Pediatric Trauma Assessment and Resuscitation

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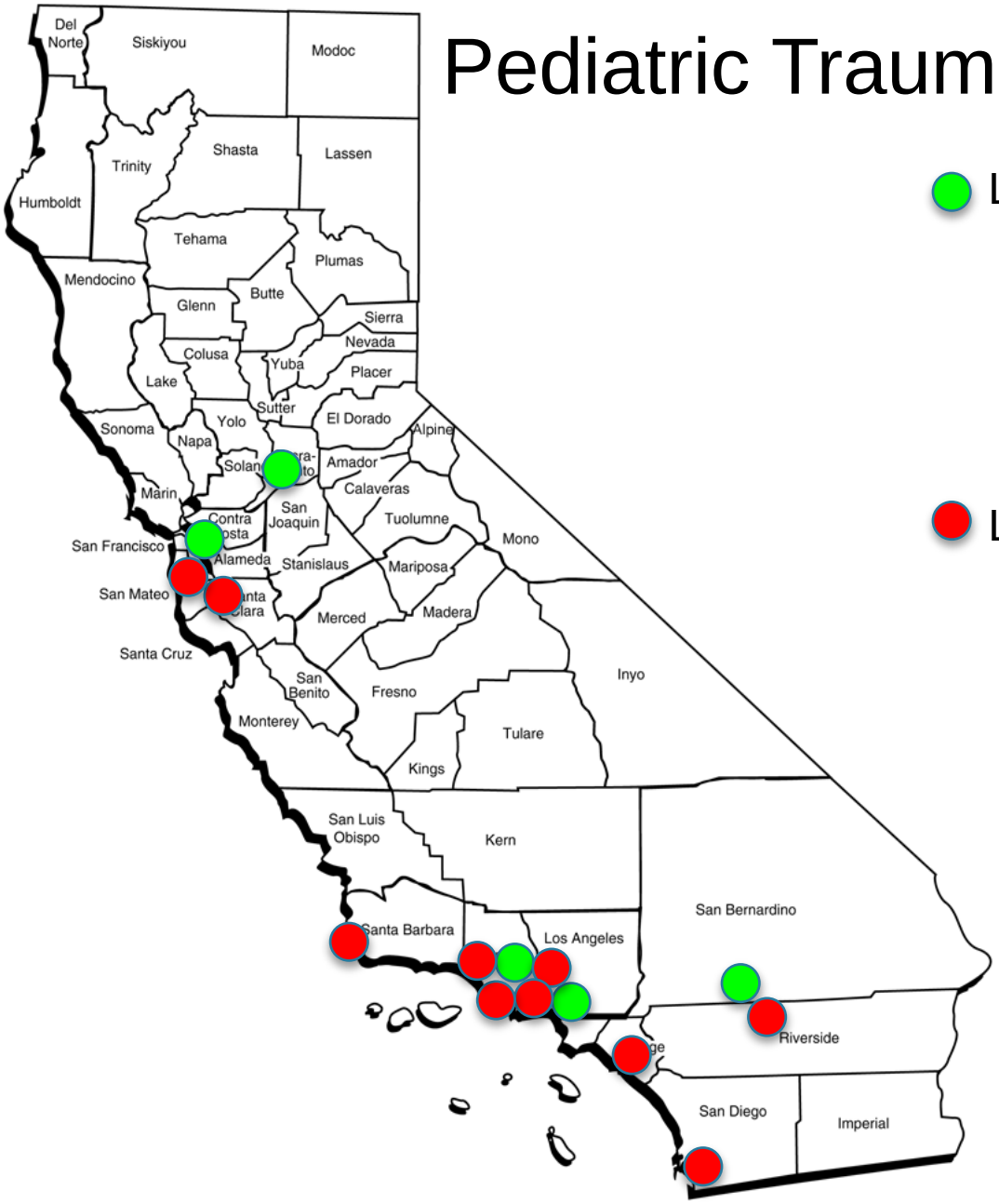
Overview

- Epidemiology of pediatric trauma
- Anatomical, physiologic and developmental issues
- Physical assessment and resuscitation of a pediatric trauma patient
- Special issues (X-ray studies, C-spine, solid organ)

Loma Linda University Children's Hospital

Level 1 Pediatric Trauma Center

Pediatric Trauma Centers - CA



- Level I
  - UC Davis
  - Oakland Children's
  - CHLA
  - UCLA
  - LLUCH
- Level II
  - Stanford
  - Santa Clara Valley
  - Santa Barbara Cottage
  - Cedar Sinai
  - Harbor UCLA
  - North Ridge
  - USC
  - Long Beach Memorial
  - CHOC
  - RCRMC
  - Rady Children's Hospital

Pediatric Trauma in the USA

- Most common cause of death and disability
- Kills more children than all other causes combined
- 12,490 deaths (2009)
- 8,067 deaths (2014)

US Dept of HHS, CDC, Nat. Ctr for Health Statistics, National Vital Statistics System, Oct 26, 2012

Pediatric Trauma in the USA

- 9.2 million ER visits/yr (2012)
- 223,000 hospitalized
- 12,000 permanently disabled
- Estimated annual cost of medical care for pediatric injuries (including time lost at work by families caring for injured children) >**$87 Billion**

ChildStats.gov, 2013

CDC Childhood Injury Report, 2010

US Dept of HHS, CDC, Nat. Ctr for Health Statistics, National Vital Statistics System, Oct 26, 2012

USA Causes of Death

- Head Injury #1 Nationwide (usually MVA related)
- Drowning #1 in warm states
- Child abuse now #1 for children < 4 yrs old

- Unintentional trauma rates of mortality in children over the last 10 years have:

A Increased dramatically
B Stayed steady
C Decreased
D Been difficult to measure

Unintentional Trauma Fatality Rates Improving!!

- 1981-1992 35% drop in overall fatalities
- 2007 – 2010 25% drop in MVA related fatalities
- Safety legislation, car seats, helmets, etc

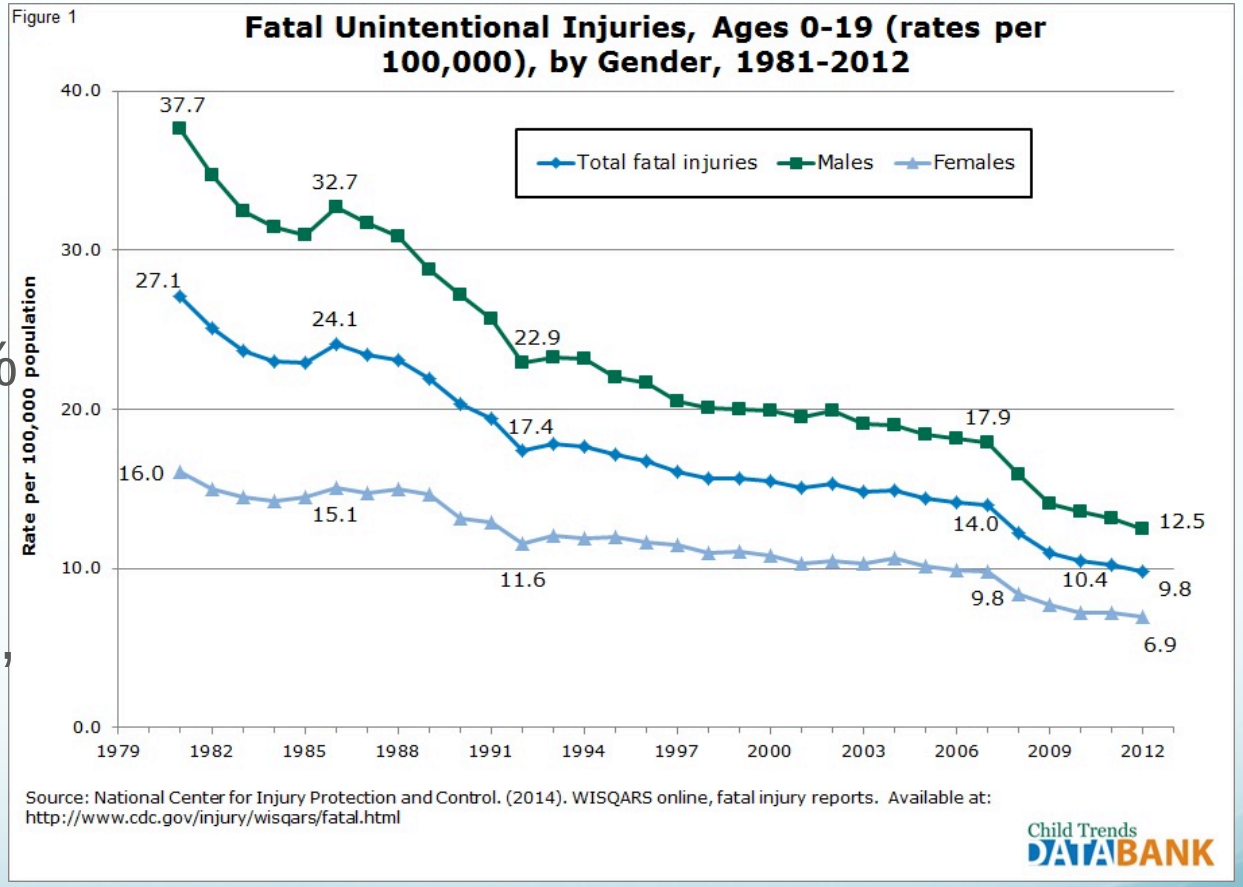


TABLE 30.2

COMMON INJURY MECHANISMS AND CORRESPONDING INJURY PATTERNS IN CHILDHOOD TRAUMA

INJURY MECHANISM	DETAILS	INJURY PATTERN
Motor vehicle injury—occupant	Unrestrained	Head/neck injuries Scalp/facial lacerations
	Restrained	Abdomen injuries Lower spine fractures
Motor vehicle injury—pedestrian	Single injury	Lower extremity fractures
	Multiple injuries	Head/neck injuries Chest/abdomen injuries Lower extremity fractures
Fall from height	Low	Upper extremity fractures
	Medium	Head/neck injuries Scalp/facial lacerations Upper extremity fractures
	High	Head/neck injuries Scalp/facial lacerations Chest/abdomen injuries Extremity fractures
Fall from bicycle	Unhelmeted	Head/neck injuries Scalp/facial lacerations Upper extremity fractures
	Helmeted	Upper extremity fractures
	Handlebar impact	Abdomen injuries

Adapted from Cooper A. Early assessment and management of trauma. In: Ashcroft KW, Holcomb GW, Murphy JP, eds. *Pediatric Surgery*. Philadelphia, PA: Elsevier, 2005:168–84.

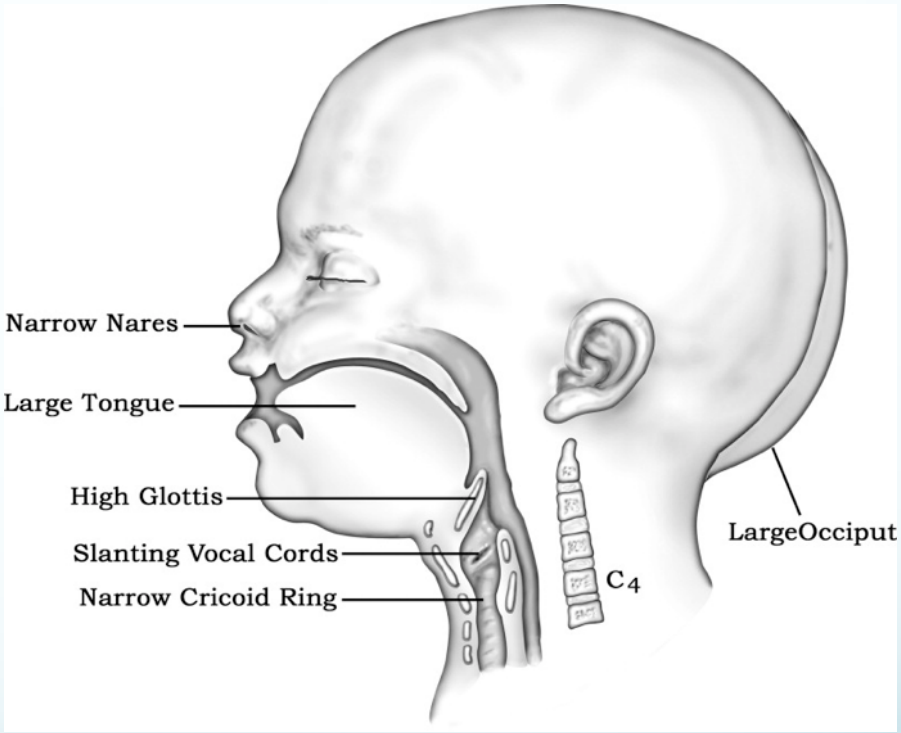
Nichols and Shaffner, *Roger's Textbook of Pediatric Critical Care*, 5th edition, 2016

What to Consider When Assessing a Child

- Children are not little adults
- Anatomical differences
  - Airway geometry, body habitus, developing musculoskeletal system, body surface area
- Physiology
  - Vital signs, blood volume, compensatory response to hypovolemia
- Child development
  - Ability to interact
  - Need for a guardian

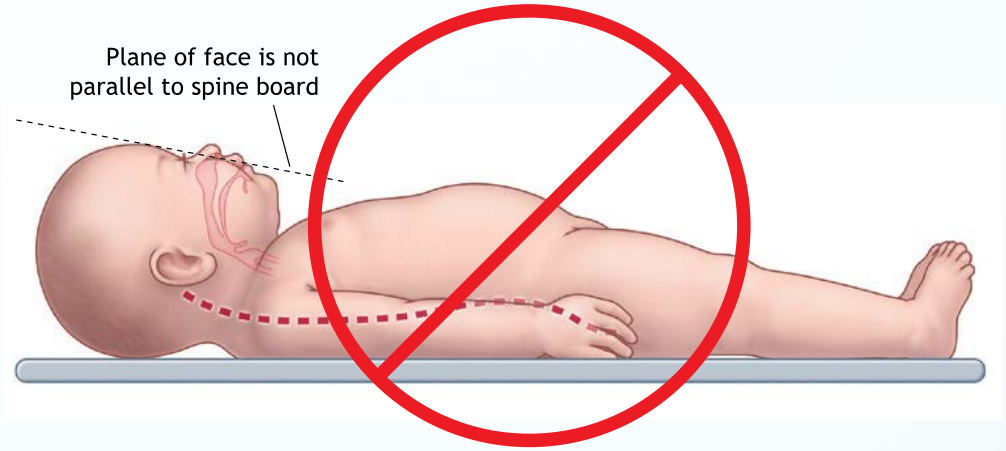
Airway Anatomy

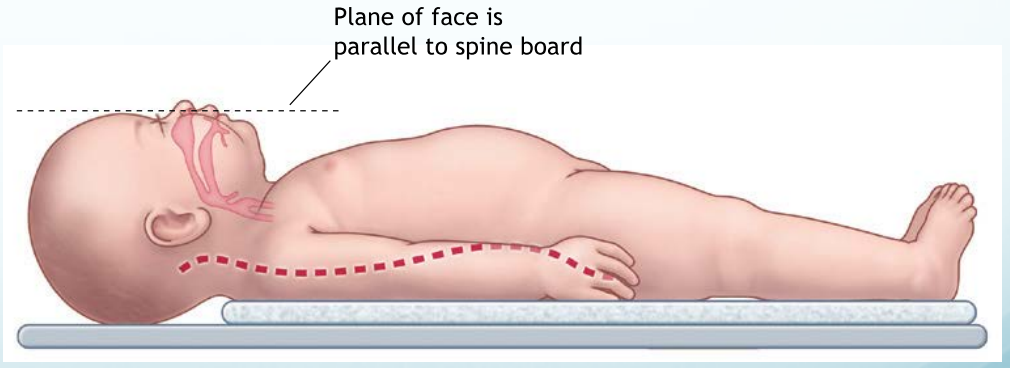
- Shorter, smaller diameter
- Large occiput & small midface → acute angulation of airway
- Small jaw, large tongue
- Anterior larynx
- Trachea narrowest at cricoid ring
  - Adults – narrowest at VC's



Torso Padding

- Prominent Occiput
  - Angulates airway
  - Cervical spine not in neutral position
- Padding
  - Permits neutral position of neck
  - A folded towel or blanket can work well

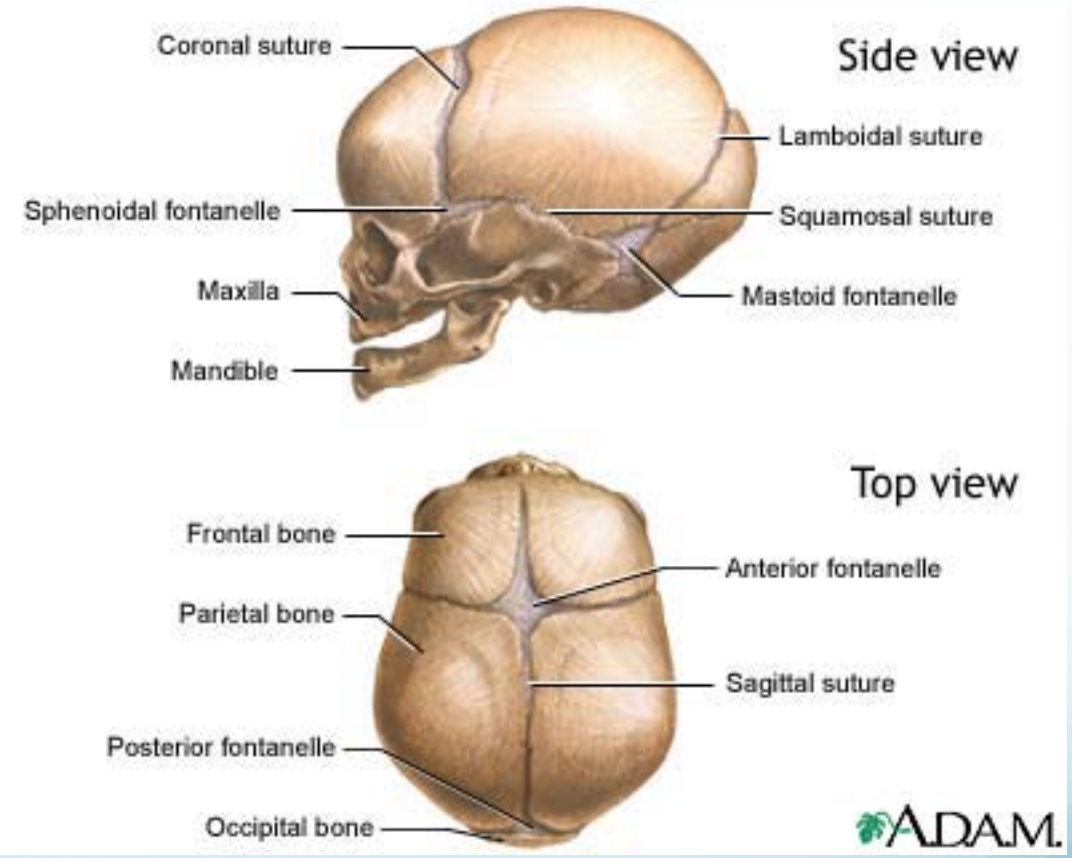




American College of Surgeons, ATLS 9th Ed.

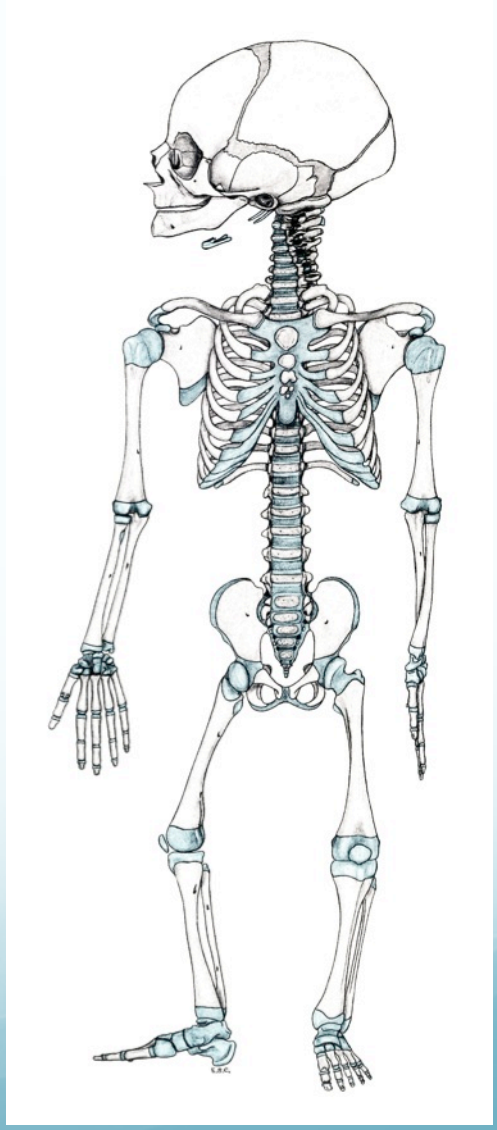
Anatomy - Head

- Large relative to body size
- Large occiput
- Soft cranium
- Open fontanelles
- Look for subgaleal hematomas as can be major source bleeding



Anatomy - Bones

- Flexible cartilagenous skeleton
- Open growth plates
- Potential for growth disturbance and limb length discrepancies

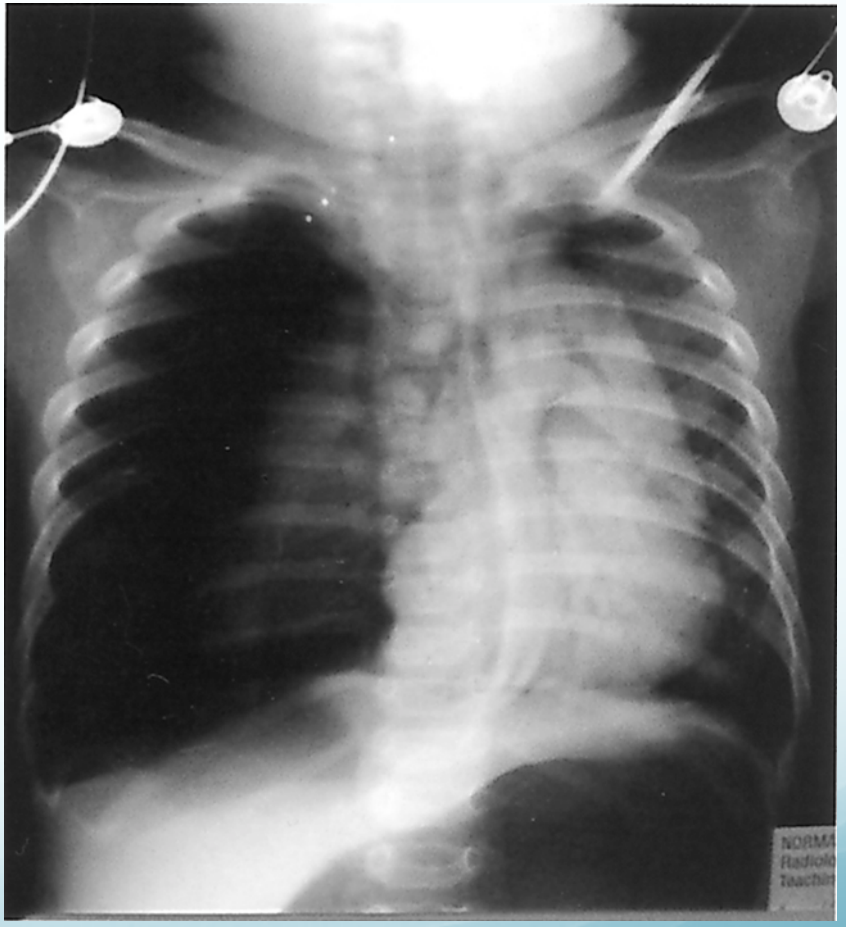


Pediatric Cervical Spine

- Anterior wedging of vertebral bodies
- Horizontal facets
- Ligamentous laxity
- Pseudosubluxation
  - flexion
- Partially cartilaginous endplates (unfused growth plates)
- Predispose to dislocations and ligamentous injuries (SCIWORA)

Pediatric Chest

- Highly compliant, thin chest wall
- Flexible ribs and weak intercostal muscles
- Allows transmission of kinetic energy → underlying lung parenchyma causing pulmonary contusion
- Mobile mediastinum increases effect of a tension pneumothorax
- Rib fractures require significant force, and are a marker for severity of injury

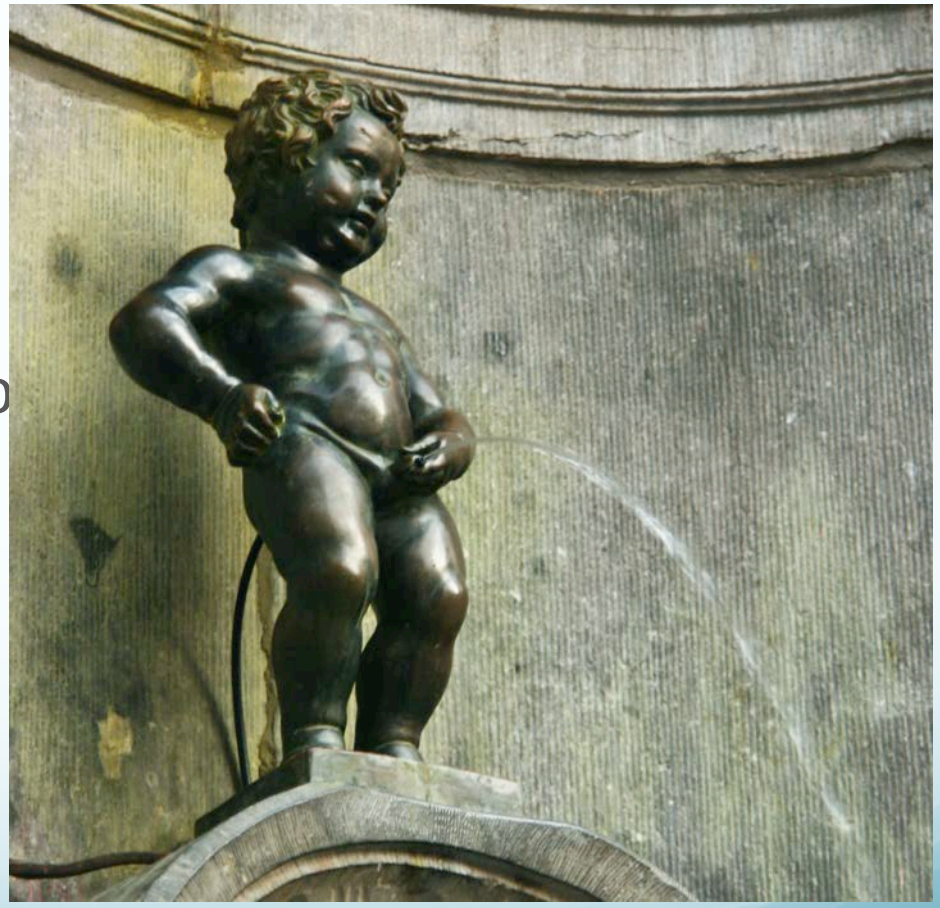


Abdomen

- Abdominal wall is thinner, softer and less muscular
- Solid organs are proportionately larger and less well protected by the rib cage
- Organs are closer together making multiple organ injuries much more likely
- Bladder is intra-abdominal in younger children, rather than low in the pelvis

Differences in Pediatric Physiology

- Age specific vital signs
- Blood volume and resuscitation requirements
- Compensatory response to hypovolemia
- Functional residual capacity
- Thermoregulation



Normal Vital Signs

Age	0 – 2 years	3 – 5 years	6 – 12 years
Heart rate	< 150 - 160	< 140	< 100 - 120
Blood Pressure	> 60 – 70	> 75	> 80 - 90
Respiratory Rate	< 40 – 60	< 35	< 30
UOP	1.5 – 2.0 cc/kg	1 cc/kg	0.5 – 1.0 cc/kg

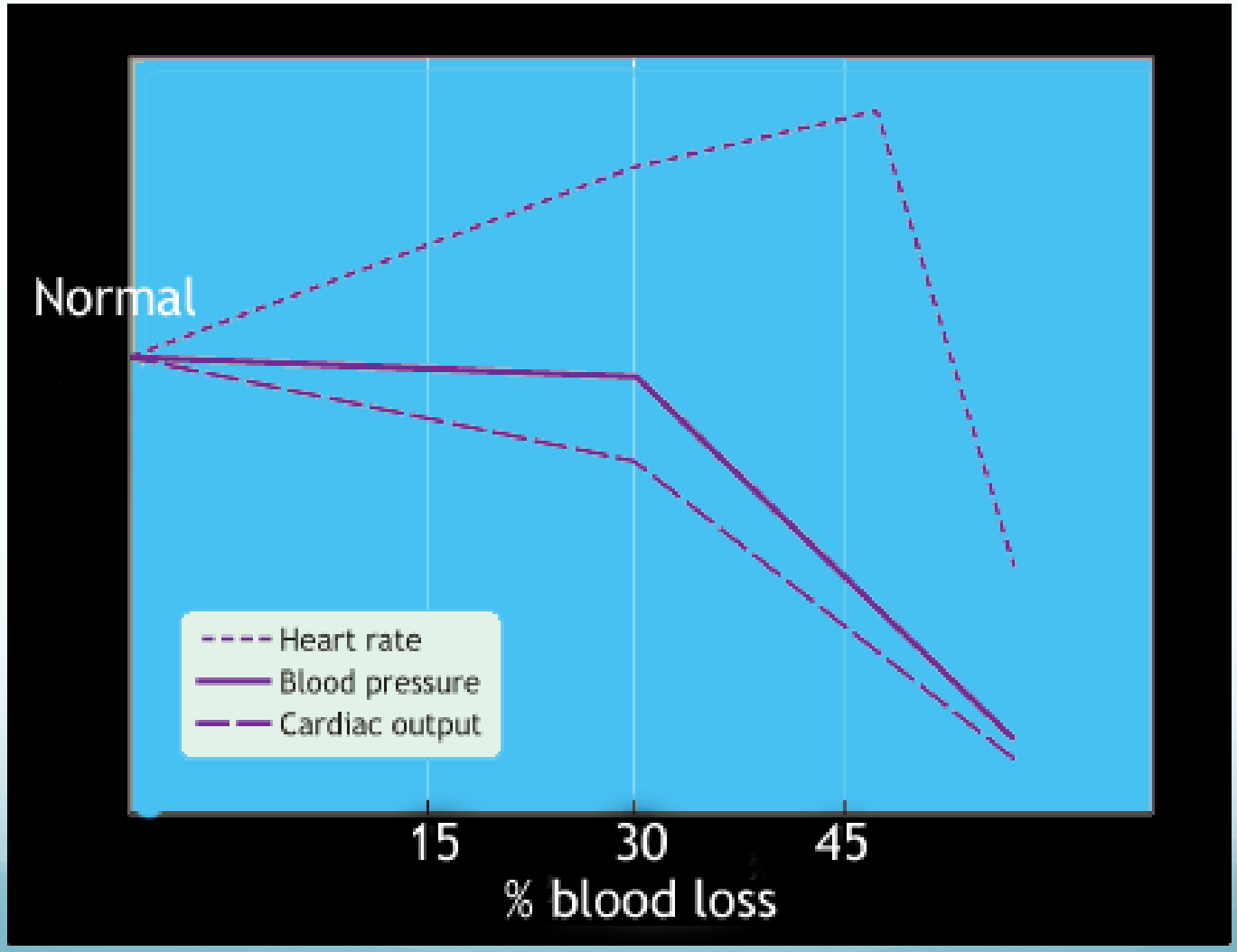
Vital Signs

- Can be difficult to assess in trauma setting
- Heart rate
  - Sensitive indicator in calm child
  - Highly variable in a frightened, screaming child
- BP
  - Requires proper size cuff for accuracy
    - Adult cuff → artificially low BP reading in a child
  - Vigorous compensatory mechanisms (vaso-constriction) prevent hypotension till significant volume loss
- True systolic hypotension → increased mortality

Hypovolemic Shock in Children

- Cardiac output - dependent on HR / filling volume
  - Myocardial contractility stays fairly constant
- First sign of shock is usually tachycardia
- SVR increases to maintain BP producing mottling, prolonged capillary refill, narrow pulse pressure
- At 35-40% blood loss, heart rate peaks
- When compensatory mechanisms overwhelmed → hypotension follows (typically a late finding)

Physiologic Compensation



Circulation

- Best assessed by a combination of…
- Quality of pulses
- Heart rate
- Capillary refill
- Frequent clinical exams
- Note: hypothermia can mimic hypovolemia
  - Decreased capillary refill, cool extremities

Fluid Resuscitation

- Isotonic crystaloid solution bolus - 20 mL/kg (x 2)
  - Look for response
- If still hypotensive – start blood – PRBC 10 mL/kg
- Failure to respond usually means ongoing hemorrhage requiring operative intervention
- Maintenance fluid in children
  - 4 mL/kg/hr for the first 10 kg body weight
  - 2 mL/kg/hr for the second 10 kg
  - 1 mL/kg/hr for every kg over 20 kg

Massive Transfusion

- Estimated blood volume
  - Term infant: 80-90 ml/kg
  - Child >3 months: 70 ml/kg
  - Adult: 60-65 ml/kg

- Transfusion > 50% EBV over 3 hours
- Transfusion 100% EBV over 24 hours
- Transfusion to replace ongoing blood loss at > 10% EBV per minute

MTP principles

Rapid surgical control
Avoid overuse of crystalloids to minimize dilutional coagulopathy
Continuously monitor patient temperature
Avoid and treat hypothermia (use fluid warmer and Bair hugger if needed)
Avoid and treat acidosis as needed; (pH < 7.2 treat with bicarbonate or THAM)
Treat low ionized calcium for hemostatic and hemodynamic effects

<3 kg:	1:1:1 units of RBCs, plasma, PLTs
3–20 kg:	2:2:2 units of RBCs, plasma, PLTs
21–40 kg:	4:4:5 units of RBCs, plasma, PLTs
>40 kg:	6:6:5 units of RBCs, plasma, PLTs

PLTs are defined as random donor units

Nichols and Shaffner, *Roger's Textbook of Pediatric Critical Care*, 5th edition, 2016

Breathing

- More susceptible to development of hypoxia
- Higher metabolic rate
  - Infants consume O2 at 6 to 8 ml/kg/min
  - Adults consume O2 at 3 to 4 ml/kg/min
- Similar tidal volume/kg compared to adults
- Functional residual capacity lower
  - Less “dead space” to be filled with O2
  - Rapid drop in O2 saturation if ventilation interrupted (eg for intubation)

Breathing

- Mechanical ventilation
  - Positive pressure can compress right atrium
    - Decreases preload
    - Effect exaggerated by hypovolemia

Thermoregulation

- Higher surface area to mass ratio
- Thinner skin
- Less subcutaneous fat to provide insulation
- Need to prevent hypothermia
  - Bradycardia, DIC, acidosis
- Warming lights, warm IV fluids, warm air blowers

Advanced Trauma Life Support

- Protocol to standardize initial management of injured patients and avoid omission of life saving interventions
  - Primary Survey
    - Airway
    - Breathing
    - Circulation
      - Control external hemorrhage
      - Fluid administration
    - Disability (neurologic assessment)
    - Exposure
      - Avoid hypothermia
  - Secondary survey
    - Detailed head to toe
    - AMPLE
      - **A**llergies, **m**edications, **p**ast medical history, **l**ast meal, **e**nvironment and **e**vents related to injury

Approach (the other “A”)

- Unconscious child – start assessment immediately
- Conscious child needs a special touch
  - May be in pain
  - Probably scared on several levels
  - Possibly separated from family and support
  - Surrounded by strangers in an unfamiliar place
- Fear → distress, tachycardia, crying, irrational behavior
- A moment or two spent reassuring a child and gaining their trust is time well spent → will increase the accuracy of your assessment

Pediatric Specific GCS

Assessed Response	Score
Best eye response	
Spontaneously	4
To verbal stimulation or to touch	3
To pain	2
No response	1
Best verbal response	
Smiles, oriented to sounds, follows objects, interacts	5
Cries but is consolable, inappropriate interactions	4
Inconsistently consolable, moaning	3
Inconsolable, agitated	2
No vocal response	1
Motor	
Normal spontaneous movement	6
Withdraws to touch	5
Withdraws to pain	4
Flexion abnormal	3
Extension, either spontaneous or to painful stimuli	2
Flaccid	1

LLUCH Pediatric Trauma Team Activation Guidelines (requires communication with EMS)

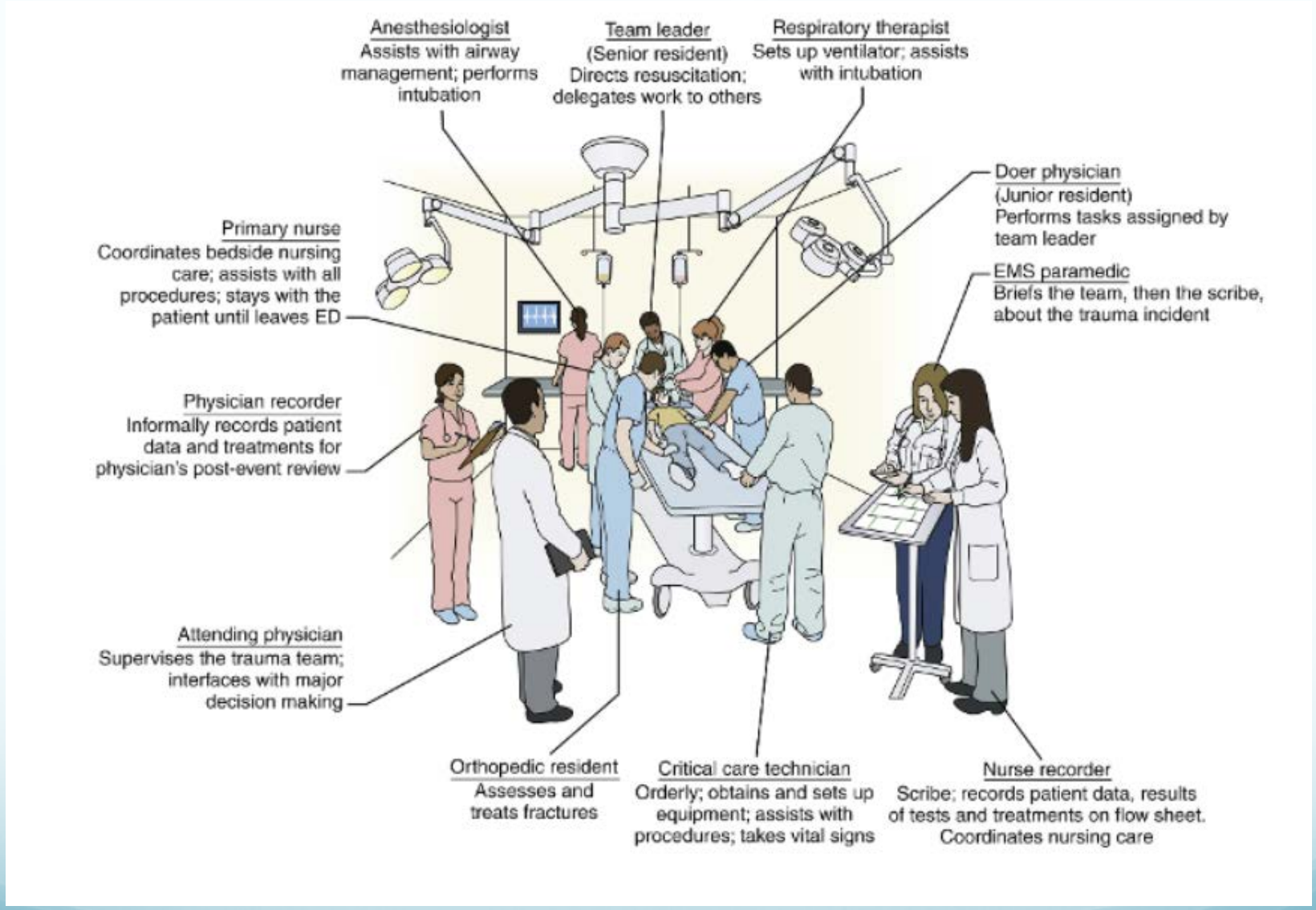
LEVEL A – FULL TEAM RESPONSE	Immediate Response within 5 Minutes
1. Confirmed age specific hypotension* or uncontrolled bleeding **Systolic blood pressure <70 + twice the age in years* 2. Intubated patients transferred from the scene OR Patients who have respiratory compromise or are in need of an emergent airway Includes intubated patients who are transferred from another facility with ongoing respiratory compromise (does not include patients intubated at another facility who are now stable from a respiratory standpoint) 3. Glasgow Coma Score < 9 with mechanism attributed to trauma* **not attributed to ISOLATED head injury* 4. Gunshot wounds to neck, chest or abdomen or extremities proximal to the elbow/knee – excluding superficial wounds * *except single air rifle or BB gun wounds to the abdomen* 5. Transfer patients from other hospitals receiving blood to maintain vital signs 6. Traumatic Full Arrest – ALL penetrating; blunt <5minutes down 7. Emergency Physician's discretion	**TEAM MEMBERS** ED Attending/Resident Trauma Attending Trauma Resident ED Staff

LLUCH Pediatric Trauma Team Activation Guidelines (requires communication with EMS)

LEVEL B – PARTIAL TEAM RESPONSE Immediate Response within 5 Minutes	
1. Neck or Back injury with neurological deficit 2. Single air rifle or BB gun wounds to the abdomen 3. Suspicion of potentially serious intra-abdominal injury - *such as supra-iliac Seatbelt mark* 4. Clinically significant multi-system injury patients 5. Trauma Transfers being accepted to or likely to be admitted to the Pediatric Trauma Service who do not meet Level A criteria. 6. Emergency Physician's discretion	**TEAM MEMBERS** ED Attending/Resident Sr & Jr Trauma Resident ED Staff

LEVEL C – LIMITED RESPONSE	Response time – up to 60 min.
1. Pediatric Trauma Consults	**TEAM MEMBERS** ED Attending/Resident Trauma Resident ED Staff

Pediatric Trauma Room



Fuhrman and Zimmerman, *Pediatric Critical Care*, 4th edition, 2011

Laboratory Studies

- Can be based on severity of injury
  - CBC
  - Electrolytes
  - ALT, AST
  - Coags
  - Type and cross
  - Urinalysis
  - Pregnancy test
  - Alcohol, UDS

Monitoring Resuscitation

- Continuous re-evaluation
  - Vital signs
  - Mental status
  - Perfusion
  - Filling pressures (CVP)
  - Urine output
  - Lactate
  - Base deficit
  - SVO2

Broselow Tape

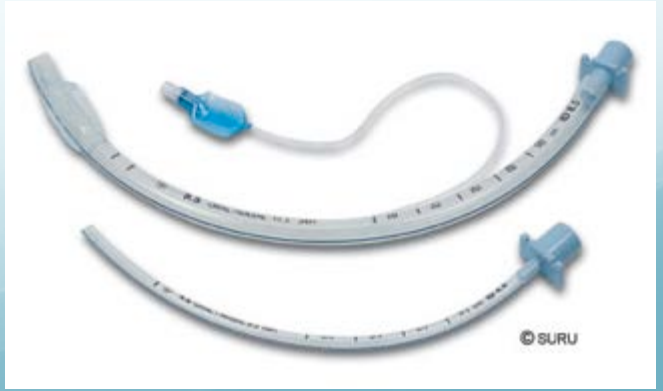
- Rapid assessment of pediatric patient
- Measure the length of the patient starting at the head
- Patient length will determine approximate patient weight
- Refer to tape for weight based resuscitation volumes, medication dosages, tube sizes, cardioversion
- Packs are color coded and contain equipment appropriate for patient size

Pediatric Airway

- A child who is awake & talking or crying has a patent airway and is breathing
- Note: Babies are obligate nose breathers
- Airway may need to be controlled
  - Unconscious child
  - Child with facial injuries
  - Mandible fracture
  - Severe agitation → risk of injury
- Jaw thrust & BVM vs intubation
- Laryngeal mask airway
- Surgical airway

Endotracheal tubes

- Tube Selection
  - Consult Broselow tape
  - Approximate size of child's 5th finger or nares
  - Cuffed tube
    - No longer considered contraindicated
    - Prevents need for tube change if undersized
    - Can prevent air leaks if lung compliance decreases
    - Use lowest cuff pressure required to maintain ventilation
- Avoid Nasotracheal intubation
  - Acute angle of oropharynx
  - Risk of brain intubation

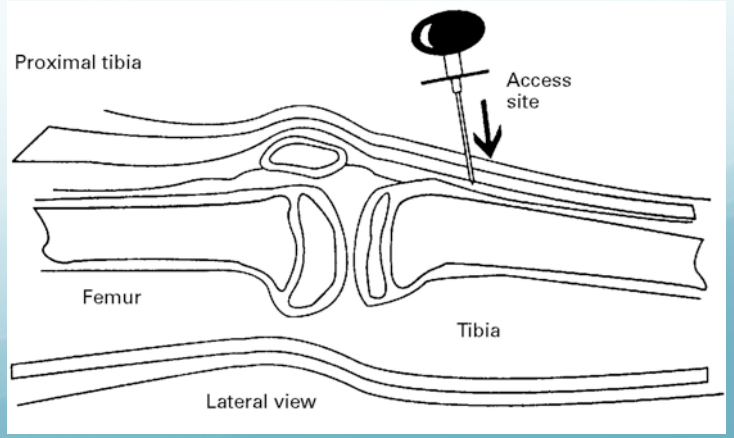


Endotracheal tubes

- Depth of insertion – (short airway)
  - Approximately 3 times the diameter
  - (4.0 ETT → 12 cm at the lip)
- Confirmation of placement
  - End tidal CO2
  - CXR
- Small tubes occlude more easily
- Avoid barotrauma – Don't bag too hard!

IV Access

- Preferable IV x2 in upper extremities
- Intraosseus (IO) catheter (especially <6 y/o)
  - Option if unable to get standard IV
  - Cannula inserted directly into bone marrow
    - Proximal tibial plateau or distal femur
  - Can be maintained x 24-48 hr
  - Comparable to standard IV for fluid infusion
  - All labs can be drawn (↑ WBC)



Patient Disposition

- Discharge
- Admission
  - Basic ward
  - PICU
- Immediate surgery
  - Refractory hypotension
  - Intracranial injury
  - Intrathoracic injury
  - Intraabdominal injury
  - Pelvic/long bone fracture
    - Interventional radiology for embolization
- Transfer to higher level of care

LLUCH Pediatric Critical Care Transport Team

- Established in 1989
- Two transport teams
  - Resident physician, transport nurse, transport respiratory therapist
- Ground ambulance, helicopter, fixed wing
- 600-700 pediatric transports per year
- Dispatch within 30 minutes of initial call
- Line placement, advanced resuscitation, intubation, mechanical ventilation, iNO, HFOV, inotropes, ABX
- ECMO

Transport Equipment

Transport Pack

Ventilator

Medications

Respiratory Supplies

Ground-Based Transport

- Advantages
  - Most frequent mode
  - Less expensive
  - Larger interior working space
  - Ability to stop vehicle for stabilization and procedures
  - Additional personnel

Helicopter Transport

- Advantages
  - Rapid deployment and transport time

Unique Pediatric Trauma Management Issues

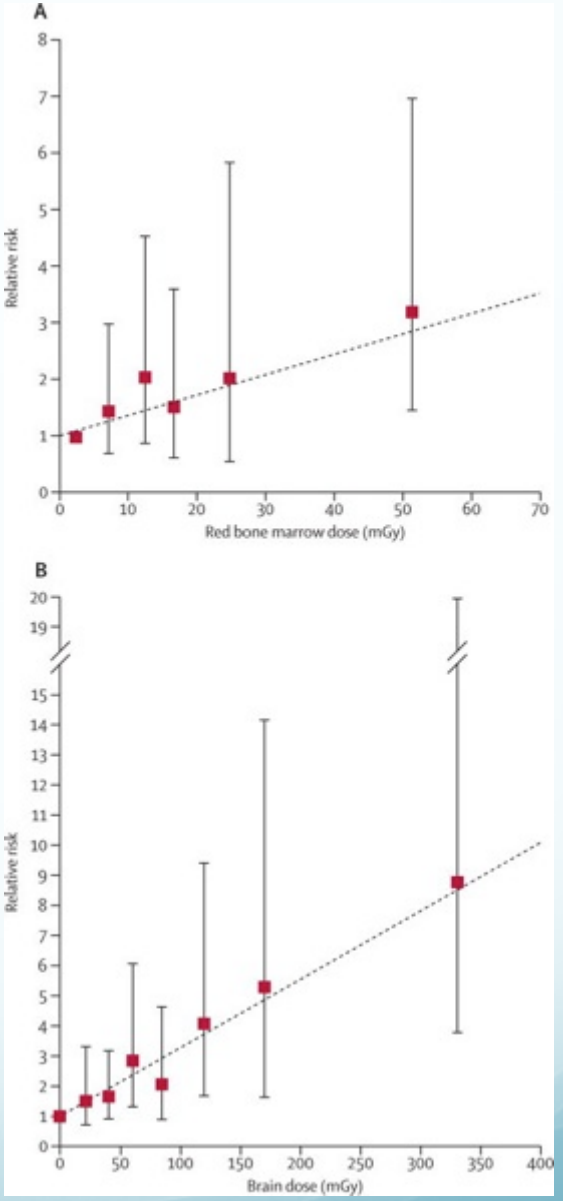
- Radiation Risk
- Pediatric Cervical Spine
- Abdominal Injuries
  - Solid Organ injuries

Radiologic Considerations

- Children more sensitive to radiation than adults
  - Actively growing, increased cellular division
- Longer life expectancy
  - Larger window of opportunity for expressing radiation damage
  - Increased likelihood of future radiation
- Smaller body mass
  - If CT settings not adjusted, may receive higher radiation dose than necessary
- ALARA (As Low As Reasonably Achievable)
- Image Gently Campaign

CT and Risk of Cancer

- Over 175,000 pediatric patients followed after CT 1985-2002
- Incidence of cancer documented
- Cumulative dose of 50 mGy triples risk of leukemia (eg 2-3 head CT's)
- Cumulative dose of 60 mGy triples risk of brain cancer
  - Glioma, meningioma, schwannoma
- Estimate 1 leukemia and 1 brain tumor per 10,000 CT scans



Pearce et al. *Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumors: a retrospective cohort study.* Lancet 380(9840):499-505, Aug 2012

Trauma Films

- Plain films
  - AP & lat C-spine films
  - CXR
  - Pelvis (if indicated)
- CT's – if indicated
  - Head
  - Abdomen / pelvis
- AVOID - CT's of cervical spine or chest unless looking for a specific injury suggested on plain films

A 5 year old boy is brought to the ER after being hit by a car going 35 mph while he was riding his bike. His vitals are stable and he is awake and alert. He has a femur fracture on the left and bruises on the left side of his face. The EMS responders placed a cervical collar to maintain spine precautions. The likelihood that he has a cervical spine injury is:

A <10%
B 30%
C 50%
D 70%

Pediatric C-Spine Injuries

- Uncommon (<2% of seriously injured children)
- Potentially devastating if missed
- 60 to 80% of all vertebral injuries in children are cervical (compared to 30 - 40% in adults)
- Injury level tends to vary with age

Pediatric C-Spine Injuries

- Age 0 – 8 years – upper cervical spine (C1-3)
- Age 9 – 17 years – lower cervical spine (C5-6)
- MVA & falls most common cause in younger patients
- Sports most common in older

SCIWORA – Spinal Cord Injury Without Radiographic Abnormality

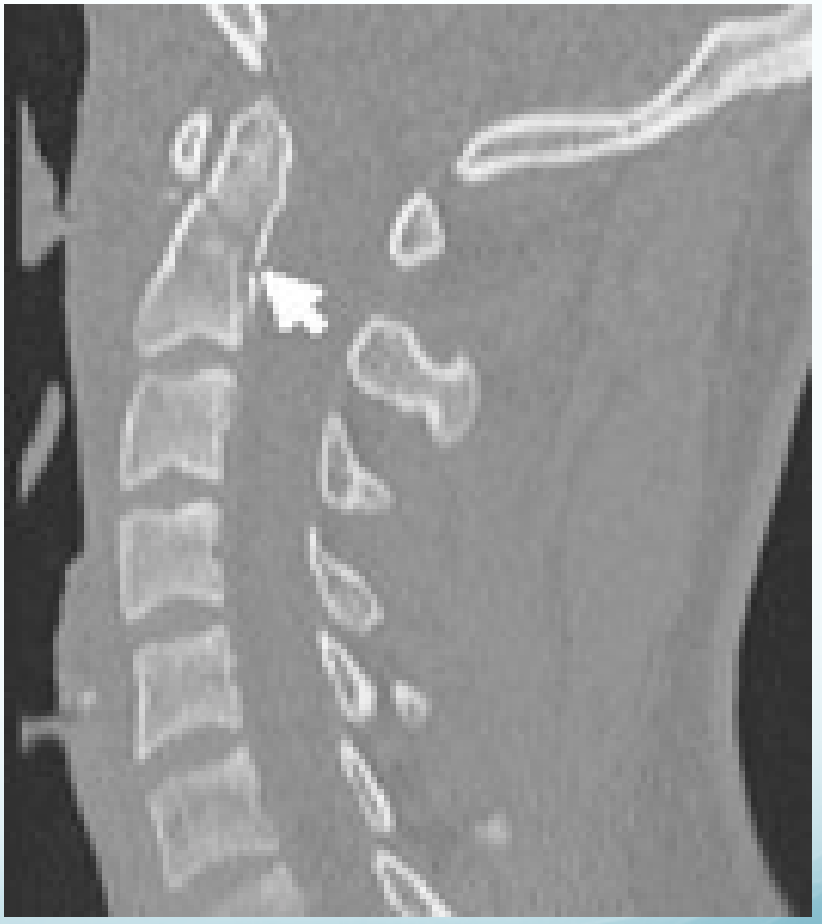
- Transient vertebral displacement with subsequent realignment, resulting in damaged spinal cord but normal appearing vertebral column on plain films
- Note: CT or MRI evidence of cord injury or ligamentous instability IS compatible with diagnosis of SCIWORA
- Literature very inconsistent regarding definition and incidence
- Reported as 0 to 50% of peds spinal injuries
- National Pediatric Trauma Registry: 17%

Pediatric C-spine Clearance

- Unfortunately, NO national guidelines currently exist for clearance of the cervical spine in children
- A clinical decision based upon the synthesis of history, clinical examination and appropriate radiologic screening
- Consequently, Pediatric Neurosurgery gets heavily involved in spine clearance

Imaging - CT

- Good for fractures
- Not great for ligamentous injuries
- Radiation risk
  - Up to 90 – 200 x higher dose to thyroid than cervical spine series
  - Doubles thyroid CA risk if patient < 4 y/o



Imaging - MRI

- No radiation
- Good for ligamentous/soft tissue injuries and SCIWORA
- Usually requires sedation, transport, and takes longer to perform
- Expensive, may not be readily available

Clearance of High Risk Pediatric C-spines: Recommendations

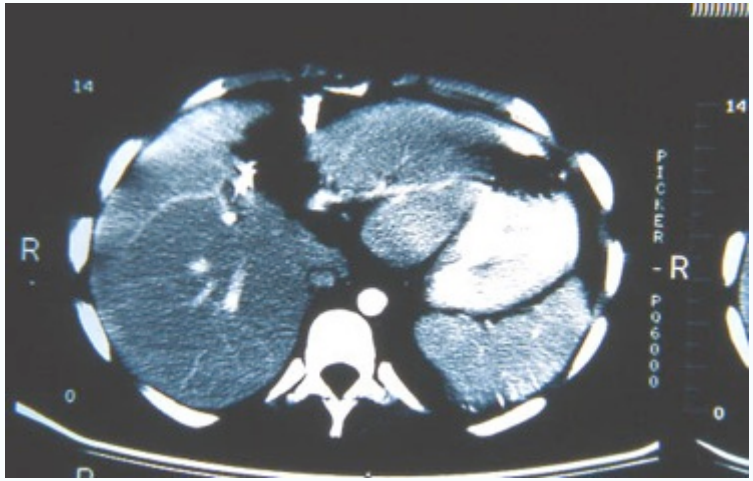
- ALL CASES:
  - AP/Lat C-spine x-rays
  - Attempt Odontoid view for age >8
- CT
  - ONLY for poorly visualized levels or questionable osseous injury
  - (Not entire C-spine)
- Need for MRI
  - Limited clinical exam expected for more than 48 hr.
  - Worrisome x-ray/CT findings
  - Abnormal neuro exam
- Flexion/Extension x-rays or flouroscopy
  - By neurosurgery only

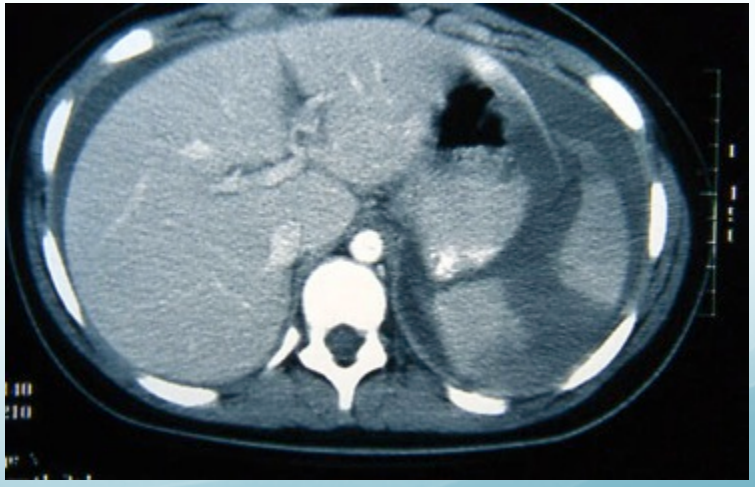
- An 11 y/o girl is struck by a car while crossing the rode. She is brought to the ED by paramedics. Vitals show HR 130's, BP 80/40. She is awake and alert but has RUQ pain to palpation. Abdominal CT shows a Grade IV liver laceration. She requires 1 U PRBC transfusion in the next 8 hrs. She should:

A Be taken to the OR immediately for exploratory laparotomy to control bleeding
B Have serial Hgb's to follow any further drop
C Undergo peritoneal lavage to decide on operative intervention
D Be placed on twice maintenance fluids to correct fluid deficit

Abdominal Injuries

- Mostly blunt trauma
- Two types
  - Solid organ (Liver, spleen, kidney, pancreas)
  - Hollow viscus (seatbelt injury)
- Solid organ injuries now managed almost exclusively non-operatively





Abdomen DPL vs CT vs FAST

- DPL – not generally done in pediatric patients
  - Non-specific - Identifies blood +/- particulate matter
  - No assessment of retroperitoneum
  - May introduce air - confusing future studies
- CT – Most reliable study
  - Complete assessment, including retroperitoneum
  - Identifies free air if present
- FAST U/S – questionable usefulness in pediatric patients

Solid Organ Injury

- Criteria for conservative management
  - Hemodynamic stability achieved with <40ml/kg IV fluids (regardless of grade)
    - Some will transfuse up to 1/2 a blood volume
  - Extent of injury documented by CT
  - No other injuries that would dictate exploration
  - Observation in PICU on a surgical service
  - Capability to proceed directly to OR if necessary
- Most trauma centers are 90-95% successful managing non-operatively

TABLE 30.6

GRADING SYSTEM[a] FOR HEPATIC AND SPLENIC INJURIES

INJURY	GRADE I	GRADE II	GRADE III	GRADE IV	GRADE V	GRADE VI
Hematoma: liver, spleen	Subcapsular, <10% surface area	Subcapsular, 10%–50% surface area; intraparenchymal diameter <10 cm (liver) vs. <5 cm (spleen)	Subcapsular, >50% surface area or expanding; ruptured subcapsular or parenchymal hematoma; intraparenchymal hematoma >10 cm (liver) vs. >5 cm (spleen) or expanding			
Laceration: liver	Capsular tear <1 cm parenchymal depth	1–3 cm parenchymal depth, <10 cm in length (liver) vs. not involving a trabecular vessel (spleen)	>3 cm parenchymal depth or involving trabecular vessels (spleen)	Parenchymal disruption of 25%–75% of hepatic lobe, or 1–3 segments within a lobe	Parenchymal disruption >75% of hepatic lobe, or >3 segments within a lobe	
Laceration: spleen			Involvement of hilar vessels with >25% devascularization	Shattered spleen		
Vascular injury: liver					Juxtahepatic venous injuries	Hepatic avulsion
Vascular injury: spleen					Hilar injury with devascularization	

[a]Advance one grade for multiple injuries, up to grade III.

Adapted from Moore EE, Cogbill TH, Jurkovich GJ, et al. Organ injury scaling: Spleen and liver (1994 revision). *J Trauma* 1995;38:323–4.

Nichols and Shaffner, *Roger's Textbook of Pediatric Critical Care*, 5th edition, 2016

Summary

- Children have unique issues related to anatomy, physiology and development that make them vulnerable and that influence trauma management strategy
- The assessment priorities (ABCDE's/secondary survey) are the same for children as they are for adults
- Transport critically ill pediatric trauma patients should be performed by skilled teams
- Try to limit radiation exposure