systolic blood pressure [(age x 2) + 80]
  - Perfusion
    - Absence of skin mottling
    - Capillary refill < 2 seconds
    - Urine output
    - CVP

Persistent Hypotension

- Persistent hypovolemia
  - Blood loss at scene
  - Intra-cavitary/pelvic/thigh hemorrhage
- Pericardial tamponade or tension PTX
  - Pericardiocentesis or chest tube
- Spinal cord injury
  - norephinephrine
- Myocardial contusion
  - ECHO, vasopressors



Major liver laceration

Brief Neurological Exam

- Level of consciousness
- Pupil size and reactivity
- Extremity movement
- GCS

- Know priorities and anticipate next moves

Complete Exposure of the Patient

- Prevent or reverse hypothermia
  - Resuscitation suite pre-warmed
  - Heat lamps
  - Warm IV fluid
  - Warm blankets
  - Warm inspired air
  - Warm OR

Secondary Survey

- Complete Physical Exam
- Radiographic Work up
  - CXR?
  - C-spine?
  - Pelvis?
  - CT if result will influence your immediate plan of care, i.e. treat, admit or transfer

Selective Imaging

- Indiscriminate use of CT
  - Delays transfer
  - Needlessly increases cancer risk in later life
    - Incomplete studies
    - Improperly formatted studies
    - Excessive radiation dosing
    - If images not sent/transferred, may need to repeat
  - Adds cost to the healthcare system

Underlying Philosophy

The vast majority of trauma patients receive their total care at a local hospital, and movement beyond that point is often not necessary.

When the need to transfer is recognized, arrangements should be expedited and not delayed for diagnostic procedures (e.g. CT imaging) that do not change the immediate care plan.

HEAD

< 2 years old

Does patient have ANY of the following?

- GCS < 15
- Palpable skull fracture
- AMS (agitation, somnolence, slow response, and/or confused speech)
- Suspicion of child abuse
- Abnormal neurological findings on PE
- Bulging fontanel
- Persistent vomiting
- Seizure activity following injury

NO → CT not indicated, observe 4-6 hours

BUT presents with:

- Episode of emesis
- Uncertain or brief LOC
- Behavior change
- Scalp hematoma
- Skull fracture >24 hours old
- High force mechanism injury: fall >3', MVC w/ rollover, ejection or fatality; struck by large object; auto vs. ped/bike/stroller
- Un-witnessed trauma

→ Observation vs. CT using shared decision making**
Observe 4-6 hrs; CT if sx's worsen

→ Decision to obtain CT Scan
Multiple vs. one skull fx
Worsening sx's
MD experience
Parental preference

YES → Obtain Head CT without IV contrast

≥ 2 years old

Does patient have ANY of the following?

- Focal neurological findings
- Skull fracture
- Persistent altered mental status
- Prolonged loss of consciousness

YES → Obtain Head CT without IV contrast

NO → CT not indicated, observe 4-6 hours

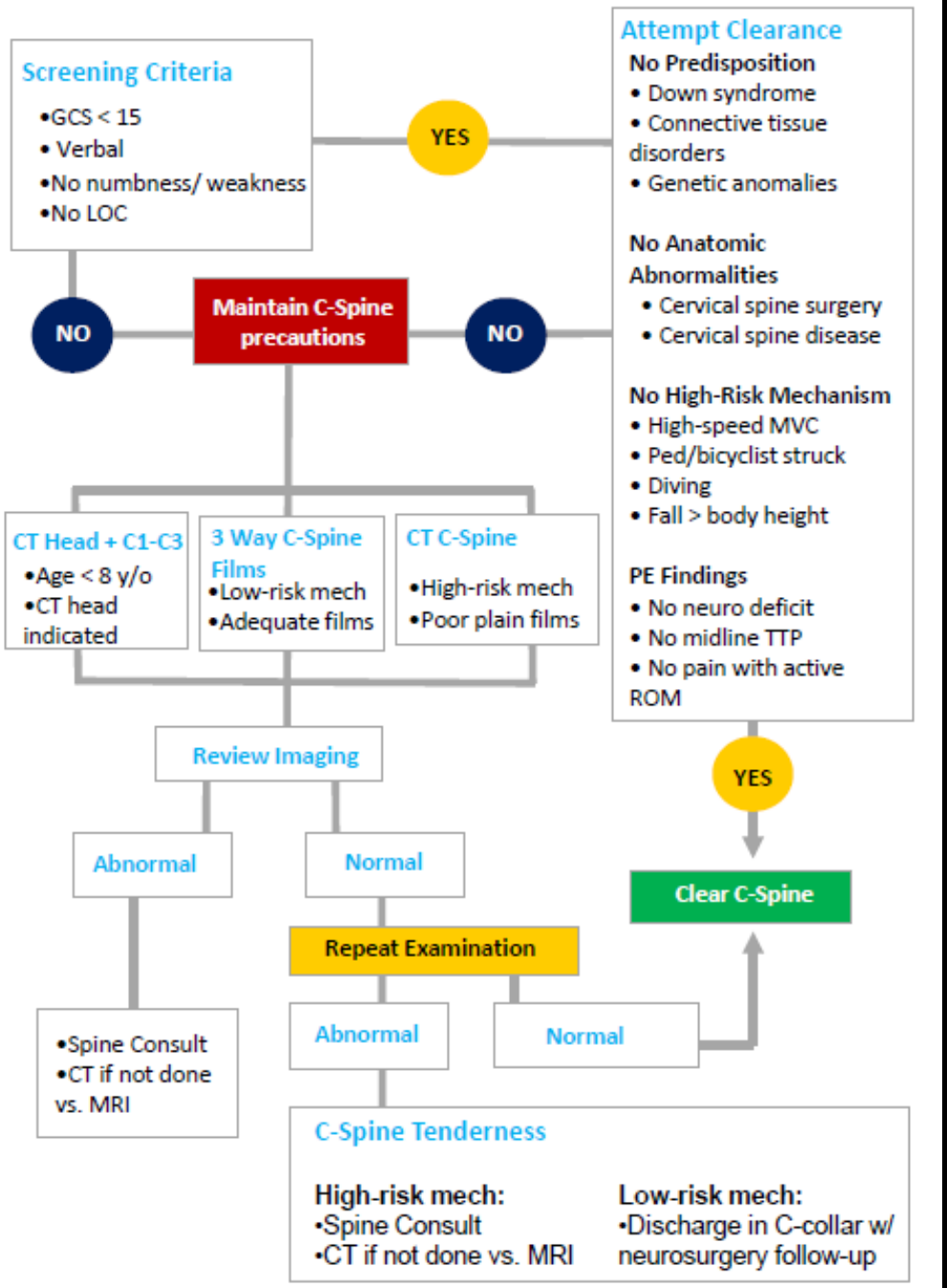
BUT presents with:

- Episode of emesis
- Uncertain or brief LOC
- Severe headache
- High force mechanism injury: fall > 5', MVA w/ rollover, ejection, or fatality, auto vs. ped/bike without helmet, struck by large object

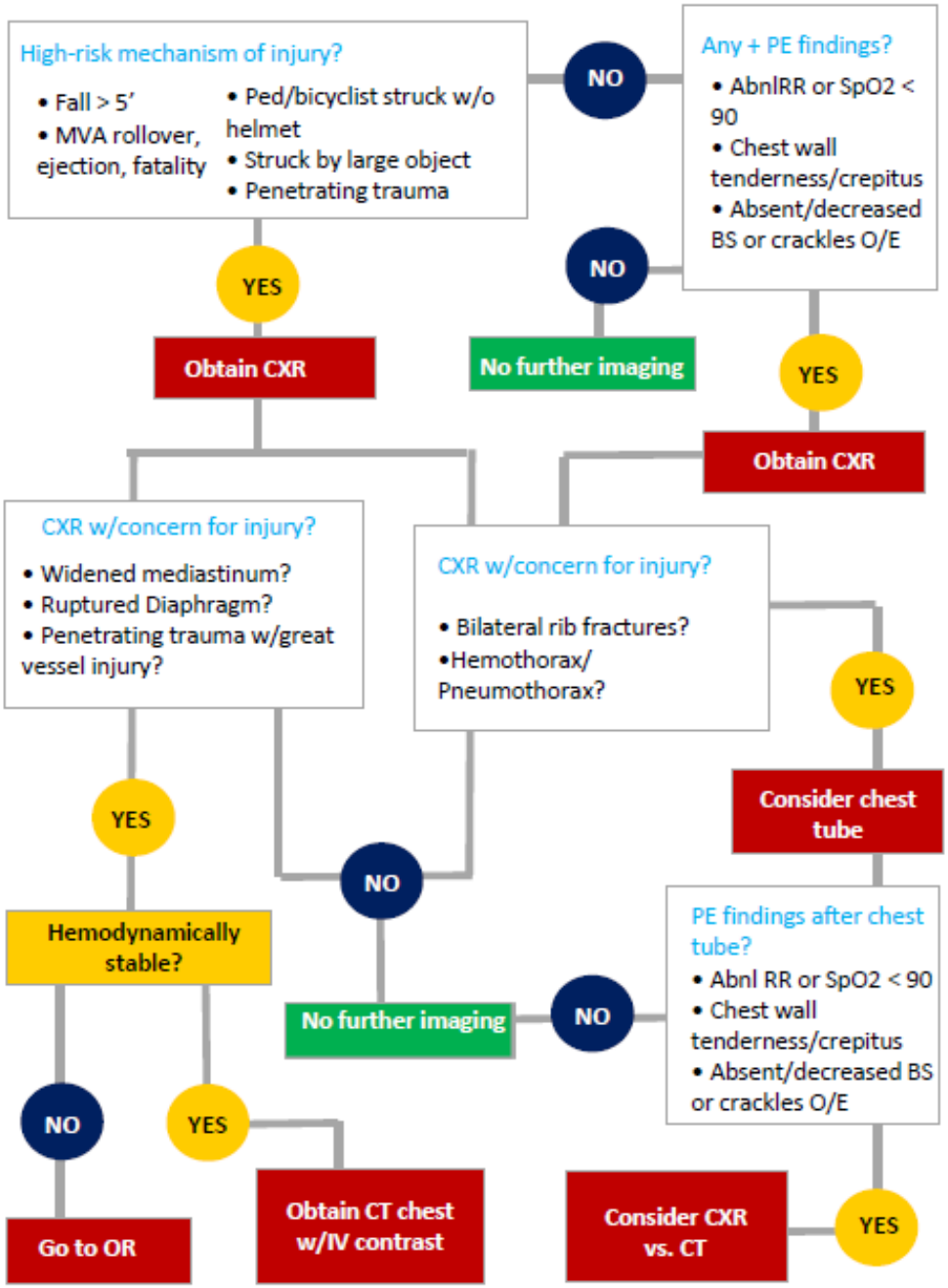
→ Observation vs. CT using shared decision making**
Observe 4-6 hrs; CT if sx's worsen

**Between provider and parent

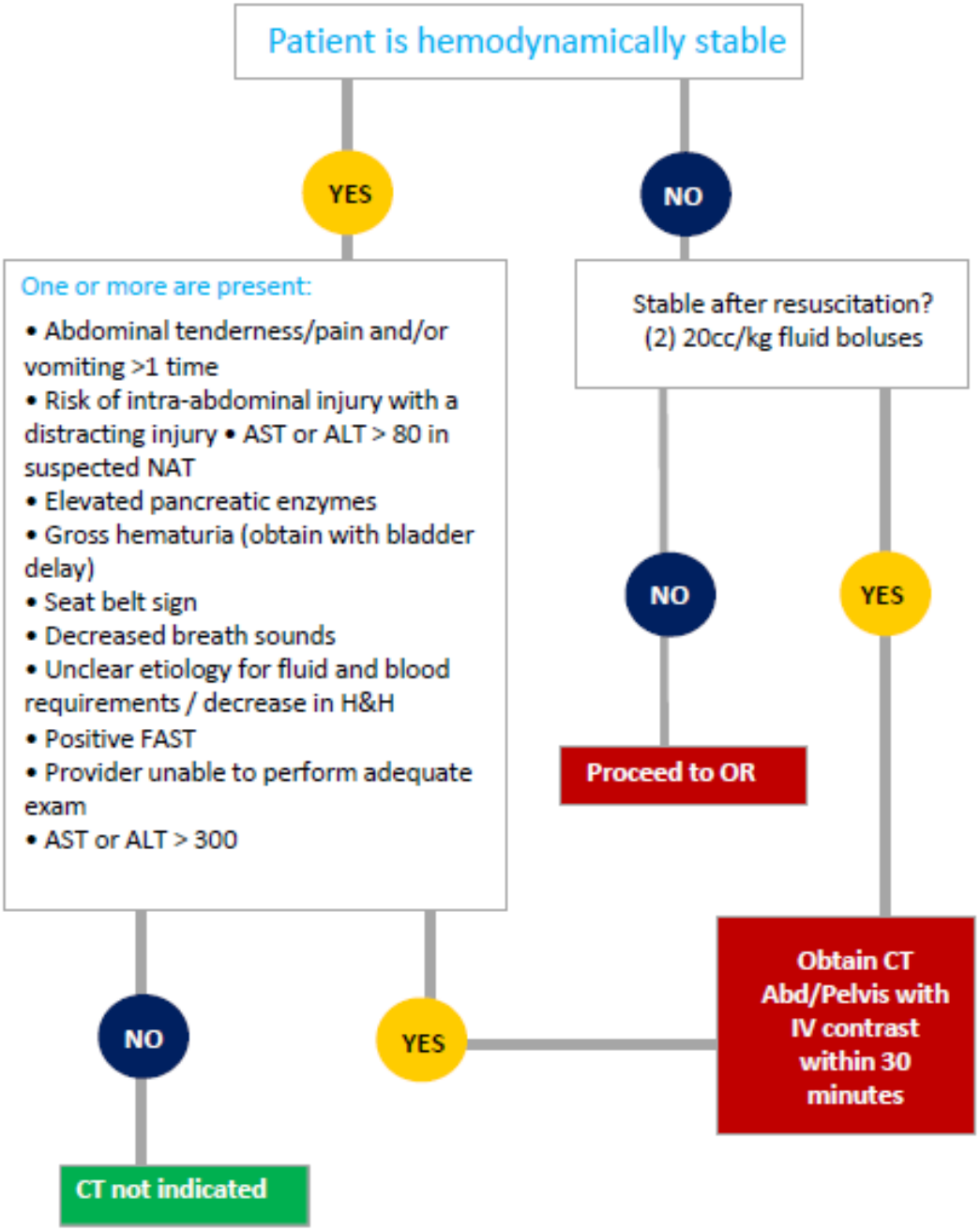
C-SPINE


Screening Criteria
•GCS < 15
• Verbal
•No numbness/ weakness
•No LOC
YES
Attempt Clearance
No Predisposition
• Down syndrome
• Connective tissue disorders
• Genetic anomalies
No Anatomic Abnormalities
• Cervical spine surgery
• Cervical spine disease
No High-Risk Mechanism
• High-speed MVC
• Ped/bicyclist struck
• Diving
• Fall > body height
PE Findings
• No neuro deficit
• No midline TTP
• No pain with active ROM
NO
Maintain C-Spine precautions
NO
CT Head + C1-C3
•Age < 8 y/o
•CT head indicated
3 Way C-Spine Films
•Low-risk mech
•Adequate films
CT C-Spine
•High-risk mech
•Poor plain films
Review Imaging
YES
Abnormal
Normal
Clear C-Spine
Repeat Examination
•Spine Consult
•CT if not done vs. MRI
Abnormal
Normal
C-Spine Tenderness
High-risk mech:
•Spine Consult
•CT if not done vs. MRI
Low-risk mech:
•Discharge in C-collar w/ neurosurgery follow-up

CHEST


High-risk mechanism of injury?
• Fall > 5'
• MVA rollover, ejection, fatality
• Ped/bicyclist struck w/o helmet
• Struck by large object
• Penetrating trauma
NO
Any + PE findings?
• AbnlRR or SpO2 < 90
• Chest wall tenderness/crepitus
• Absent/decreased BS or crackles O/E
YES
Obtain CXR
NO
No further imaging
YES
Obtain CXR
CXR w/concern for injury?
• Widened mediastinum?
• Ruptured Diaphragm?
• Penetrating trauma w/great vessel injury?
CXR w/concern for injury?
• Bilateral rib fractures?
•Hemothorax/ Pneumothorax?
YES
Consider chest tube
YES
Hemodynamically stable?
NO
No further imaging
NO
PE findings after chest tube?
• Abnl RR or SpO2 < 90
• Chest wall tenderness/crepitus
• Absent/decreased BS or crackles O/E
NO
Go to OR
YES
Obtain CT chest w/IV contrast
Consider CXR vs. CT
YES

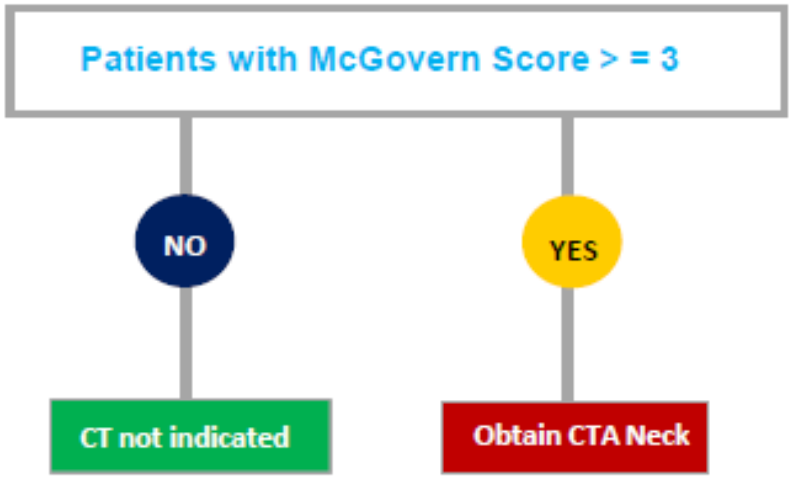
ABDOMEN AND PELVIS



BCVI

McGovern BCVI Prediction Score

Characteristic	Points
GCS < or = 8	1
Focal neuro deficit	2
Carotid canal fracture	2
High speed MVA or ped struck	2
Petros temporal bone fracture	3
Cerebral infarct on CT	3



YES Note: CTA neck not recommended in patients with an isolated seat belt mark on the neck.

Gunshot Wound Cases Meeting Trauma Registry Criteria Colorado's Regional Pediatric Trauma Center

122%

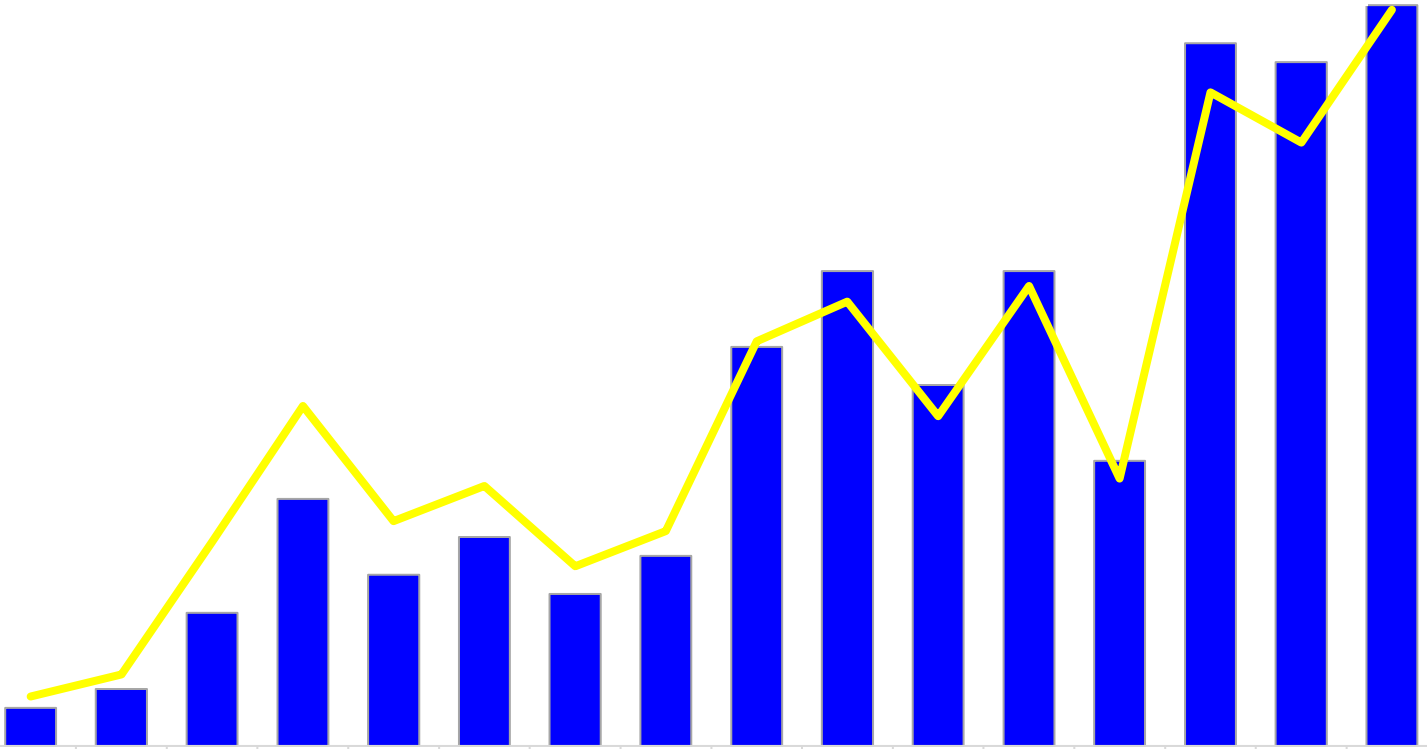
Increase in 5 Years

1,418%

Increase in 15 Years

14

Average Age



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Count of GSWs	2	3	7	13	9	11	8	10	21	25	19	25	15	37	36	39
Percentage	0.17%	0.25%	0.72%	1.19%	0.79%	0.91%	0.63%	0.75%	1.42%	1.56%	1.16%	1.61%	0.94%	2.29%	2.12%	2.58%

Since 2020 Gunshot Wounds are the Leading Cause of Traumatic Death at CHCO

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National trends in pediatric firearm and automobile fatalities☆,☆☆

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ABSTRACT

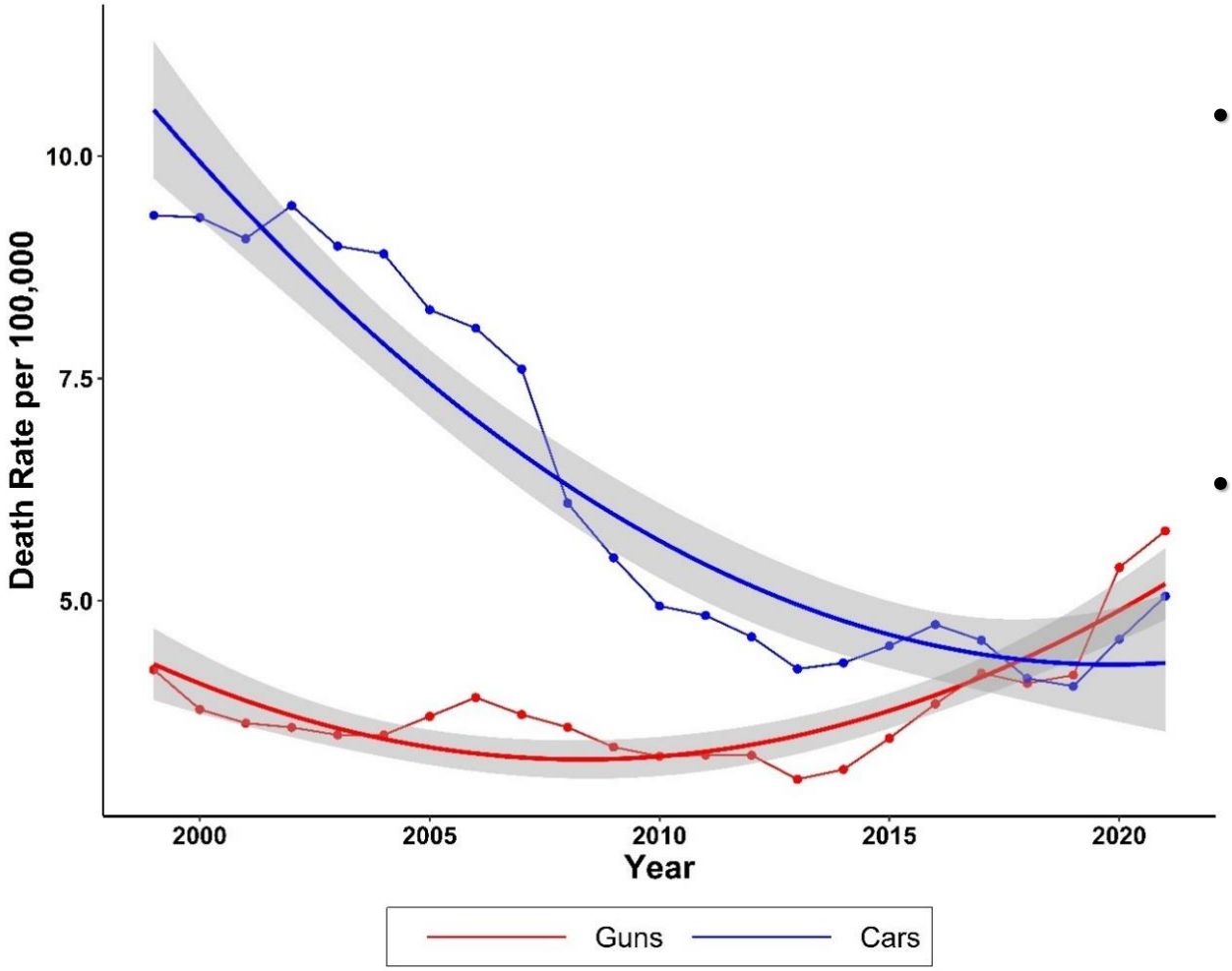
Background: Successful public health policies and injury prevention efforts have reduced pediatric automobile fatalities across the United States. In 2019, firearm injuries exceeded motor vehicle crashes (MVC) as the leading cause of childhood death in Colorado. We sought to determine if similar trends exist nationally and if state gun laws impact firearm injury fatality rates.

Methods: Annual pediatric (≤19 years-old) fatality rates for firearm injuries and MVCs were obtained from the CDC WONDER database (1999–2020). State gun law scores were based on the 2014–2020 Gifford's Annual Gun Law Scorecard and strength was categorized by letter grades A-F. Poisson generalized linear mixed models were used to model fatality rates. Rates were estimated for multiple timepoints and compared between grade levels.

Results: In 1999, the national pediatric fatality rate for MVCs was 248% higher than firearm injuries (Incidence Rate Ratio (IRR) 95% Confidence Interval (CI): 2.25–2.73, $p<0.0001$). By 2020, the fatality rate for MVCs was 16% lower than that of firearm injuries (IRR 95% CI: 0.75- 0.93, $p = 0.0014$). For each increase in letter grade for gun law strength there was an 18% reduction in the firearm fatality rate (IRR 95%CI: 0.78–0.86, $p<0.0001$). States with the strongest gun laws (A) had a 55% lower firearm fatality rate compared to those with the weakest laws (F).

Conclusion: Firearm injuries are the leading cause of death in pediatric patients across the United States. State gun law strength has a significant impact on pediatric firearm injury fatality rates. New public health policies, political action, media attention and safer guns are urgently needed to curb this national crisis.

Level of Evidence/Study Type: Level III, retrospective



Results

- In 1999, the national pediatric fatality rate for automobile injuries was **248% higher** than that of firearm injuries ($p<0.0001$)
- By 2021, the national pediatric fatality rate for automobile injuries was **24% lower** than that of firearm injuries ($p=0.001$)

In 2020, firearm injuries surpassed automobile injuries to become the leading cause of death in children and adolescents across the U.S.

Estimate Year	Gun Law Strength				
	A (Strongest)	B	C	D	F (Weakest)
2014	1.86 (1.46, 2.38)	2.22 (1.83, 2.69)	2.64 (2.27, 3.07)	3.15 (2.75, 3.59)	3.75 (3.22, 4.35)
2019	2.90 (2.33, 3.61)	3.45 (2.93, 4.06)	4.11 (3.64, 4.63)	4.89 (4.38, 5.46)	5.83 (5.07, 6.70)
2020	3.17 (2.54, 3.94)	3.77 (3.20, 4.44)	4.49 (3.96, 5.08)	5.34 (4.76, 6.01)	6.36 (5.50, 7.37)
2021	3.46 (2.77, 4.31)	4.12 (3.48, 4.87)	4.90 (4.30, 5.59)	5.84 (5.15, 6.62)	6.95 (5.95, 8.12)

Table 2: Estimated Pediatric Firearm Injury Fatality Rates Stratified by State Gun Law Strength, 2014 – 2021

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Results

- For each increase in letter grade (F A) for gun law strength there was an **16% reduction** in the pediatric firearm fatality rate (95% CI: 0.78-0.90, p<0.0001)
- States with the **strongest gun laws (A)** had an estimated **50% lower** pediatric firearm fatality rate compared to **states with the weakest gun laws (F)**

Conclusions

State gun law strength has a significant impact on pediatric firearm injury fatality rates:

- States with the **strongest gun laws (A)** had the **lowest pediatric firearm fatality rates**
- States with the **weakest gun laws (F)** had the **highest pediatric firearm fatality rates**

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Long Term Effects

- Acute Stress Disorder (ASD)
  - Psychological condition after a traumatic event
  - Numbing, detachment, de-realization
  - Re-experiencing e.g. flashbacks; avoidance
  - Risk factor for PTSD
- Growth and development
  - Social, affective, and learning disabilities present in 50% of seriously injured children
- Impact on family structure
  - Sibs/parents; financial; employment hardships

Conclusions

- So…
  - Keep an eye on your children
  - Buckle up
  - Wear a helmet
  - Don’t drink and drive

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