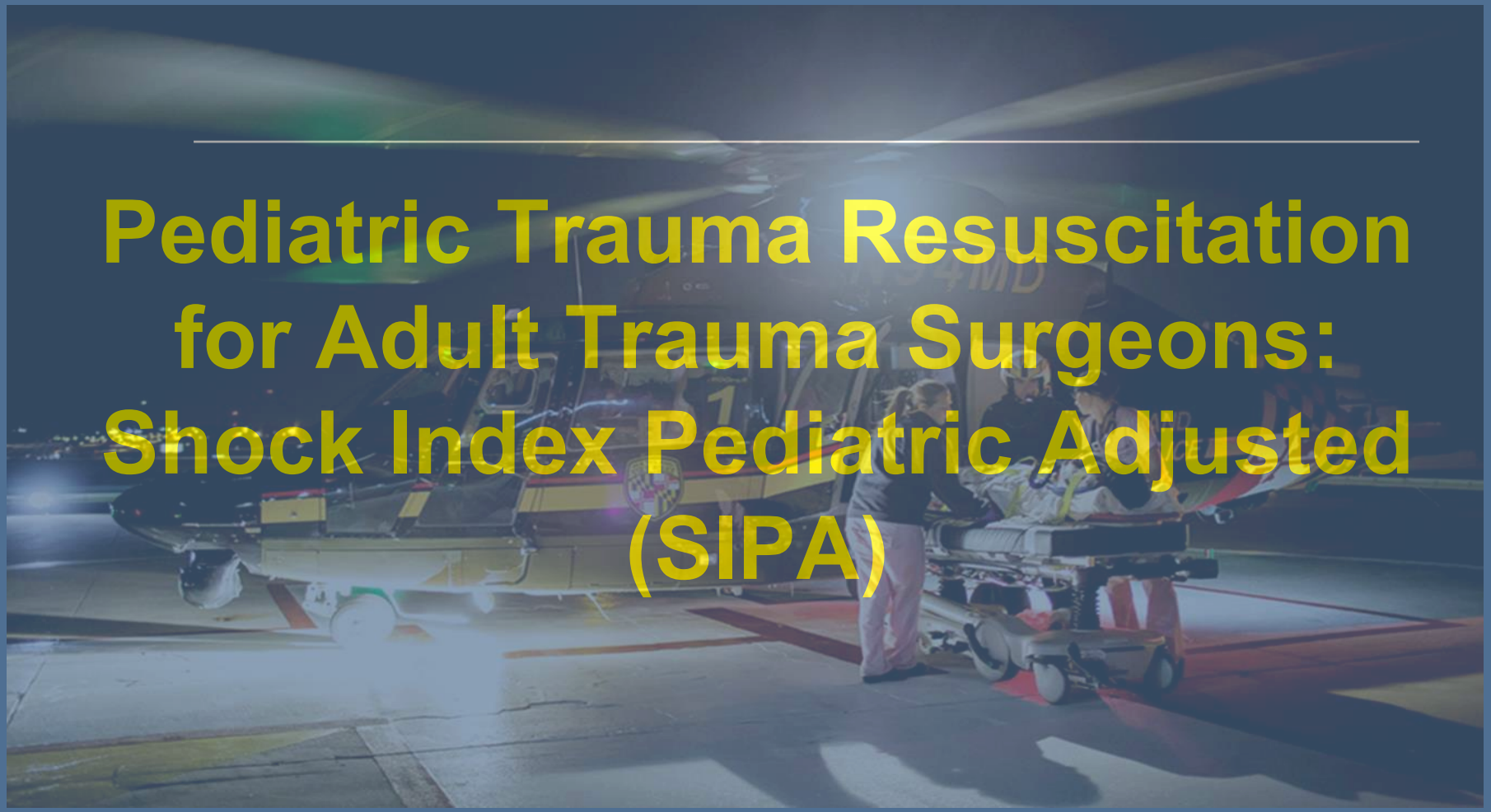


Pediatric Trauma Resuscitation for Adult Trauma Surgeons: Shock Index Pediatric Adjusted (SIPA)

Alexis D. Smith, M.D.

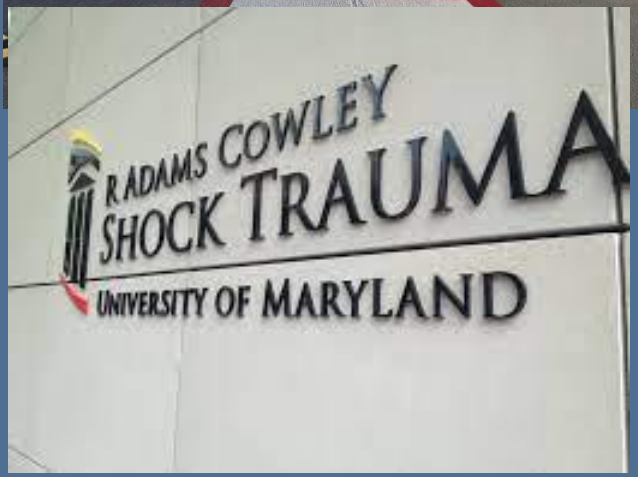
August 11th, 2023

Children's Healthcare of Atlanta

No disclosures or conflicts of interest

EMORY

LAKESIDE VIKINGS



Children's Healthcare of Atlanta

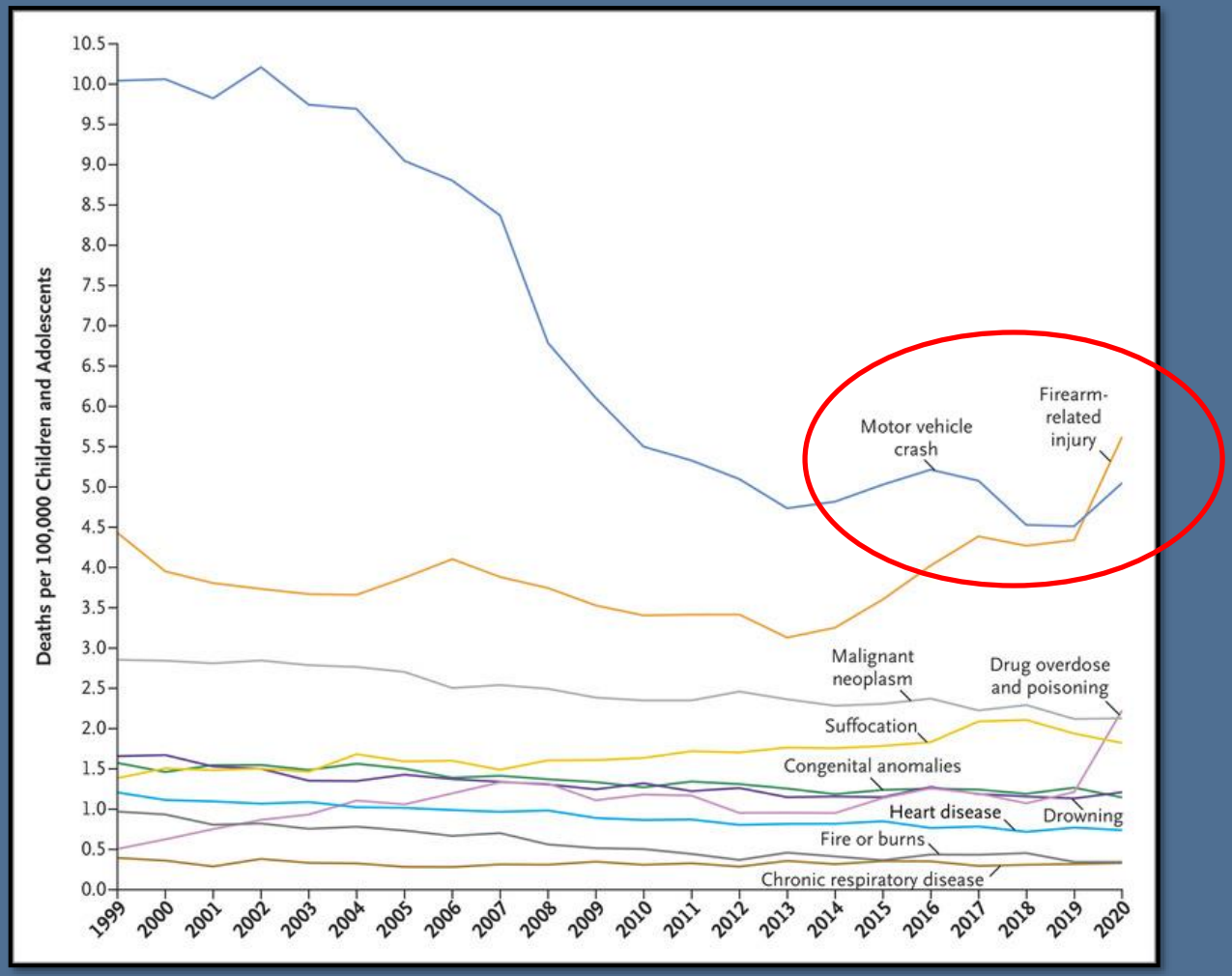
BROWN UNIVERSITY

What makes Pediatric Trauma Different?

- Children and adolescents ARE just little adults, but with notable differences
- HEALTHY PATIENTS
  - Dynamic and responsive physiologic reserve
- Pristine vessels that allow for effective vasospasm → successful non-operative management
- 80% of children with multiple trauma injuries die because of severe head injury (50% in adults)
    - > Head/body ratio, softer skull, open fontanelles
- Non-accidental trauma/child abuse
- No difference in how we care for penetrating injuries

Children's™ Healthcare of Atlanta

Firearm-related injuries now the leading cause of mortality in children and adolescents

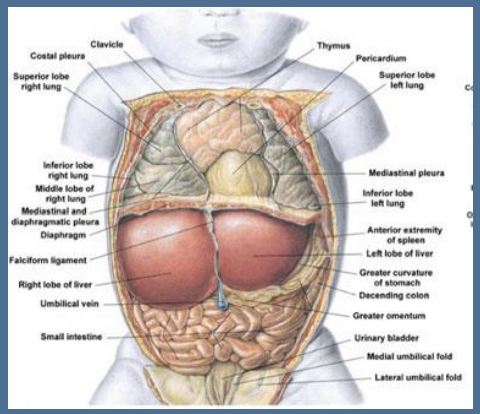


Children's Healthcare of Atlanta

N Engl J Med 2022; 386:1955-1956 DOI: 10.1056/NEJMc2201761

Pediatric Thorax/Torso Anatomy

- Distribution of force
  - Smaller bodies → more energy onto smaller space
  - Organs in smaller space, overlap
  - Liver and spleen anterior
  - More organs get injured
- Bone flexibility
  - Ouyang et al: Cadaver study[1]
    - Specific measured force/location
    - 60% of subjects had pneumothorax in absence of rib fracture
    - Pulmonary injury common in children in absence of rib fracture
  - Garcia et al[2]
    - Rib fractures in children associated with severe trauma/death



Children's Healthcare of Atlanta

1. Ouyang J, et al. Thoracic impact testing of pediatric cadaveric subjects. J Trauma (2006) 61:1492–1500
2. Garcia VF, et al. Rib fractures in children: a marker of severe trauma. J Trauma Inj Infect Crit Care (1990) 30:695–700

Causes of early mortality in pediatric trauma patients

Christina M. Theodorou, MD, Laura A. Galganski, MD, Gregory J. Jurkovich, MD, Diana L. Farmer, MD, Shinjiro Hirose, MD, Jacob T. Stephenson, MD, *and* **A. Francois Trappey, MD**, *Sacramento, California*

- When compared with adult trauma, children are more likely to die in the ED rather than surviving long enough for hospital admission or transfer to the OR
- In large part this is due to high rates of TBI, but proportion of injured children who die from hemorrhage and timing of their deaths has not well studied.
- Retrospective review of all deaths from trauma registry in patients <18 yo at a level I PTC from 2009-2019
- Sought to characterize the causes of early death versus late death

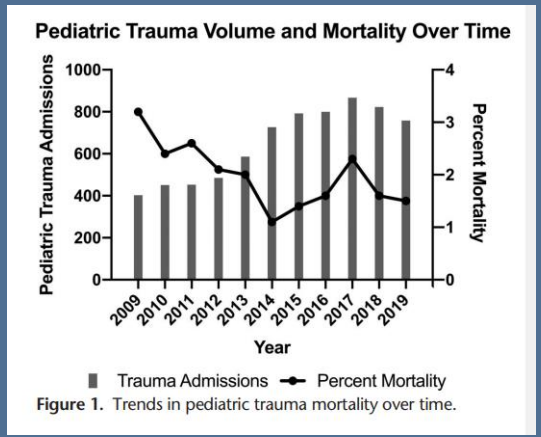


Figure 1. Trends in pediatric trauma mortality over time.

Children's Healthcare of Atlanta

J Trauma Acute Care Surg. (2021) 90: 574-581.

Causes of early mortality in pediatric trauma patients

Christina M. Theodorou, MD, Laura A. Galganski, MD, Gregory J. Jurkovich, MD, Diana L. Farmer, MD, Shinjiro Hirose, MD, Jacob T. Stephenson, MD, *and* **A. Francois Trappey, MD**, *Sacramento, California*

- 2% mortality rate over the 10 year period (N=134) with no age or gender differences
- 54% of deaths occurred within the first 24 hours of hospital arrival
- TBI was the most common cause of death (66%)
  - Anoxia (10%)
  - Hemorrhage (8%)
- Hemorrhage contributed to 18% of deaths which were a combination of TBI and hemorrhage
- Half of all pediatric deaths from hemorrhage considered potentially preventable
- Elevated SIPA was significantly more common in patients who died (64.7% vs. 29.4% of surviving patients)

TABLE 3. Overall Outcomes of Pediatric Trauma Mortalities

Variable	Results
Any transfusion: n (%)	89 (66.4)
Massive transfusion: n (%)	50 (37.3)
ED disposition: n (%)	
Died in ED	42 (31.3)
ICU	61 (45.5)
OR	31 (23.1)
TTD: median (IQR), h	14.4 (0.5–87.8)
TTD: median (IQR), d	1 (1–4)
Early mortality: n (%)	72 (53.7)
Location of death: n (%)	
ED	42 (31.3)
ICU	82 (61.2)
OR	9 (6.7)
Ward	1 (0.8)
Cause of death: n (%)	
TBI	89 (66.4)
Anoxia	13 (9.7)
Hemorrhage	11 (8.2)
Other	8 (6.0)
Unknown	13 (9.7)

Massive transfusion defined as >40 ml/kg of blood product. ICU LOS is calculated for patients admitted to the ICU only.

Children's Healthcare of Atlanta

J Trauma Acute Care Surg. (2021) 90: 574-581.

Drake et al. Ann Surg. (2020) 271 (2): 375-382.

What can we do better to identify these children during resuscitation and how can we get these critically injured children to the resources they need?

Access to Pediatric Trauma Systems Nationally and Locally

Access to Pediatric Trauma Care:

Government Accountability Office (GAO 2017)

- 2017 Report on:

  Availability of trauma centers for children in United States.

  Outcomes for children treated at different types of facilities?

- Mapped:
  - 136 High-level pediatric trauma centers
    - Defined as Level 1 (L1) and Level II (L2) PTCs that can treat all injuries regardless of severity.

Children's Healthcare of Atlanta

Pediatric Trauma Centers: Availability, Outcomes, and Federal Support Related to Pediatric Trauma Care. March 2017 GAO-17-334.

Access to Pediatric Trauma Care:

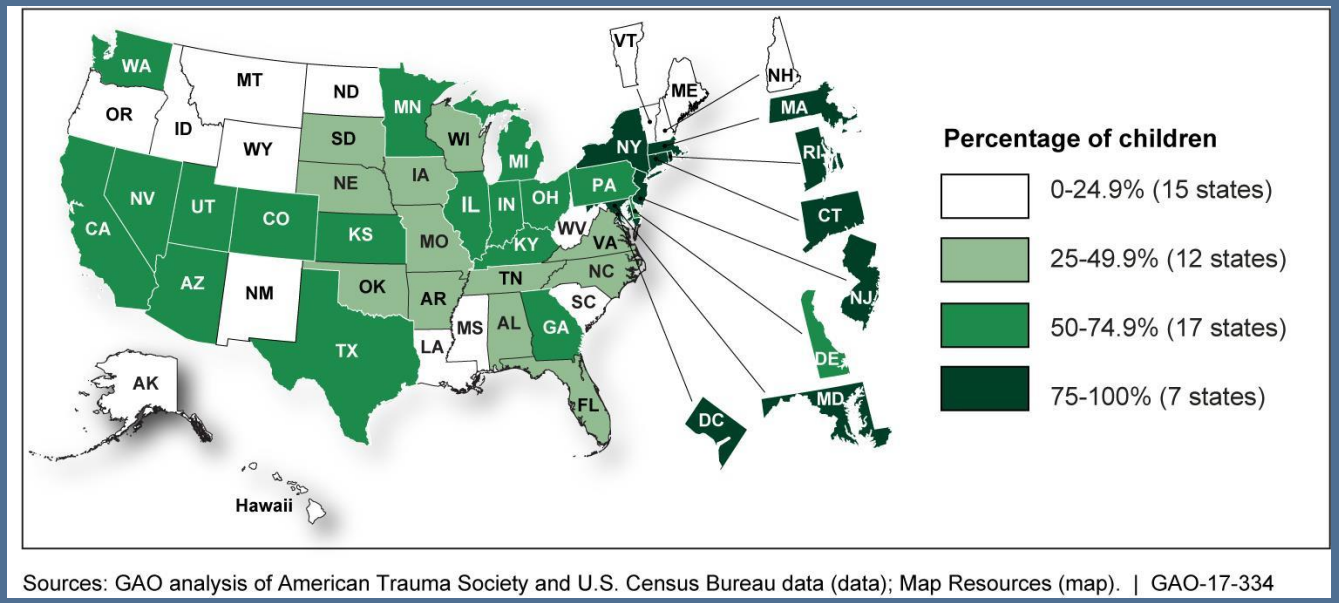
Government Accountability Office (GAO 2017)

- 73.7 million children in the United States;

  57% (41.9 million) < 30 miles from “high level” PTC

  43% (31.8 million) >30 miles. from “high level” PTC

- High level trauma centers included L1 and L2 PTCs



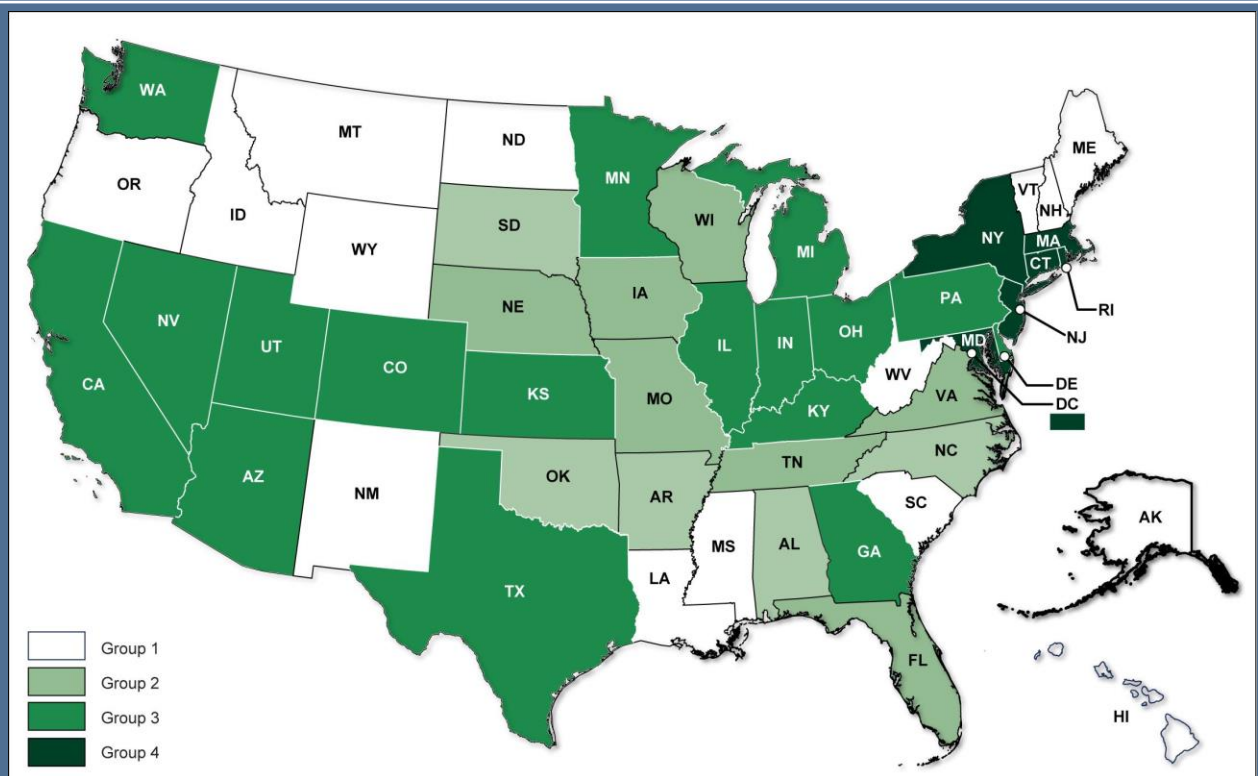
Sources: GAO analysis of American Trauma Society and U.S. Census Bureau data (data); Map Resources (map). | GAO-17-334

Children's Healthcare of Atlanta

Pediatric Trauma Centers: Availability, Outcomes, and Federal Support Related to Pediatric Trauma Care. March 2017 GAO-17-334.

Access to Pediatric Trauma Care:

Government Accountability Office (GAO 2017)



Group 1 0-24.9% of state's children lived within 30 miles of a high-level pediatric trauma center	Group 2 25-49.9% of state's children lived within 30 miles of a high-level pediatric trauma center	Group 3 50-74.9% of state's children lived within 30 miles of a high-level pediatric trauma center	Group 4 75-100% of state's children lived within 30 miles of a high-level pediatric trauma center
● 15 states ● 393,628 children within 30 miles ● 8 states with no children within 30 miles	● 12 states ● 6.7 million children within 30 miles	● 17 states ● 26.1 million children within 30 miles	● 7 states ● 8.8 million children within 30 miles ● 4 states with 90% or more children within 30 miles

Sources: GAO analysis of American Trauma Society and U.S. Census Bureau data (data); Map Resources (map). | GAO-17-334

Children's Healthcare of Atlanta

Pediatric Trauma Centers: Availability, Outcomes, and Federal Support Related to Pediatric Trauma Care. March 2017 GAO-17-334.

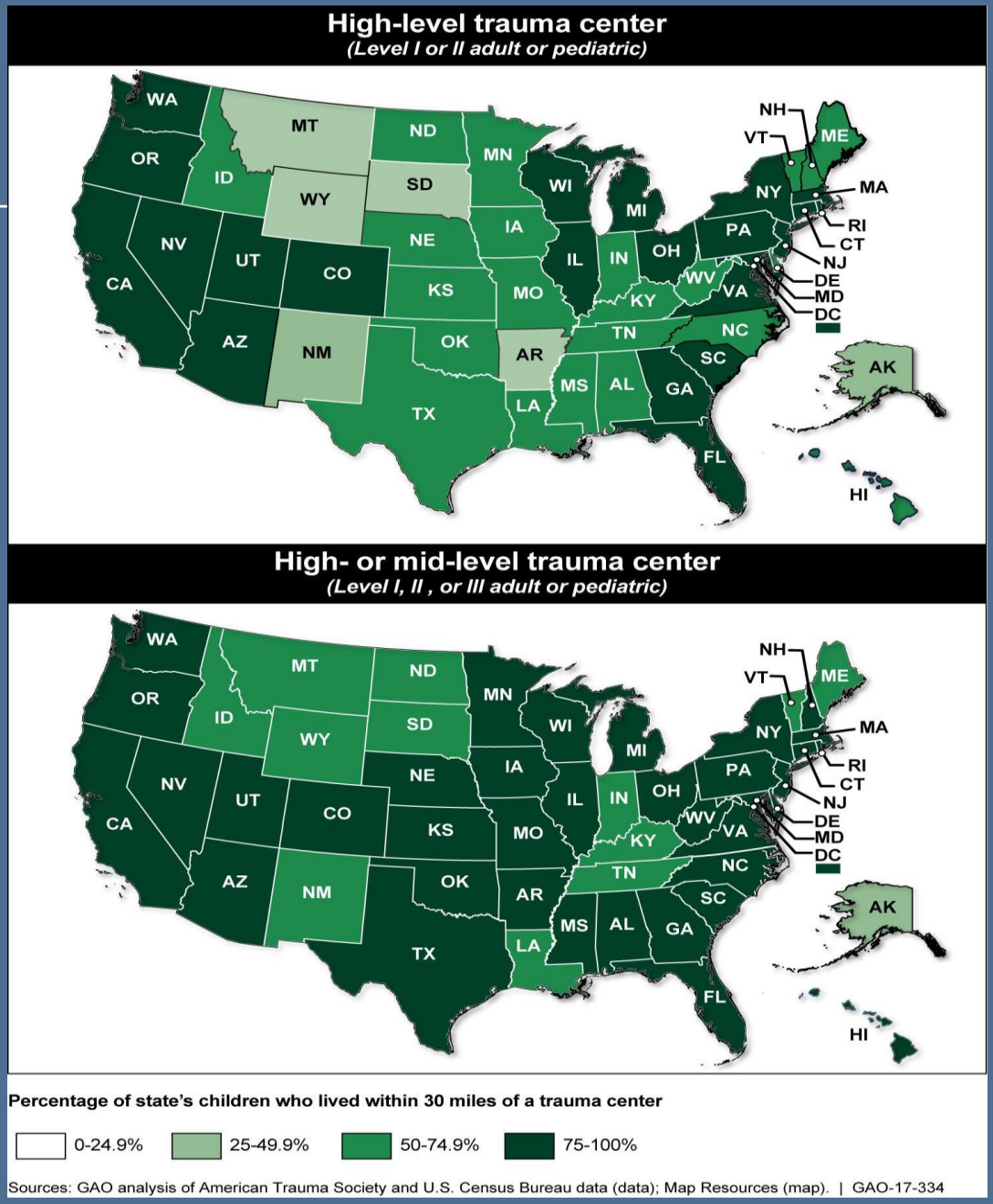
What About Access to ANY Trauma Center?:

- In areas without PTCs, injured children rely on ATC (+/- pediatric capabilities), or less specialized trauma centers for initial care.
- 80% < 30 miles of a "high level" ATC or PTC
  - (Level 1 or Level 2)
- 88% (65.1 million) < 30 miles of a "high level"or "mid-level" ATC or PTC
  - (Level 1, Level 2 or Level 3 trauma center)
  - Significant variation by state.

Children's Healthcare of Atlanta

Pediatric Trauma Centers: Availability, Outcomes, and Federal Support Related to Pediatric Trauma Care. March 2017 GAO-17-334.

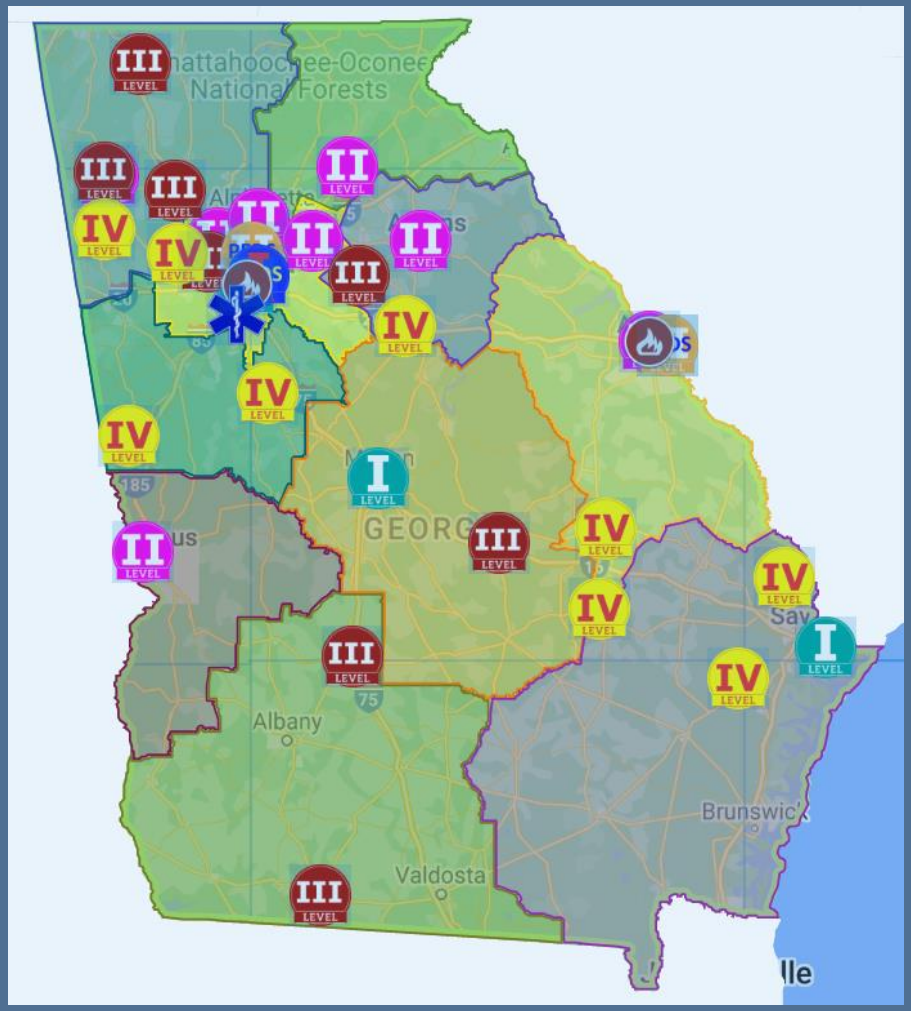
Percentage of children in America < 30 miles from high or mid-level trauma centers (adult or pediatric)



Children's Healthcare of Atlanta

Pediatric Trauma Centers: Availability, Outcomes, and Federal Support Related to Pediatric Trauma Care. March 2017 GAO-17-334.

Georgia Trauma Centers



Children's Healthcare of Atlanta

Pediatric Trauma Centers: Availability, Outcomes, and Federal Support Related to Pediatric Trauma Care. March 2017 GAO-17-334.

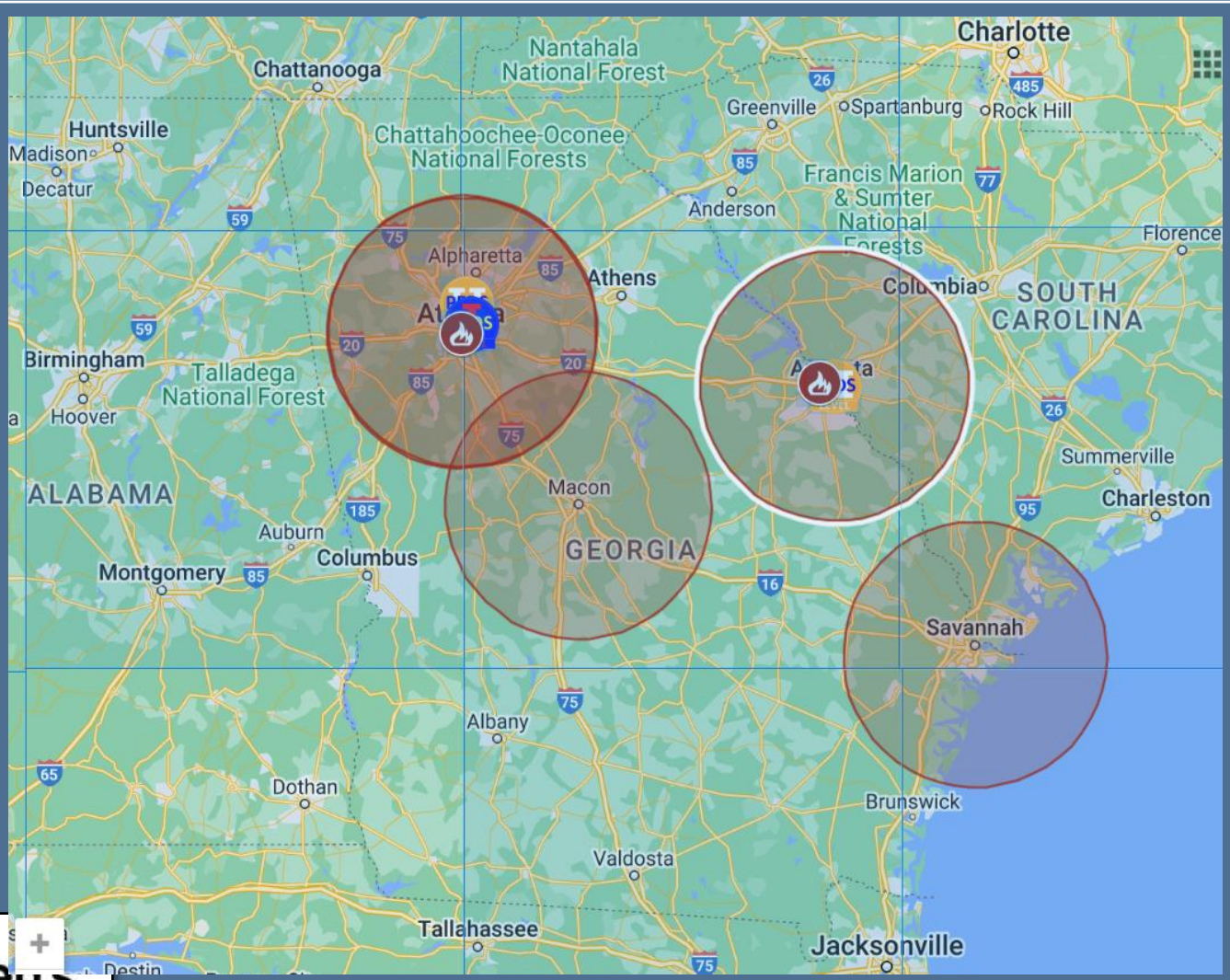
Georgia Trauma Centers

State	Est. Child Pop.	High Level Pediatric Trauma Center			High Level Adult or Pediatric Trauma Center			High- or Mid-Level Adult or Pediatric Trauma Center		
		<10 Miles	10-30 Miles	>30 Miles	<10 Miles	10-30 Miles	>30 Miles	<10 Miles	10-30 Miles	>30 Miles
All States	73,682,658	26.7	30.2	43.1	48.9	31.2	19.9	59.8	28.6	11.6
MD	1,348,280	35.2	46.6	18.2	48	37.4	14.6	52.4	44.4	3.3
VA	1,864,755	11.7	29.6	58.6	43.3	43.8	12.9	50.4	38	11.6
NC	2,283,835	13.8	33.9	52.3	28.8	40.3	30.9	37.3	41.6	21.2
SC	1,081,833	5.2	14.8	80	29.6	51.4	19	54.1	39	6.8
GA	2,491,080	11.3	39.2	49.5	41.9	38.4	19.8	43.2	38.9	18
FL	4,041,002	13.8	24.3	61.9	51.8	39.9	8.3	51.8	39.9	8.3
WV	382,286	4.1	7	88.9	18	35.4	45.6	35	40.5	24.5
TN	1,490,321	16.4	21	62.7	29.5	37.3	33.2	33.1	38.1	28.7
AL	1,111,974	13	20.6	66.5	28.7	39.6	31.8	67.3	30.1	2.7
KY	1,018,630	22.1	28	49.8	22.8	29.9	47.3	25.1	35.6	39.3

Children's Healthcare of Atlanta

Estimated Child Population and Percentage of Children Who Lived within 30 Miles of a High- or Mid-Level Trauma Center, Detailed Tables by State, 2011-2015

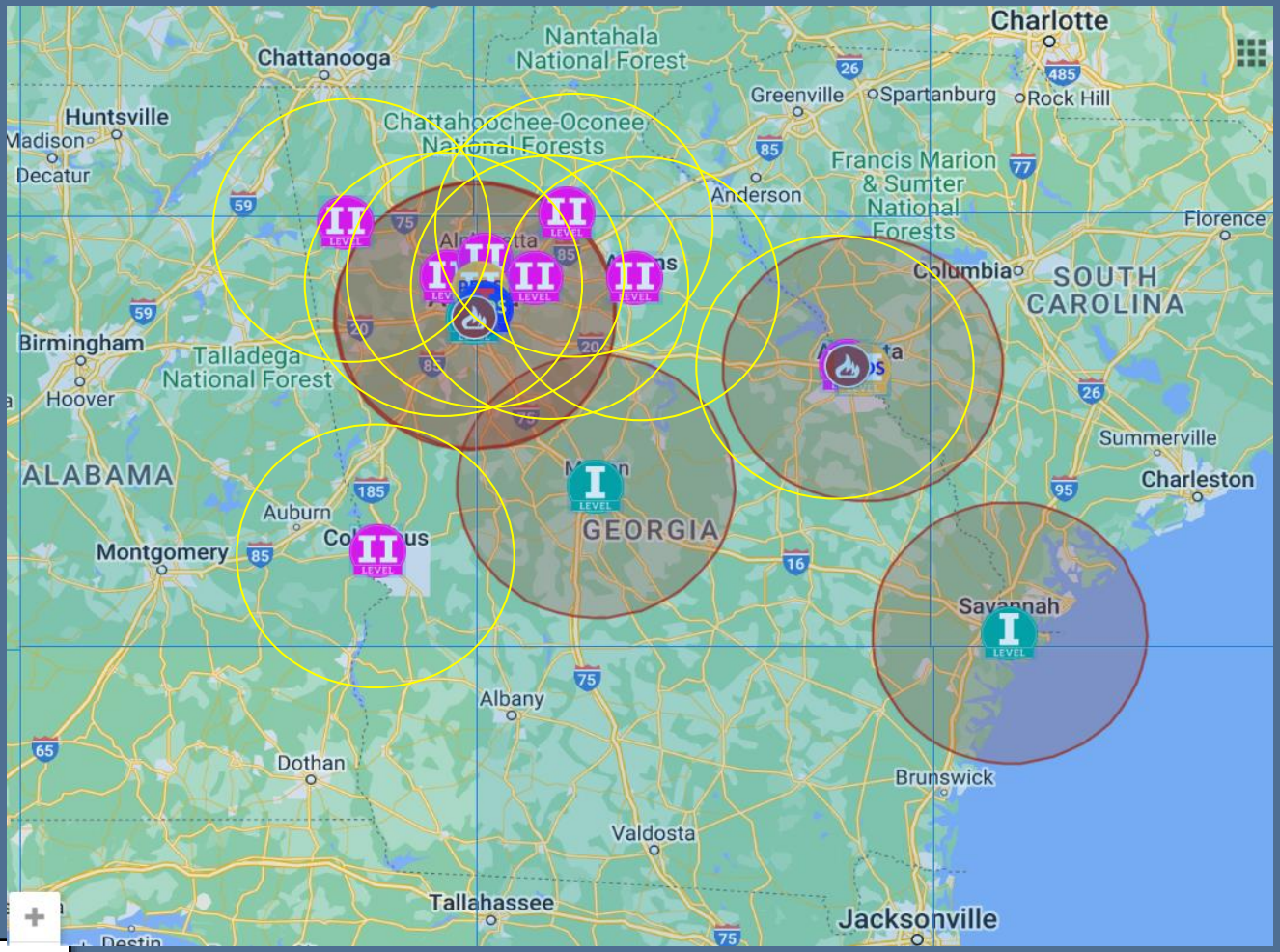
Georgia Pediatric Trauma Centers



Children's Healthcare of Atlanta

Pediatric Trauma Centers: Availability, Outcomes, and Federal Support Related to Pediatric Trauma Care. March 2017 GAO-17-334.

Georgia L1 &L2 ATC and PTC



Children's Healthcare of Atlanta

Pediatric Trauma Centers: Availability, Outcomes, and Federal Support Related to Pediatric Trauma Care. March 2017 GAO-17-334.

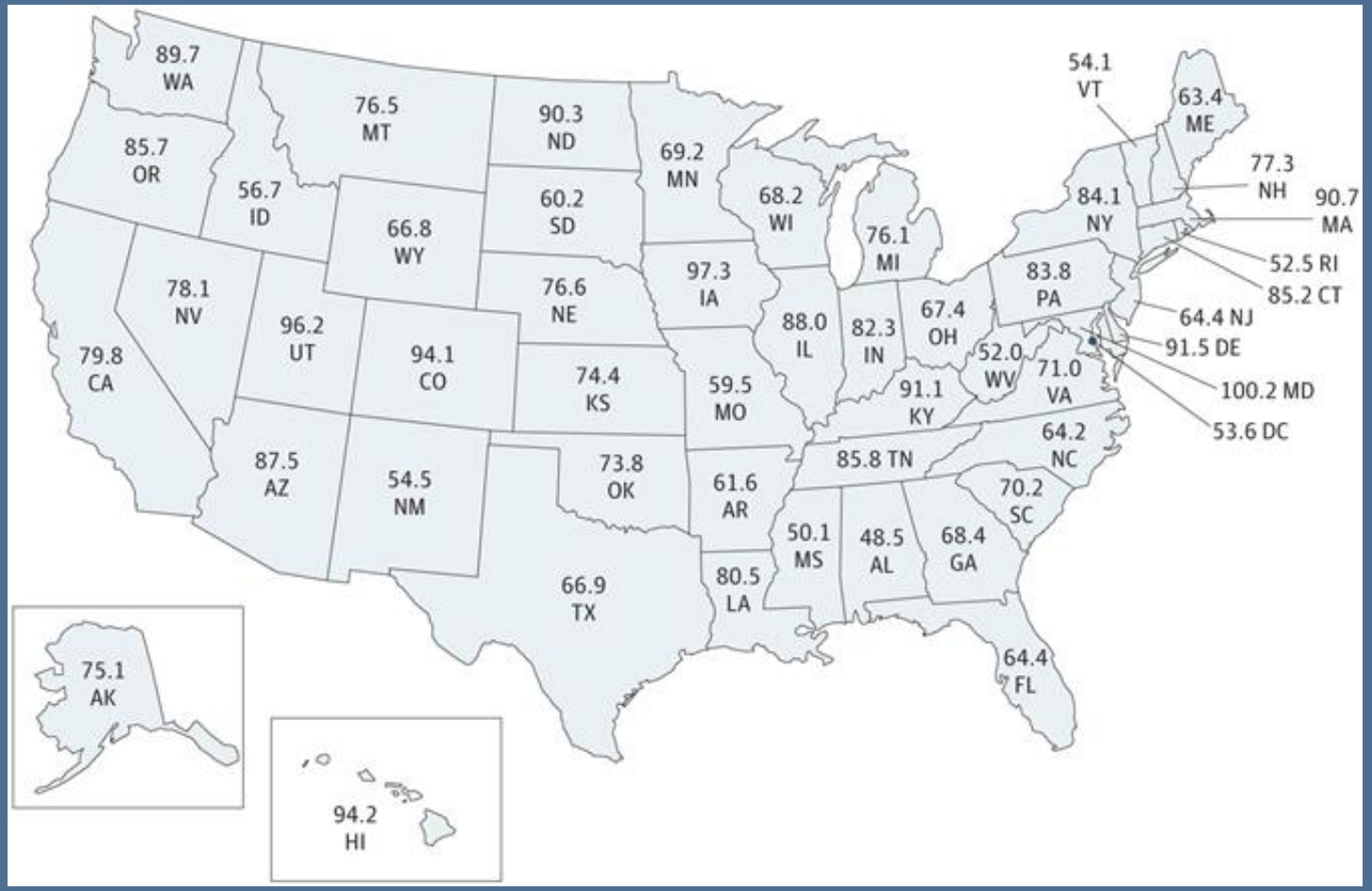
Current State of Pediatric Trauma System Evaluation

- Developed the Pediatric Trauma System Assessment Score (PTSAS)
  - externally validated
- Showed that a more mature State trauma system significantly decreased child mortality from injury.

Children's Healthcare of Atlanta

Fallat ME, Treager C, Humphrey S, Gumer L, Jawad K, Butler E, Rogers FB, Rivara FP, Collings AT. **A Novel Approach to Assessment of US Pediatric Trauma System Development**. JAMA Surg. 2022 Nov 1;157(11):1042-1049

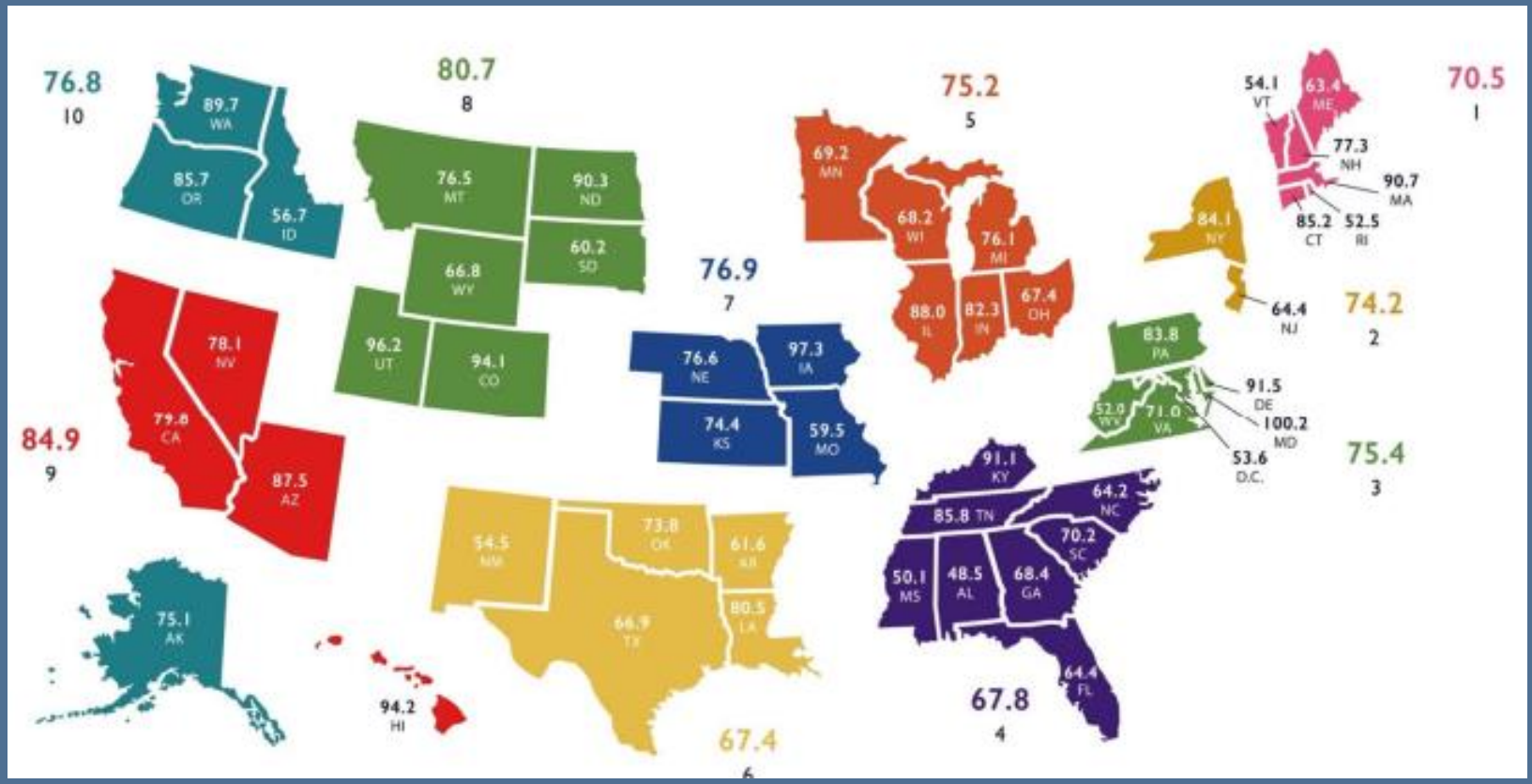
PTSAS By State



Children's Healthcare of Atlanta

Fallat ME, Treager C, Humphrey S, Gumer L, Jawad K, Butler E, Rogers FB, Rivara FP, Collings AT. **A Novel Approach to Assessment of US Pediatric Trauma System Development**. JAMA Surg. 2022 Nov 1;157(11):1042-1049

PTSAS By Region



Children's Healthcare of Atlanta

Fallat ME, Treager C, Humphrey S, Gumer L, Jawad K, Butler E, Rogers FB, Rivara FP, Collings AT. **A Novel Approach to Assessment of US Pediatric Trauma System Development**. JAMA Surg. 2022 Nov 1;157(11):1042-1049

How Can We Improve Upon This?

Develop More PTCs?

- Number of Level 1 PTCs constrained by:
  - ~1,100 board certified Pediatric Surgeons in U.S.
  - Supply of peds sub-specialists even more constrained
    - Neurosurg., Ortho, CT Surg., Anesthesia, Radiology, etc.
  - Specialized Resources (pediatric equipment) required
    - Financial constraints within hospitals

Children's Healthcare of Atlanta

Build More Children's Hospitals?

- Hospitals Providing Pediatric Care
  - 2000 - >3,500 hospitals
  - 2022 – 2,412 hospitals (~32% less)

2022 U.S. Centers of Medicare and Medicaid Services

Children's Healthcare of Atlanta

Pediatric Inpatient Capacity Decreasing Across the US

- AHA survey of 4720 US hospitals (2008–2018)
  - Peds inpatient units decr. by 19.1% (34 units per year)
  - Peds inpatient beds decr. by 11.8% (407 beds per year)
    - Primarily at children's hospitals
    - Rural unit beds decreasing at a higher rate than urban units beds (26.1% vs 10.0%)
    - Low-volume pediatric units and those without an associated PICU were at highest risk of closin.
    - **~25% US children experienced increase in distance to their nearest pediatric inpatient unit.**

- While access to inpatient care is declining for many children, (especially in rural areas), PICU beds are increasing, primarily at large children's hospitals.

Children's Healthcare of Atlanta

Cushing AM, et. al. **Availability of Pediatric Inpatient Services in the United States**. Pediatrics. 2021 Jul;148(1):e2020041723. doi: 10.1542/peds.2020-041723. Epub 2021 Jun 14

How Can "We" at GQIP Improve Upon This?

Education
Collaboration
"Stabilize and Transfer"

Children's Healthcare of Atlanta

GEORGIA QUALITY IMPROVEMENT PROGRAM

Resuscitation in Pediatric Trauma

- Basic principles of taking care of critically injured adults in the first hour of trauma apply to children
- Massive transfusion and balanced resuscitation in children follow adult trends
- Infants and children have a pronounced cardiovascular physiologic reserve
  - Increased HR first sign of shock
  - Quiet and tachycardic child→ signs of early shock
- BP is one of the last physiologic variables to decline
- SIPA (Pediatric Age-Adjusted Shock Index)
  - Incorporates age specific HR into the SI in order to identify children prior to CV collapse
  - Proven tool to predict mortality and outcomes in pediatric blunt trauma
  - Accurately identify children with BLSI who may need transfusions and operative interventions

Children's Healthcare of Atlanta

Phillips R et al. J Pediatr Surg. (2021) 56 (2): 401-404.

So what about the shock index?

- Shock index **(HR/SBP)** >0.9 predicts mortality in adult trauma
- HR up and/or SBP down = Increasing SI
- Based upon standard VS in adults
- VS vary with age and children have pronounced cardiovascular reserve with hypotension representing late stages of shock

Table 3. Normal Vital Signs For Age Of Pediatric Patients.

Age	Heart Rate (bpm)	Respiratory Rate (bpm)	Systolic Blood Pressure (mm Hg)	Diastolic Blood Pressure (mm Hg)
Newborn	90-180	30-50	60 ± 10	37 ± 10
1-5 months	100-180	30-40	80 ± 10	45 ± 15
6-11 months	100-150	25-35	90 ± 30	60 ± 10
1 year	100-150	20-30	95 ± 30	65 ± 25
2-3 years	65-150	15-25	100 ± 25	65 ± 25
4-5 years	65-140	15-25	100 ± 20	65 ± 15
6-9 years	65-120	12-20	100 ± 20	65 ± 15
10-12 years	65-120	12-20	110 ± 20	70 ± 15
13+ years	55-110	12-18	120 ± 20	75 ± 15

*Adapted from: Silverman BK. Practical Information. In: *Textbook of Pediatric Emergency Medicine*, ©2006. Also: Jorden RC. Multiple Trauma. In: *Emergency Medicine: Concepts and Clinical Practice*, ©1990. All rights reserved. See References 94 and 95, respectively.

Children's Healthcare of Atlanta

Papers From the 2nd Western Pediatric Trauma Conference

Pediatric specific shock index accurately identifies severely injured children ☆

Shannon N. Acker [a,*], James T. Ross [a], David A. Partrick [a], Suhong Tong [b], Denis D. Bensard [a,c]

[a] Department of Pediatric Surgery, Children's Hospital Colorado, University of Colorado School of Medicine, Aurora, CO USA
[b] Department of Biostatistics and Informatics, Colorado School of Public Health, Aurora, CO USA
[c] Department of Surgery, Denver Health Medical Center, Denver, CO USA

- Landmark paper in which SIPA gained traction in the pediatric trauma world
- SIPA defined by maximum HR/minimum SBP by age and compared to Shock Index (SI)
- Formula for SI is the same, but cut-offs at presentation included:
  - 1.22 (1–6 y/o)
  - 1.0 (7–12 y/o)
  - 0.9 (13–16 y/o)
- SIPA demonstrated improved discrimination of the following factors as compared to SI (unadjusted for age)
  - ISS > 30 (really injured)
  - Blood transfusion within the first 24 hours
  - Grade III liver/spleen laceration requiring blood transfusion
  - In-hospital mortality

Children's Healthcare of Atlanta

(SIPA= HR/SBP)

J Pediatr Surg. (2015) 50 (2): 331-34.

Validation of the age-adjusted shock index using pediatric trauma quality improvement program data

Andrew Nordin [1], Alan Coleman [2], Junxin Shi [3], Krista Wheeler [3], Henry Xiang [4], Shannon Acker [5], Denis Bensard [6], Brian Kenney [7]

- TQIP dataset of greater than 22,000 civilian pediatric trauma patients
- SIPA was elevated in 15.6% of blunt trauma and 19.4% of penetrating trauma (vs. 41.3% and 40% for SI)
- SIPA was a significantly better predictor of transfusion needs, ISS, ICU admission, ventilator use and mortality
- Validated usage of SIPA for children 1-4 years old
- Not as useful/better than SI for penetrating trauma

Children's Healthcare of Atlanta

(SIPA= HR/SBP)

J Pediatr Surg. (2017) 50 (2): 331-34.

Validation of Shock Index Pediatric-Adjusted for children injured in warzones

Christopher W. Marenco, MD, Woo S. Do, MD, Daniel T. Lammers, MD, John D. Horton, MD, Kenneth Azarow, MD, *and* **Matthew J. Eckert, MD**, *Tacoma, Washington*

- Retrospective review of DoD Trauma Registry for all patients <18 yo from 2008-2015
- Classified into two groups of normal vs. elevated SIPA using age-specific threshold values
- Mean ISS of 12 with penetrating injuries most common (63%); 25% blunt injuries; 12% burns
- Patients with elevated SIPA (43%) had a significantly greater need for transfusions, emergency surgical procedures, ICU admission and mortality

TABLE 1. Age Categories With Associated SIPA Threshold Values[14]

Age Category (Years)	HR Range	SBP Range	SIPA Threshold Values
0–3	70–110	90–110	>1.2
4–6	65–110	90–110	>1.2
7–12	60–100	100–120	>0.9
13–17	55–95	100–135	>0.9

Children's Healthcare of Atlanta

J Trauma Acute Care Surg. (2020) 89: 642-648.

SIPA Score

SIPA and
Prehospital Care
in Pediatric Trauma
Patients

Children's
Healthcare of Atlanta

Age-adjusted shock index: From injury to arrival

Andrew Nordin [1], Junxin Shi [2], Krista Wheeler [2], Henry Xiang [3], Brian Kenney [4]

- Prior studies evaluated only SIPA on ED arrival, therefore goal was to evaluate the utility of SIPA at the trauma scene and describe changes in SIPA from scene to ED.
- Retrospective review of TQIP database for all trauma patients 1-15 yo with ISS >15 (N= 2,917) and SIPA calculated at trauma scene and ED arrival
- 17.9% with persistently elevated SIPA from injury scene to arrival (compared to 34% SI)
- Elevated SIPA at scene was more predictive of greater ISS, LOS, and ventilator requirements, transfusions
- SIPA that remained abnormal also associated with increased mortality
- Prehospital SIPA values may predict worse outcomes but trending those values may have a greater utility than a single value alone.

Children's Healthcare of Atlanta

(SIPA= HR/SBP)

J Pediatr Surg. (2019) 54: 984-988.

The shock index, pediatric age-adjusted (SIPA) enhanced: Prehospital and emergency department SIPA values forecast transfusion needs for blunt solid organ injured children

Ryan Phillips [1], Shannon Acker [2], Niti Shahi [2], Gabrielle Shirek [2], Maxene Meier [3], Adam Goldsmith [2], John Recicar [4], Steven Moulton [2], Denis Bensard [5]

- Determine the utility of serial SIPA values from prehospital to the ED to help identify children with blunt liver or splenic injury who required a blood transfusion
- Retrospective single institution review of children 1-18 yo admitted with BLSI to level 1 PTC over a 10 year period
- 477 patients of which 20% received a blood transfusion within 24 hours of arrival
- Nearly 90% of patients who received blood had at least one elevated SIPA score in either setting
- Demonstrated that the trend was superior to any one elevated score.

Children's Healthcare of Atlanta

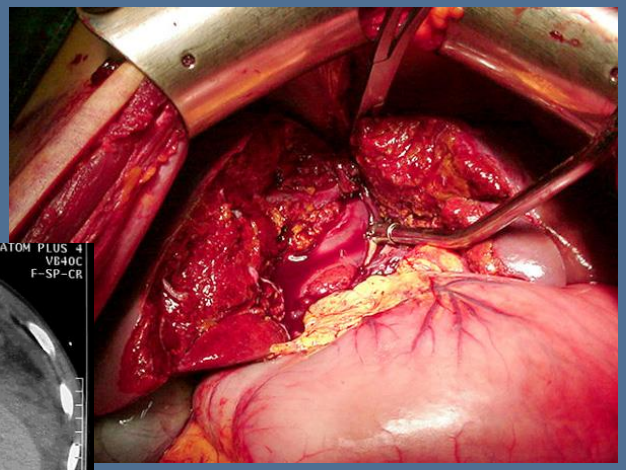
(SIPA= HR/SBP)

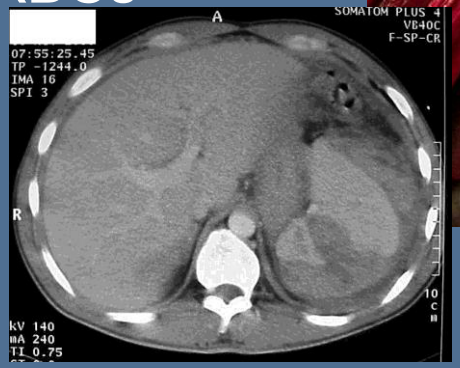
Surgery. (2020) 168: 690-694.

Prospective validation of the shock index pediatric–adjusted (SIPA) in blunt liver and spleen trauma: An ATOMAC+ study

Maria E Linnaus [1], David M Notrica [2], Crystal S Langlais [1], Shawn D St Peter [3], Charles M Leys [4], Daniel J Ostlie [5], R Todd Maxson [6], Todd Ponsky [7], David W Tuggle [8], James W Eubanks 3rd [9], Amina Bhatia [10], Adam C Alder [11], Cynthia Greenwell [11], Nilda M Garcia [8], Karla A Lawson [8], Prasenjeet Motghare [12], Robert W Letton [12]

- First prospective cohort utilizing SIPA
- Compared to SI, elevated SIPA was more associated with:
  - PRBCs in 24h
  - ISS >24
  - BLSI Grade >3 requiring PRBCs
  - ICU
  - Intervention

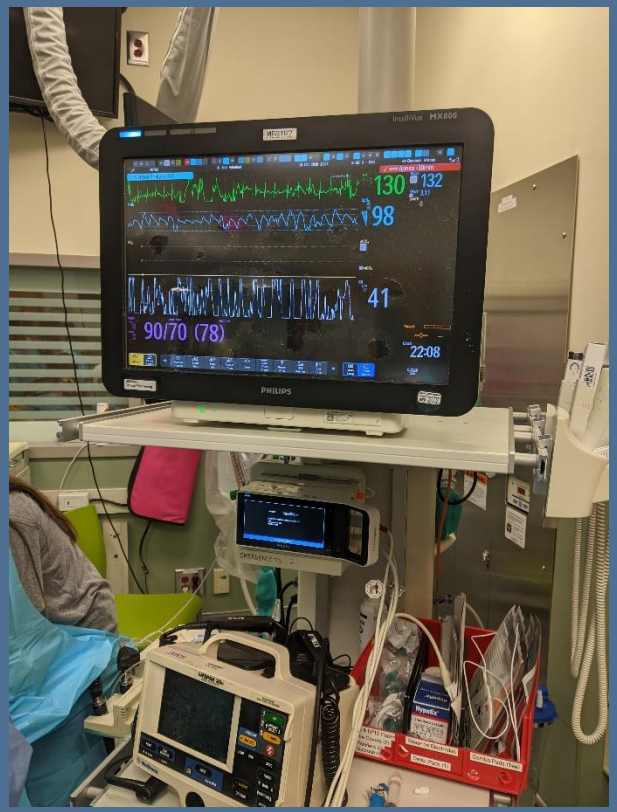




Children's Healthcare of Atlanta

J Pediatr Surg (2017) 52: 340-344.

Warm up the Level 1?



4y/o: 130/90= 1.4

Low speed MVC

GCS 15 On backboard

Away from parent

Pt is screaming

……and screaming

…….and screaming

Children's Healthcare of Atlanta

My Opinion?

- SIPA has its uses
  - Marker for Injury Severity (mod -> high ISS)
  - Triage
  - BSI and Need for Blood
  - Activation criteria (midlevel activations?)
  - MTP?
    - Should be incorporated
- Tachycardia in children is caused by many things other than bleeding

Children's Healthcare of Atlanta

My Opinion?

- SIPA easy to calculate (I do it every trauma activation)
  - Can't remember VS
- Can't calculate an ISS on arrival, can calculate SIPA
- I use it as a "tie breaker"
  - Blood/MTP
  - ICU admit
  - Scanning

Children's Healthcare of Atlanta

SIPA Worksheet

Shock Index, Pediatric Age-Adjusted (SIPA)

Tip Sheet for Nurses and Providers

Summary

SIPA (Shock Index, Pediatric Age Adjusted) is defined as the ratio of heart rate to systolic blood pressure for pediatric patients. Elevated *Shock Index* has been proven to monitor and predict severity in illness and prognosis in addition to correlate with increased mortality and the risk of massive transfusion. SIPA additionally improves the discriminatory ability of identifying severely injured children at-risk of requiring operative intervention, and requiring ICU admission. This score will be calculated for all patients, however, SIPA scores for patients 4 years and older will be flagged in the chart if abnormal.

Index Ratio Values

Sipa Scores	Ages 4-5	Ages 6-12	Ages>12
Normal Values	0-1.2	0-1.0	0-.0
Abnormal ***inform attending if abnormal**	**>1.2**	**>1.0**	**>0.9**

Pediatric Shock Index

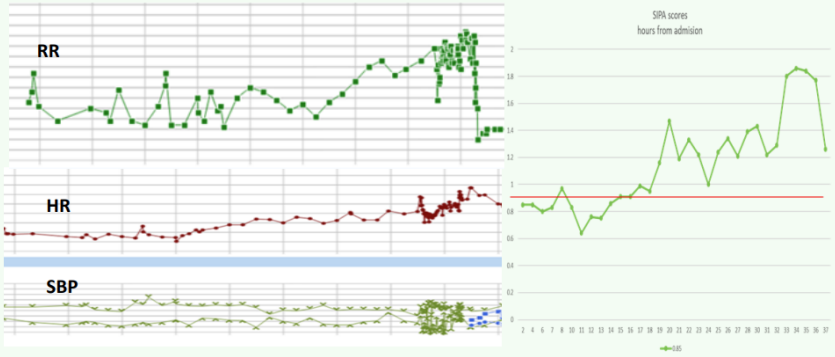
$$1\text{–}12 \text{ years}: \frac{HR}{SBP} > 1.55 - 0.05 \times \text{age (in years)}$$

*SIPA scores will automatically populate in Trauma Narrator for all patients, abnormal values will only flag for patients that are 4 years old and greater

**SIPA scores will only populate when vitals signs are validated

Data Example

Below demonstrates the relation of SIPA Scoring and Vitals Signs



Children's Healthcare of Atlanta

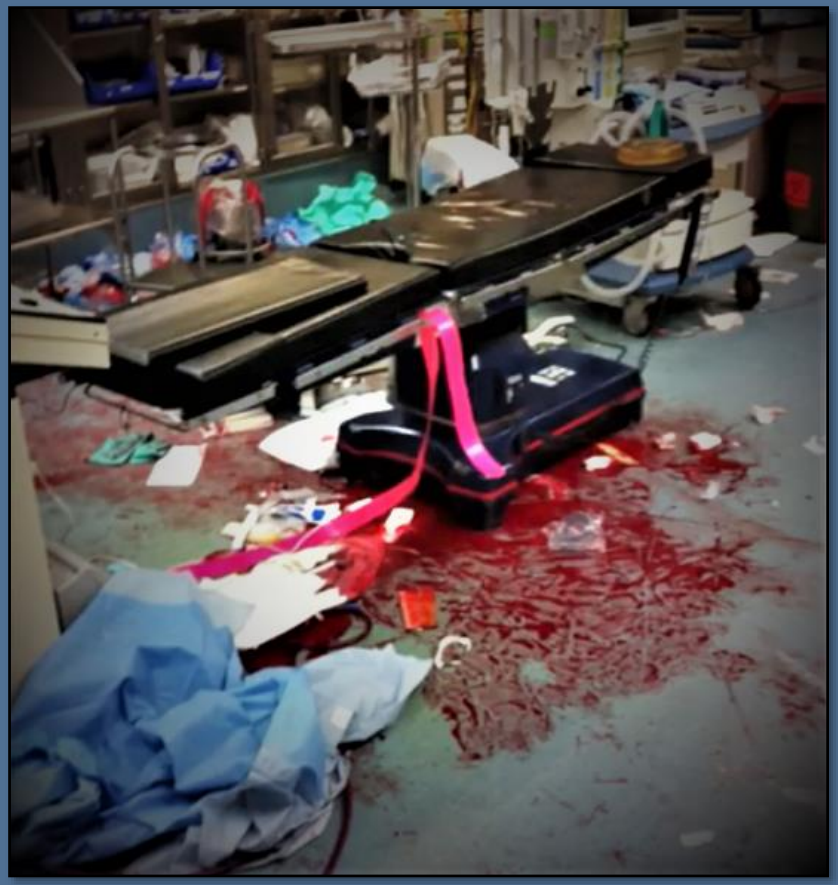
My Opinion?

- Its useless in a neurologically alert child losing his/her mind
- Tachycardia/Hypertension with elevated SIPA probably means nothing either from a resuscitation standpoint
  (tib-fib fx)
- A fool with a tool…. (we still need good clinicians)

Children's Healthcare of Atlanta

What if we do have a bleeding child…

- SIPA
- Product vs. crystalloid
- MTP
- Whole Blood
- FAST



Children's Healthcare of Atlanta

Timing and volume of crystalloid and blood products in pediatric trauma: An Eastern Association for the Surgery of Trauma multicenter prospective observational study

- Multi-institutional prospective observational study of pediatric trauma patients younger than 18 yo transported from scene with elevated SIPA on arrival
- Volume and timing of prehospital, ED, and initial admission resuscitation with crystalloid boluses overall and before transfusion were analyzed
- Half (53%) of patients who received greater than one crystalloid bolus required transfusion
- Patients that received product first (less crystalloid) → decreased ventilatory days, ICU LOS and hospital stay
- No difference in mortality
- Supported crystalloid-sparing, early transfusion approach for resuscitation of injured children.

Children's Healthcare of Atlanta

Polites *et al. J Trauma Acute Care Surg.* (2020) 89: 36-42.

MTP in Pediatric Trauma

- Convincing evidence that implementation of MTPs in adult patients with severe trauma improves outcomes
- Consensus on the ideal component ratio continues to change and adjust
  - 1:1:1 ratio used in combat support hospitals
  - 10:4:2 ratio implemented in civilian trauma centers
- No evidence of improved outcomes with pediatric trauma until 2019

Children's Healthcare of Atlanta

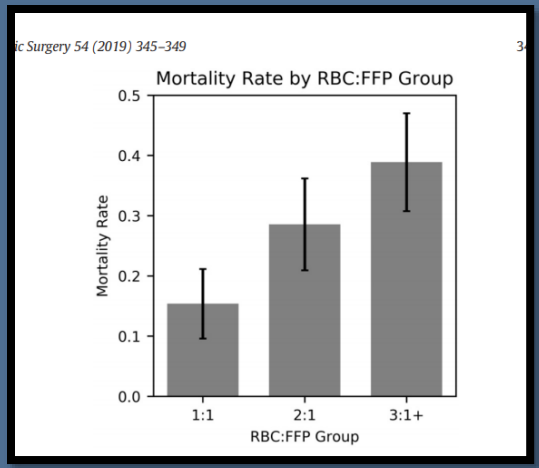
Phillips R et al. J Pediatr Surg. (2021) 56 (2): 401-404.

Massive transfusion in pediatric trauma: An ATOMAC perspective

Daniel K. Noland [a], Nadja Apelt [a], Cynthia Greenwell [a,*], Jefferson Tweed [a], David M. Notrica [b], Nilda M. Garcia [c], R. Todd Maxson [d], James W. Eubanks III [e], Adam C. Alder [a]

[a] Children's Medical Center, the flagship of Children's Health℠, 1935 Medical District Dr, Dallas, TX, USA 75235
[b] Phoenix Children's Hospital, 1919 E Thomas Rd, Phoenix, AZ, USA 85016
[c] Dell Children's Medical Center, 4900 Mueller Blvd, Austin, TX, USA 78723
[d] Arkansas Children's Hospital, 1 Children's Way, Little Rock, AR, USA 72202
[e] Le Bonheur Children's Hospital, 50 N Dunlap St, Memphis, TN, USA 38103

- Landmark study multicenter retrospective review of 5 level one pediatric trauma centers
- Analyzed patients <18 yo who received in excess of 2u pRBC, 20 cc/kg of pRBC, or activation of MTP
- Massive transfusion defined as 40 cc/kg of blood products/24 hrs
- First study to demonstrate a survival benefit with balanced 1:1 resuscitation
- Viscoelastic monitoring for goal-directed resuscitation and whole blood showing early benefit but not widely used



Children's Healthcare of Atlanta

J Pediatr Surg. (2019) 54 (2): 345-349.

Safety profile of low-titer group O whole blood in pediatric patients with massive hemorrhage

Katrina M. Morgan[1] | Mark H. Yazer[2] | Darrell J. Triulzi[2] | Stephen Strotmeyer[3] | Barbara A. Gaines[3] | Christine M. Leeper[1]

- Determine risk of acute hemolytic reactions in non-group O recipient children due to the passive transfusion of anti-A and anti-B in LTOWB
- Single institution review (Pitt) of 47 children that received LTOWB between 2016-2020 (21 group O recipients and 26 non-group O recipients)
- Evaluated children for evidence of hemolysis during the first two days following transfusion via LDH, haptoglobin, Tbili, retic count, potassium and creatinine
- No clinically or statistically significant difference in baseline, post-transfusion day 1 or post-transfusion day 2 hemolysis markers between the groups.
- No adverse effects or transfusion reactions reported

Children's Healthcare of Atlanta

Transfusion (2021) 61: S8-S14.

Whole Blood Hemostatic Resuscitation in Pediatric Trauma: A Nationwide Propensity-Matched Analysis

Tanya Anand [1], Omar Obaid, Adam Nelson, Mohamad Chehab, Michael Ditillo, Ahmad Hammad, Molly Douglas, Letitia Bible, Bellal Joseph

- TQIP Database to compare children aged 1-17 yo who were transfused within 4 hours of presentation and either received WB versus component therapy (CT)
- 135 WB versus 270 CT
- 34% penetrating injuries and 41% operative intervention for hemorrhage control
- Decreased total blood products transfused and ventilatory days in children receiving WB at 4 hours and 24 hours
- No difference in mortality

Children's Healthcare of Atlanta

J Trauma Acute Care Surg (2021) Online ahead of print

FAST

Is the use of FAST accurate in Pediatric Trauma?

Children's Healthcare of Atlanta

Focused assessment with sonography for trauma in children after blunt abdominal trauma: A multi-institutional analysis

Bennett W. Calder, MD, Adam M. Vogel, MD, Jingwen Zhang, MS, Patrick D. Mauldin, PhD, Eunice Y. Huang, MD, Kate B. Savoie, MD, Matthew T. Santore, MD, KuoJen Tsao, MD, Tiffany G. Ostovar-Kermani, MD, Richard A. Falcone, MD, M. Sidney Dassinger, MD, John Recicar, Jeffrey H. Haynes, MD, Martin L. Blakely, MD, Robert T. Russell, MD, Bindi J. Naik-Mathuria, MD, Shawn D. St Peter, MD, David P. Mooney, MD, Chinwendu Onwubiko, MD, Jeffrey S. Upperman, MD, Jessica A. Zagory, MD, *and* **Christian J. Streck, MD**, *Charleston, South Carolina*

- Several studies on FAST in children indicated that those children who underwent FAST when presenting hemodynamically normal were less likely to undergo a CT scan to assess intraabdominal injuries
- Multi-institutional study to investigate the role of FAST for diagnosis of IAI and IAI requiring acute intervention (IAI-I) in children after BAT
- Prospectively analyzed children less than 16 presenting to 14 level 1 PTCs over a one-year period
- Excluded children presenting >6 hours from injury, penetrating injuries, and those than received a CT prior to arrival to the PTC
- Decision to perform a FAST was at the discretion of the trauma team

Children's™ Healthcare of Atlanta

Utility of FAST for Evaluation of Blunt Abdominal Trauma in Children

14 pediatric emergency centers

2,188 injured children with suspected blunt abdominal trauma

FAST use 38% (829)

CT after FAST 41% (340)

CT without FAST 46% (625)

+Intra abd injury 29%
+Intervention 8%

All identified by CT

81 injuries missed by FAST

15 intervention injuries missed by FAST

FAST for Intraabdominal injury (IAI)

Sensitivity 28%
Specificity 91%
PPV 56%
NPV 76%
Accuracy 73%

SUMMARY

FAST has low sensitivity, can miss serious intrabdominal injuries, and should be used with caution

Calder et al. J Trauma Acute Care Surg 2017 Aug; 83(2):218-24

Children's Healthcare of Atlanta

Research

JAMA | Original Investigation

Effect of Abdominal Ultrasound on Clinical Care, Outcomes, and Resource Use Among Children With Blunt Torso Trauma
A Randomized Clinical Trial

James F. Holmes, MD, MPH; Kenneth M. Kelley, MD; Sandra L. Wootton-Gorges, MD; Garth H. Utter, MD, MSc; Lisa P. Abramson, MD; John S. Rose, MD; Daniel J. Tancredi, PhD; Nathan Kuppermann, MD, MPH

- Use of FAST in pediatric trauma is controversial
- Randomized clinic trial in which 925 children < 18 yo were randomized to FAST or no FAST during trauma resuscitation
- Among hemodynamically stable pediatric patients following blunt trauma, FAST exam did NOT decrease CT rates, identify missed injuries, decrease ED LOS or hospital costs.
- Question remains to abandon FAST completely in pediatric trauma
- Negative FAST exam in stable children should not reassure you of no intraabdominal injury

Children's Healthcare of Atlanta

JAMA (2017) 22: 2290-2296

Unique Aspects of Pediatric Trauma

- ~ 50% of Georgia's pediatric population live >30 miles from a pediatric trauma center making stabilization and early resuscitation in critically injured children a shared responsibility with adult trauma centers
- Infants and children have a pronounced cardiovascular physiologic reserve and BP is one of the last physiologic variables to decline
- SIPA is a proven clinical tool to help recognize early shock and hemorrhage in children
- Initial resuscitation in children often mirrors adult trends
- FAST is not accurate in pediatric trauma

Children's Healthcare of Atlanta

Questions

Please feel free to contact me with any questions or patient care assistance

Alexis D. Smith, MD
Alexis.smith@choa.org
404-668-5382

Children's Healthcare of Atlanta

EXTRA SLIDES

7 yo girl restrained passenger in high speed MVC with fatality on scene

- 20 cc/kg crystalloid bolus en route by EMS for HR 132 and SBP of 95 (SIPA= 1.4)
- Airway intact, GCS 14 and complaining of abdominal pain
- Initial vitals: HR 140 and BP 84/42 (SIPA 1.67)
- Activated MTP and transfused 1:1 PRBC:FFP (20 cc/kg)
- Responded to product transfusion and HR 122 BP 102/55 (SIPA 1.2)
- Labs sent and vitals remained stable, CXR with 9th right rib fx, but no PTX…CT of head, abd/pelvis to assess for injuries

Children's Healthcare of Atlanta

Grade V spleen and IV liver: Non-operative management (NOM)

Children's Healthcare of Atlanta

Nonoperative management of blunt liver and spleen injury in children: Evaluation of the ATOMAC guideline using GRADE

David M. Notrica, MD, James W. Eubanks III, MD, David W. Tuggle, MD, Robert Todd Maxson, MD, Robert W. Letton, MD, Nilda M. Garcia, MD, Adam C. Alder, MD, MSCS, Karla A. Lawson, PhD, Shawn D. St Peter, MD, Steve Megison, MD, *and* Pamela Garcia-Filion, PhD, MPH,
Phoenix, Arizona

- Arizona-Texas-Oklahoma-Memphis-Arkansas Consortium (ATOMAC) created to create new guidelines for NOM of BLSI to replace the standards of treatment based on grade of injury that APSA created in 2000
- The algorithm generated 27 clinical questions and was supported by multiple recommendations
- **Strong recommendations include**:
- Management of pediatric BLSI based on hemodynamic status rather than grade
- Abbreviated bed rest of 1 day or less for stable patients whose Hgb has been documented to be stable
- Transfusion threshold of 7 g/dL
- NOM guideline can be applied to patients with multiple injuries
- Children with isolated BLSI without signs of bleeding and stable Hgb can be discharged home before 24 hours

Children's Healthcare of Atlanta

J Trauma Acute Care Surg (2015) 79: 683-693

Nonoperative management of blunt liver and spleen injury in children: Evaluation of the ATOMAC guideline using GRADE

David M. Notrica, MD, James W. Eubanks III, MD, David W. Tuggle, MD, Robert Todd Maxson, MD, Robert W. Letton, MD, Nilda M. Garcia, MD, Adam C. Alder, MD, MSCS, Karla A. Lawson, PhD, Shawn D. St Peter, MD, Steve Megison, MD, *and* Pamela Garcia-Filion, PhD, MPH,
Phoenix, Arizona

- **Conditional recommendations include**:
- Hemodynamic status at presentation should guide ICU admission regardless of grade with the exception of Grade V injuries which require ICU
- Patients not admitted to ICU and are stable with no signs of bleeding can start PO when comfortable and able.
- Angioembolization may be used in NOM to improve splenic salvage, but not all children with contrast extravasation require AE
- 1:1:1 transfusion radios early in resuscitation should be considered
- Limiting crystalloid volume (20 cc/kg) and early use of transfusion with significant bleeding should be considered

Children's Healthcare of Atlanta

J Trauma Acute Care Surg (2015) 79: 683-693

Non-operative Management Pediatric Liver & Spleen Injury The ATOMAC Guidelines

1. Follow ATLS protocol first.
2. Patients with peritonitis are managed per surgeon discretion. Do not use this algorithm for patients with peritonitis.
3. Guideline was based on pediatric studies with younger patients, so use caution in patient 16 or older.
4. May be used for polytrauma patients where not contraindicated
5. Continued bleeding is defined by the surgeon. Examples: inadequate Hb increase to transfusion, hemodynamic signs of hypovolemia +/- anemia
6. "Stable Hb" means a Hb value not dropping more than 0.5mg/dL in 12hrs. Repeat Hb at 24hrs is optional.
7. Any lab suspected to be erroneous may be repeated prior to medical decision-making
8. Times refer to the time of injury
9. Late presentation: Stable patients presenting within 48hrs post injury are still admitted for 24hrs of observation, but Hb rechecks are optional. Injuries >48hr are at surgeon discretion.

Liver or Spleen Injury By CT scan (or suspected injury)

Ongoing or very recent bleeding
as determined by surgeon (may include: high HR, low BP, delayed cap refill)

No signs of ongoing bleeding

Stable

Type and Screen
Admit to non-ICU
Vitals q2h x 4, then q4h
Bedrest overnight
Hb at 6, 12, and 24 hrs*

No continued bleeding

Floor status
Regular Diet
Ambulate if Hb Stable for 24 hrs

Home when:
Vital signs stable
Tolerating regular diet
Minimal abdominal Pain

Hb <7.0 mg/dL or symptomatic

10mL/Kg PRBC
NPO
Bedrest additional 24 hrs
Hb q6h until stable x 2

Stabilized

Continued bleeding

Non-responder to PRBCs

Surgery

Hypoperfused
1. 20mL/Kg LR or NS
2. If non-responder or transient response, 10-20 mL/kg PRBCs
3. Consider other causes (tamponade, spinal shock, etc)
4. Consider massive transfusion protocol, 1:1:1 (FFP:PRBC:plts)

HR/BP/Perfusion stabilize

CT if not already done

Admit to PICU
Vitals per ICU routine
NPO
Hb q6h
Bedrest until Hb stable

Stabilized

No bleeding for 24 hrs. Transfer to floor not contraindicated by other injuries.

Hb < 7.0 or symptomatic

10mL to 30mL/Kg PRBC
NPO
Bedrest x 24hr
Hb q6h
Consider embolization

Hb or vital signs still unstable After >40mL/Kg PRBCs or >4 units PRBCs

Hb >=7.0 & <4 units & <40mL/Kg

Failure of NOM Algorithm

Rebleed or Continued bleeding

PICU until Hb stable* for 24 hr

Angiograophy and embolization if available

Surgery

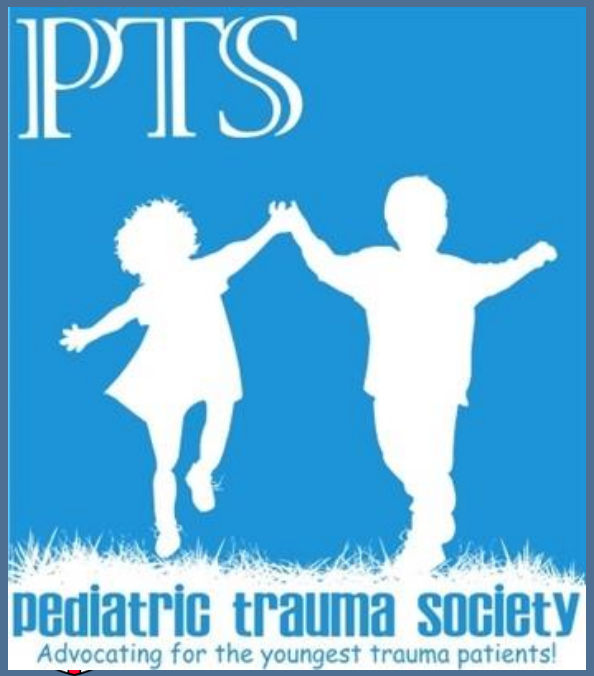
Continued NOM at surgeon discretion

Hb Stable

Discharge instructions

No Ibuprofen or other NSAIDS.
Acetaminophen is okay.
May go back to school when off pain meds
Restricted activity for length per APSA Guidelines (grade +2 = weeks).
Return to ED for increasing pain, pallor, dizziness, vomiting, worsening shoulder pain, GI bleeding or black tarry stools. Call office for jaundice.
Phone call follow-up for grade 1-2 injury at 2 weeks and again at 60 days.
Office visit for Grade 3- 5 injury at 2 weeks.
Phone call at 60 days post-injury
No follow-up imaging is required. Imaging is optional

ATOMAC (Arizona Texas Oklahoma Memphis Arkansas Consortium) v7.4 Nov 2012
***24hr hb is only done if patient still in-house)**



How did children treated with the ATOMAC guideline fare? ?

Failure of nonoperative management of pediatric blunt liver and spleen injuries: A prospective Arizona-Texas-Oklahoma-Memphis-Arkansas Consortium study

Maria E. Linnaus, MD, Crystal S. Langlais, MPH, Nilda M. Garcia, MD, Adam C. Alder, MD, James W. Eubanks, III, MD, R. Todd Maxson, MD, Robert W. Letton, MD, Todd A. Ponsky, MD, Shawn D. St. Peter, MD, Charles Leys, MD, Amina Bhatia, MD, Daniel J. Ostlie, MD, David W. Tuggle, MD, Karla A. Lawson, PhD, Alexander R. Raines, MD, *and* David M. Notrica, MD, *Phoenix, Arizona*

- Prospective study of centers using ATOMAC management guidelines for BLSI to identify frequency and characteristics of failure of NOM in pediatric patients
- 18 years or younger at 10 Level 1 PTC from April 2013-January 2016
- Failure of NOM: patient undergoing surgical procedure in their abdominal cavity including ex-lap or laparoscopy for splenectomy, splenorrhaphy, hepatectomy, hepatorrhaphy, abdominal packing, intestinal resection/repair, mesenteric repairs, pancreatectomy, drain placement or diagnostic procedures
- Angio/embo not considered failure of NOM
- N= 1,008 with median age of 10.3 years and 62% male
- MVC > Fall > Ped struck
- 50% liver injury; 41% splenic injury; 10% both

Children's Healthcare of Atlanta

J Trauma Acute Care Surg. (2017) 82: 672-679.

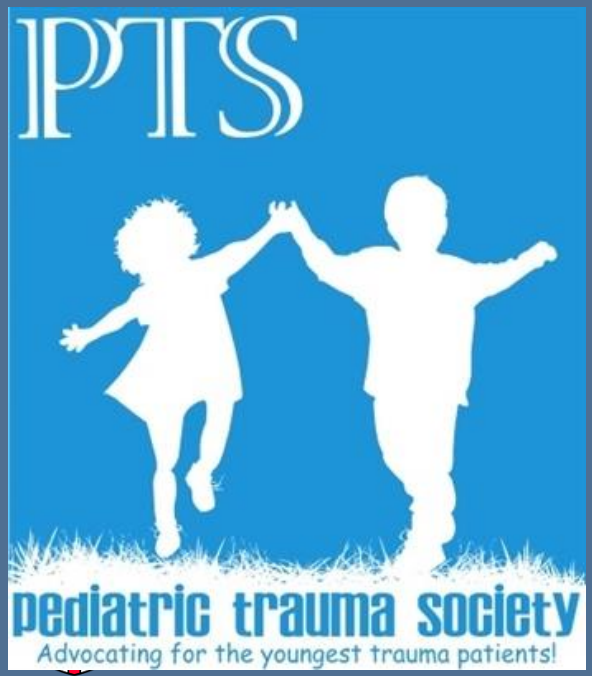
Failure of nonoperative management of pediatric blunt liver and spleen injuries: A prospective Arizona-Texas-Oklahoma-Memphis-Arkansas Consortium study

Maria E. Linnaus, MD, Crystal S. Langlais, MPH, Nilda M. Garcia, MD, Adam C. Alder, MD, James W. Eubanks, III, MD, R. Todd Maxson, MD, Robert W. Letton, MD, Todd A. Ponsky, MD, Shawn D. St. Peter, MD, Charles Leys, MD, Amina Bhatia, MD, Daniel J. Ostlie, MD, David W. Tuggle, MD, Karla A. Lawson, PhD, Alexander R. Raines, MD, *and* **David M. Notrica, MD**, *Phoenix, Arizona*

- 93% patients successfully managed non-operatively (7% failed NOM)
- Failure rate for bleeding 3.4% (34 patients)
- 10% failure rate for bleeding when children presented with spleen and liver injury
- Failure rates for a patient with an isolated liver or isolated spleen injuries were 3.8% and 0% respectively
- Mortality rate of 2.5% (TBI most common cause of death)
- Overall median hospital LOS: 57 hours
- Children with combined liver and spleen injuries as well as children with pancreatic injuries are at higher risk for failure of NOM

Children's Healthcare of Atlanta

J Trauma Acute Care Surg. (2017) 82: 672-679.



How do often do we utilize angioembolization in children and adolescents?

Use of angioembolization in pediatric polytrauma patients WITH BLUNT SPLENIC INJURYAngioembolization in Pediatric Blunt Splenic Injury

Robert A. Swendiman[a,*], Alexey Abramov[b], Stephen J. Fenton[c], Katie W. Russell[c], Michael L. Nance[b], Gary W. Nace Jr.[b], Myron Allukian III[b]

- Retrospective cohort study queried the NTDB for all pediatric patients (< 18 years old) that sustained a blunt splenic injury from 2010-2015.
- Excluded patients with concomitant severe abdominal trauma (i.e. injuries to small bowel, liver and pancreas that required immediate operative intervention thereby confounding the role of splenectomy in an operative setting)
- Sought to explore the relationship between adult and pediatric trauma centers and angioembolization (AE) utilization
- Primary outcome: mortality
- Secondary outcome: splenectomy and utilization of AE
- ~ 14,000 patients met inclusion criteria and 3.7% of patients underwent AE
- Odds of AE were higher in older patients, those who received a blood transfusion, those with higher ISS, and those who presented to adult trauma center and dual-certified trauma center as compared to pediatric trauma center

Children's Healthcare of Atlanta

Journal of Pediatric Surgery 56 (2021) 2045–2051

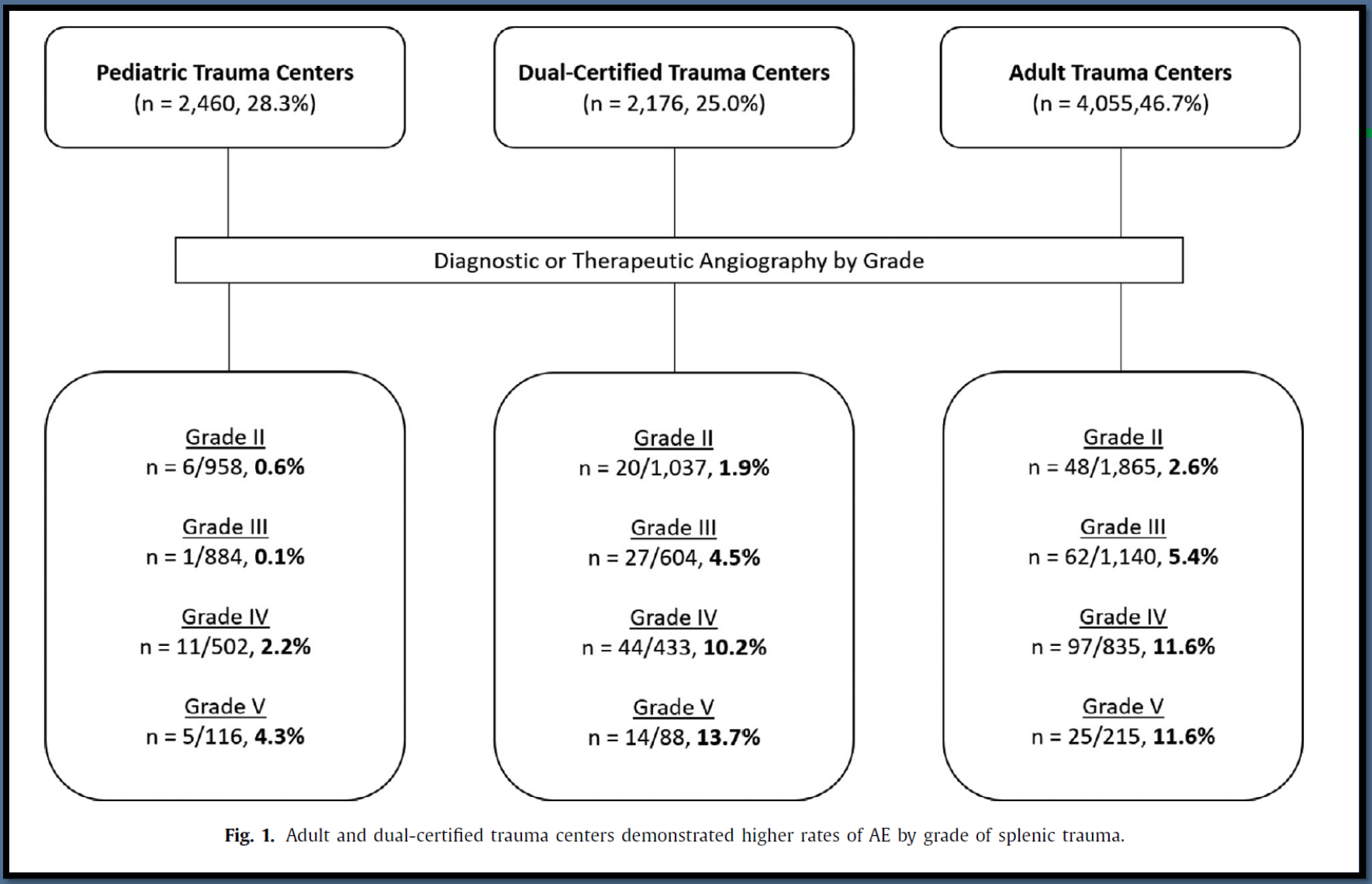


Fig. 1. Adult and dual-certified trauma centers demonstrated higher rates of AE by grade of splenic trauma.

Journal of Pediatric Surgery 56 (2021) 2045–2051

Children's Healthcare of Atlanta

Use of angioembolization in pediatric polytrauma patients WITH BLUNT SPLENIC INJURYAngioembolization in Pediatric Blunt Splenic Injury

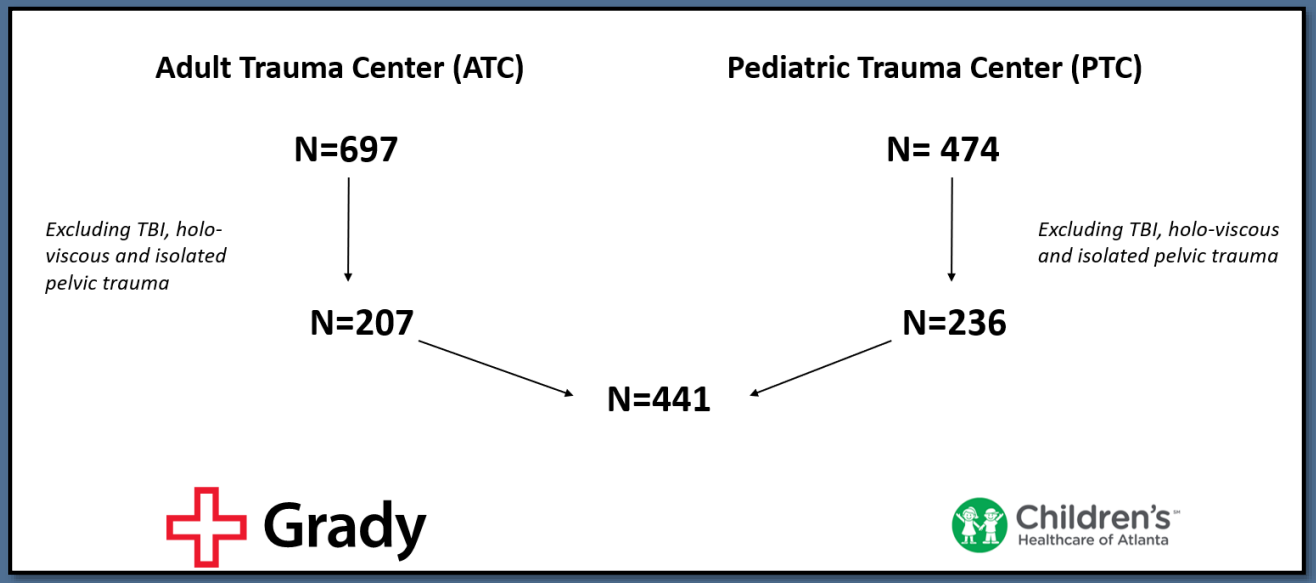
Robert A. Swendiman[a,*], Alexey Abramov[b], Stephen J. Fenton[c], Katie W. Russell[c], Michael L. Nance[b], Gary W. Nace Jr.[b], Myron Allukian III[b]

- Patients treated at ATCs were **4 times** more likely to undergo AE and **7 times** more likely to require a splenectomy when compared to patients treated at PTCs
- PTCs performed only 27 splenectomies and 23 AEs over the 6 year study period
- No patients undergoing AE at a PTC failed management and progressed to a splenectomy (5.2% failure rate at ATC)
- Regression models demonstrated no difference in mortality between the cohorts
- PTCs accomplished a higher splenic salvage rate with a lower AE utilization

Children's Healthcare of Atlanta

Journal of Pediatric Surgery 56 (2021) 2045–2051

Atlanta Adolescent Trauma Project

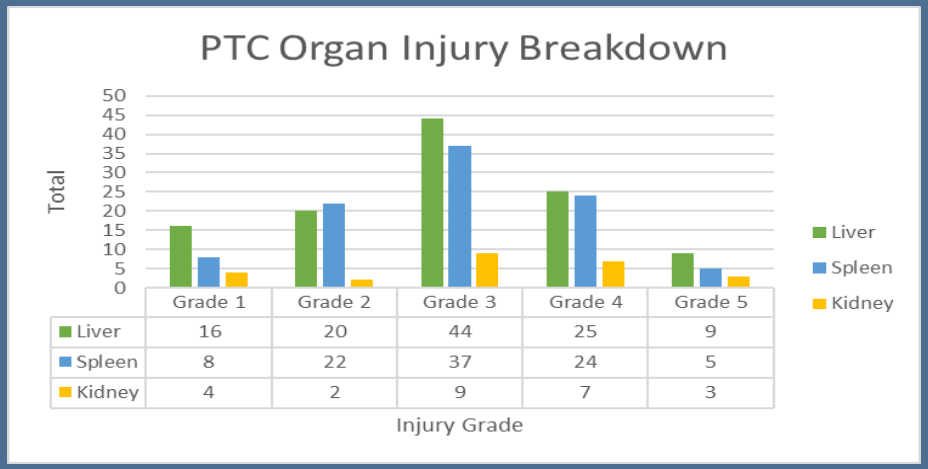


- Unifying management of blunt abdominal trauma in adolescent (11-18) trauma patients across Atlanta
- Retrospective review comparing management, outcomes and interventions for solid organ injuries at Grady versus CHOA.
- Our first study is to compare angioembolization rates between our two centers from 2016-2021
- Goal to integrate BAT algorithm across the city for trauma patients 18 years and younger

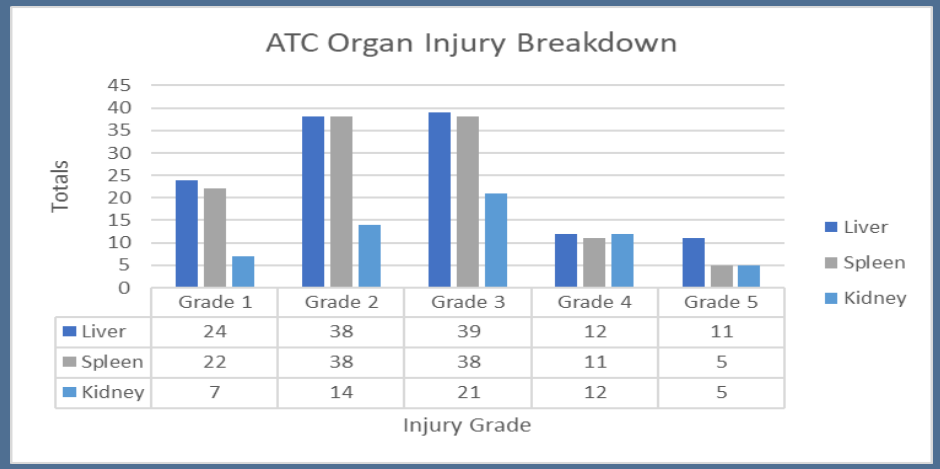
Children's Healthcare of Atlanta

Slide complements of Dr. Geoto Dantes

Atlanta Adolescent Trauma Project



	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Liver	16	20	44	25	9
Spleen	8	22	37	24	5
Kidney	4	2	9	7	3



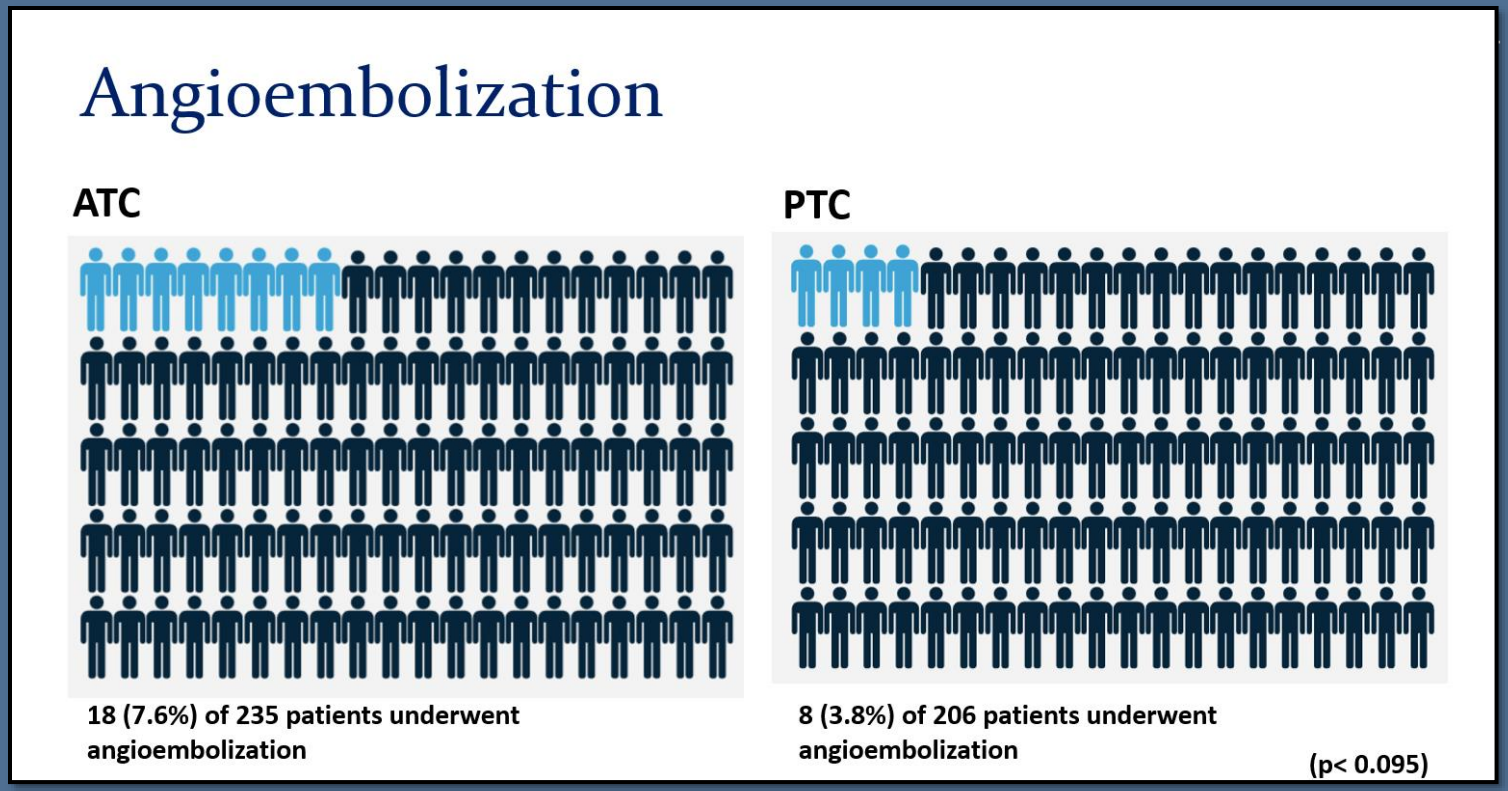
	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5
Liver	24	38	39	12	11
Spleen	22	38	38	11	5
Kidney	7	14	21	12	5

Higher proportion of Grade 4/5 injuries in the pediatric trauma center (31%) when compared to the Adult trauma center (19%)

Children's Healthcare of Atlanta

Slide complements of Dr. Geoto Dantes

Atlanta Adolescent Trauma Project



- 18 adolescent patients underwent angiography at Grady, 9 of which underwent subsequent angioembolization compared to 8 patients who underwent angiography with embolization at PTCs.
- When comparing angioembolization rates amongst patients with only Grade 4/5 injuries, the difference between centers still do not meet significance

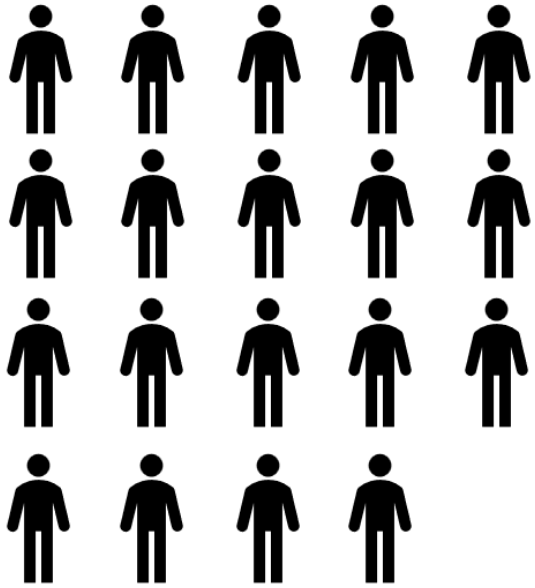
Children's Healthcare of Atlanta

Slide complements of Dr. Geoto Dantes

Atlanta Adolescent Trauma Project

Surgery Rate

ATC



VS.

PTC

19 (8.0%) of 235 patients underwent surgery

1 (0.5%) splenectomy in 206 patients

Patients treated at ATCs were significantly more likely to undergo surgery than those treated at PTCs (P<0.005)

Children's Healthcare of Atlanta

Slide complements of Dr. Geoto Dantes

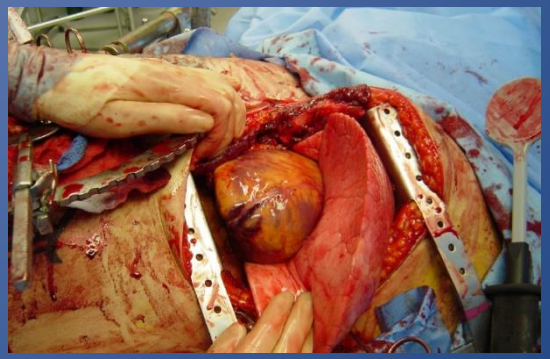
What if we do have a bleeding child…

- 11 yo boy ped struck transported from scene with GCS 3 and hypotensive
- 20 cc/kg crystalloid bolus en route by EMS for HR 148 and SBP of 82 (SIPA= 1.8)
- MTP activated and intubated on arrival (SIPA 1.9)
- Transient responder to massive transfusion→ CT grade IV liver and right renal injury
- Ex-lap
- REBOA placed intraoperatively when coded with Pringle maneuver

Children's Healthcare of Atlanta

Aortic Occlusion in Pediatric Trauma

- Resuscitative Thoracotomy (RT) or Emergency Dept Thoracotomy (EDT) historically has been the only method available for aortic occlusion for non-compressible torso hemorrhage in pediatric/adolescent trauma
- RT utilization in children widely debated due to dismal outcomes and a high percentage of severe TBI pts
- **No** reported survivors in children less than 9 years of age who underwent an EDT after penetrating trauma
- Until recently, **no** reported survivors of pediatric blunt trauma who underwent aortic occlusion under the age of 14.

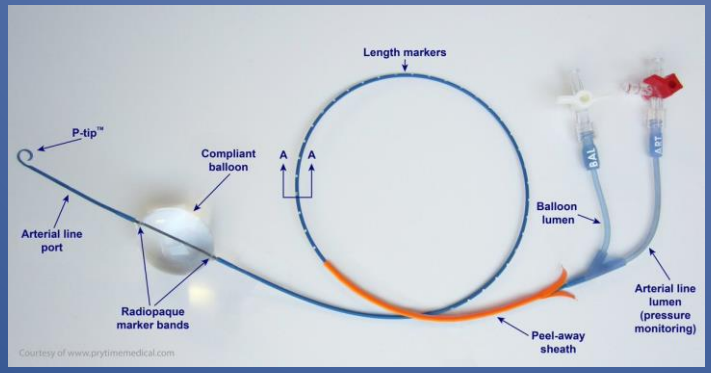


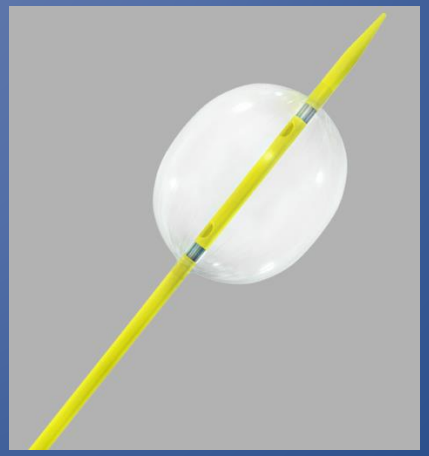
Children's
Healthcare of Atlanta

Aortic Occlusion in Pediatric Trauma

Why does EDT remain prevalent despite poor outcomes in adolescents and children?

Is REBOA feasible and safe in children/adolescents?





Children's Healthcare of Atlanta

Bedside Placement of an Aortic Occlusion Balloon to Control a Ruptured Aorto-Esophageal Fistula in a Small Child

Sarah J. Hill,[1] Abdalla E. Zarroug,[2] Richard R. Ricketts,[1] and Ravi Veeraswamy,[1]
Atlanta, Georgia

- First described in 2010 in an acute care surgical patient by vascular surgeons at Emory with deployment to control a ruptured aortoesophageal fistula in a 10 year old child
- Utilized 7F sheath and 14 mm angioplasty balloon
- Temporized hemorrhage and bridged to endovascular stent placement

Hill et al. Ann Vasc Surg (2010) 24: 822, e7-9

EMORY UNIVERSITY SCHOOL OF MEDICINE

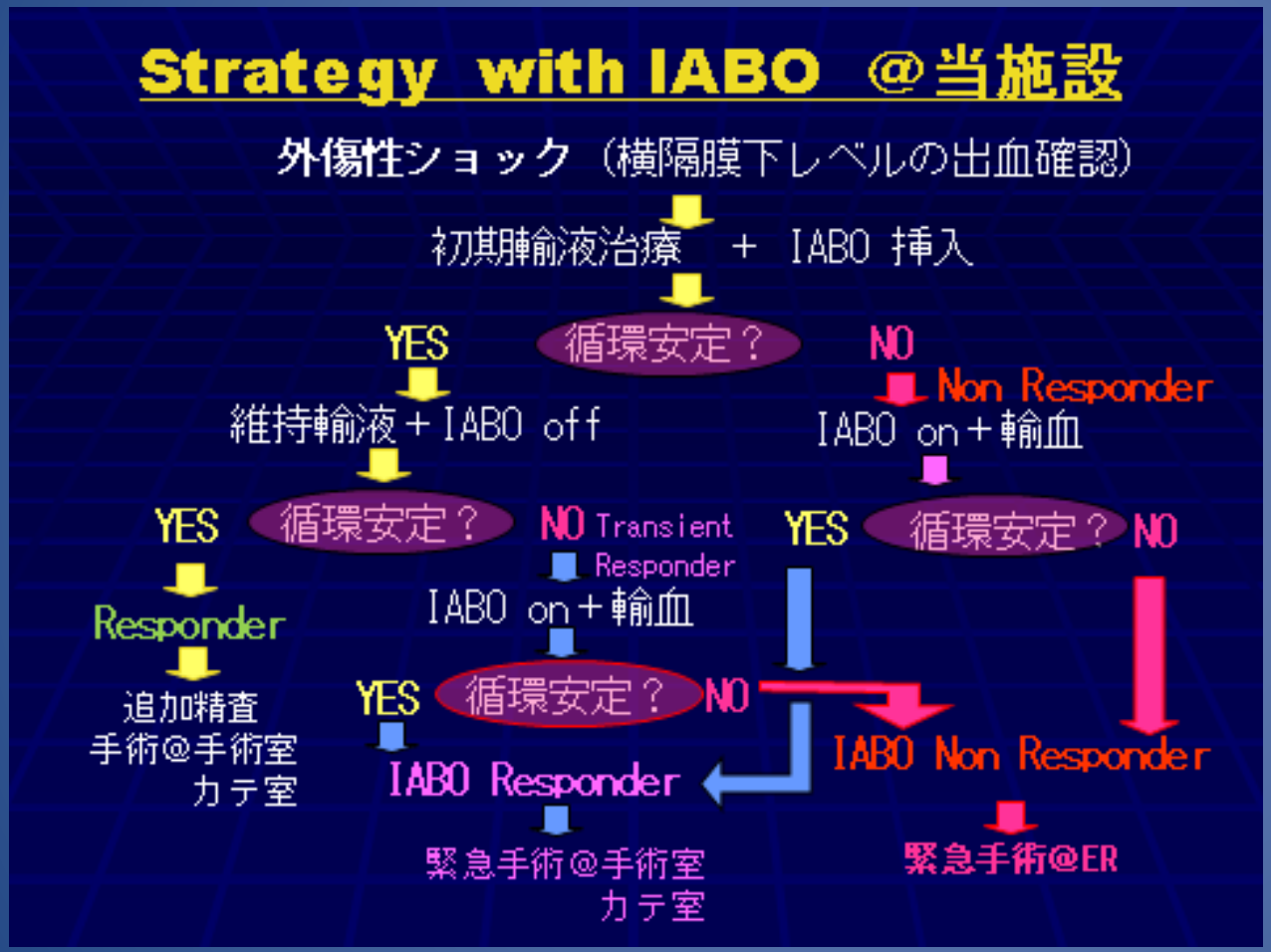
REBOA in Pediatric Trauma

Resuscitative endovascular balloon occlusion of the aorta in trauma patients in youth

- Retrospective review of Japanese Trauma Databank from 2004-2015
- 54 patients treated with REBOA under the age of 18 (0.3% of all trauma patients)
- 25% of those ≤ 15 years old
- Youngest patient 11 years old
- 53% of children and 38% of adolescents survived to discharge
- REBOA-specific details not available
- 97% of REBOA by Japanese ER physicians

Norii et al. *J Trauma Acute Care Surg* (2017) 82:915-920

Pediatric REBOA in Japan



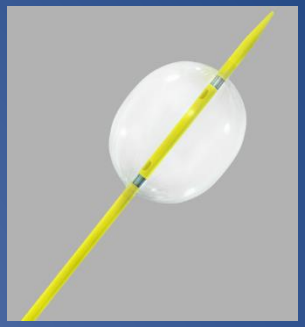
- ER Physicians +/-IR (1/3 of all ER physicians in Japan do IR fellowships)
- REBOA placed early for hemodynamic instability
- Inflated decided on responder/non-responder to MTP
- Sheaths left in place
- Zone 1 regardless of injury pattern

Trauma

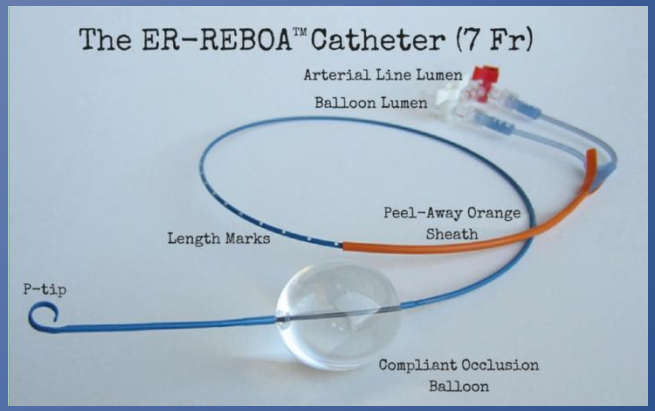
Resuscitative endovascular balloon occlusion of the aorta (REBOA) for temporization of hemorrhage in adolescent trauma patients

Alexis D. Smith [a,*], Jessica Hudson [b], Laura J. Moore [b], Thomas M. Scalea [c], Megan L. Brenner [d]

[a] Children's Healthcare of Atlanta, Department of Pediatric Surgery, 5461 Meridian Mark Rd Suite 570, Atlanta, GA 30342
[b] University of Texas Health Sciences Center at Houston, Department of Surgery, 6550 Fannin Street #583, Houston, TX 77030
[c] R Adams Cowley Shock Trauma Center, Department of Surgery, 22 South Greene Street, Baltimore, MD 21201
[d] University of California Riverside, Department of Surgery, 26520 Cactus Avenue Moreno Valley, CA 92555



- Describe the experience with REBOA in adolescent trauma patients including timing to AO, size of catheters and complications
- Retrospective review of a prospectively managed REBOA database
- Patients included were 18 years of age or younger who received REBOA for AO over a 5 year period at the R. Adams Cowley Shock Trauma Center and Red Duke Texas Trauma Institute.
- During the study period, both institutions transitioned from using a 12 Fr. sheath for the CODA balloon to the newer 7 Fr. sheath for the ER-REBOA



Texas Trauma Institute
MEMORIAL HERMANN

Smith et al. *J Pediatric Surg* (2020) 55: 2732- 2735

R ADAMS COWLEY SHOCK TRAUMA CENTER
UNIVERSITY OF MARYLAND

REBOA in Pediatric Trauma

Table 1
Patient characteristics.

Patient ID	Age	Gender	Mechanism of Injury	ISS	CPR on admission	Admission SBP (mmHg)	Post-AO SBP (mmHg)	Survival during initial resuscitation (survival to OR)	Survival to discharge
A	17	Male	Blunt	36	Yes	0	100	Yes	No
B	16	Male	Blunt	29	Yes	0	0	Yes	No
C	18	Male	Penetrating	34	No	120	180	Yes	Yes
D	18	Female	Blunt	57	Yes	0	100	Yes	No
E	18	Male	Penetrating	29	Yes	0	160	Yes	No
F	18	Male	Penetrating	45	No	73	139	Yes	Yes
G	14	Male	Blunt	48	No	50	105	Yes	No

- 7 adolescent trauma patients with mean age of 17 received REBOA for both blunt (n=4) and penetrating mechanisms (n=3)
- Youngest patient: 14 years old
- Median ISS: 36 (29-57)
- 57% patients were in arrest with ongoing CPR at time of REBOA
- For patients presenting in extremis: mean pre-AO SBP was 61.5 ± 16.3 mmHg and increased to 122 ±24 mmHg following REBOA

Table 2
REBOA-specific details.

Patient ID/survivor (S) or nonsurvivor (NS)	REBOA zone	Sheath Size (French)	Access for sheath placement	Time to AO (min)	Aortic occlusion time (min)	Repositioning of REBOA	Adjunctive procedures following REBOA	Complications from REBOA[a]
A (NS)	3	12F	Cutdown	11	75	No	Pelvic binder, pelvic packing, pelvic embo, pelvic ex-fix, ex-lap, bowel resection	No
B (NS)	1	12F	Cutdown	8	24	No	Thoracotomy, right ventricular cardiac repair, ex-lap, splenectomy, nephrectomy	No
C (S)	1	12F	Cutdown	Unk[a]	15	No	Ex-lap, splenectomy, bowel resection	No
D (NS)	1	7F	Cutdown	5	67	Yes	Thoracotomy, nonanatomic lung resection, REBOA repositioned to zone 3, ex-lap, pelvic packing, pelvic angioembolization, pelvic ex-fix, craniectomy	No
E (NS)	1	7F	Cutdown	26	125	No	Ex-lap, attempted repair of retrohepatic caval injury and liver injury	No
F (S)	1	7F	Percutaneous	9	77	Yes	Repositioned REBOA owing to migration near zone 2, thoracotomy, bronchial repair and lung resection	No
G (NS)	1	7F	Percutaneous	5	53	No	Pelvic bind, pelvic angioembolization, ex-lap, splenectomy, liver packing, craniectomy	No

[a] Unk: REBOA deployed intraoperatively when decompensating during exploratory laparotomy.

- No failed REBOA attempts
- Overall in-hospital mortality was 71% (5/7 patients died)
- All patients survived to the operating room with usage of REBOA
- 1 patient died intraoperatively due to a penetrating injury to the liver and retrohepatic cava
- 4 other patients (all blunt mechanisms of injury) died in postoperatively in the ICU due to sequelae related to severe TBI.
- Concluded that REBOA was feasible for use in adolescents and be an effective bridge to the OR

Endovascular Resuscitation with Aortic Balloon Occlusion in Pediatric Trauma

Mitra Sadeghi MD[1], David T McGreevy MD[1], Rickard Lindgren MD PhD[2], Kjell Ågren MD[2] and Tal M Hörer MD PhD[1]

[1]Department of Cardiothoracic and Vascular Surgery, Faculty of Medicine and Health, Örebro University Hospital and Örebro University, Örebro, Sweden
[2]Department of Surgery, Örebro University Hospital, Örebro, Sweden

- Landmark paper out of Sweden describing the first survivor to discharge for a patient under the age of 14 who presented in cardiac arrest and underwent aortic occlusion for blunt trauma
- 11 year old boy in high speed MVC who lost vital signs during helicopter transport (17 minutes)
- REBOA placed on arrival to trauma bay when confirmed pulseless but with SOL
- Pre-AO SBP: 40 mmHg; Post-AO SBP: 110 mmHg
- Balloon occlusion time: unclear- 7 minutes complete occlusion, partial occlusion for ?
- Injuries included: blunt SBI with massive hemorrhage from a transected ileocolic artery necessitating extensive SBR, traumatic diaphragm injury, BCVI, SDH/SAH, multiple rib fracture, L3 chance fracture, craniocervical dissociation, grade 2 aortic injury

J Endovasc Resusc Trauma Manag (2019) 3:139-142

REBOA is a feasible option for proximal control and temporization of hemorrhage in adolescent trauma patients

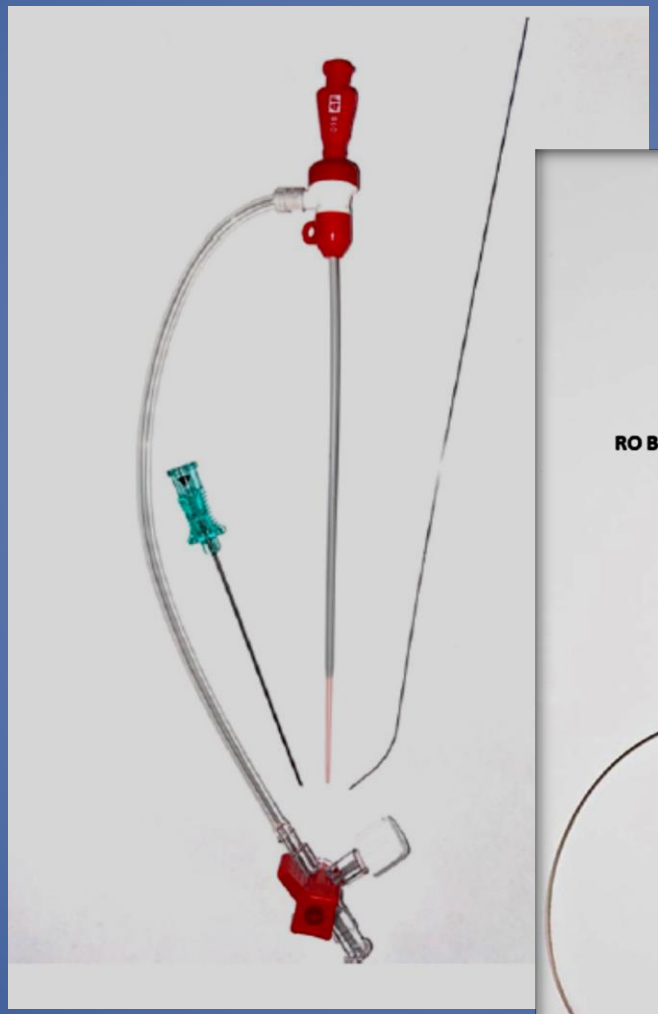
Texas Trauma Institute
MEMORIAL HERMANN

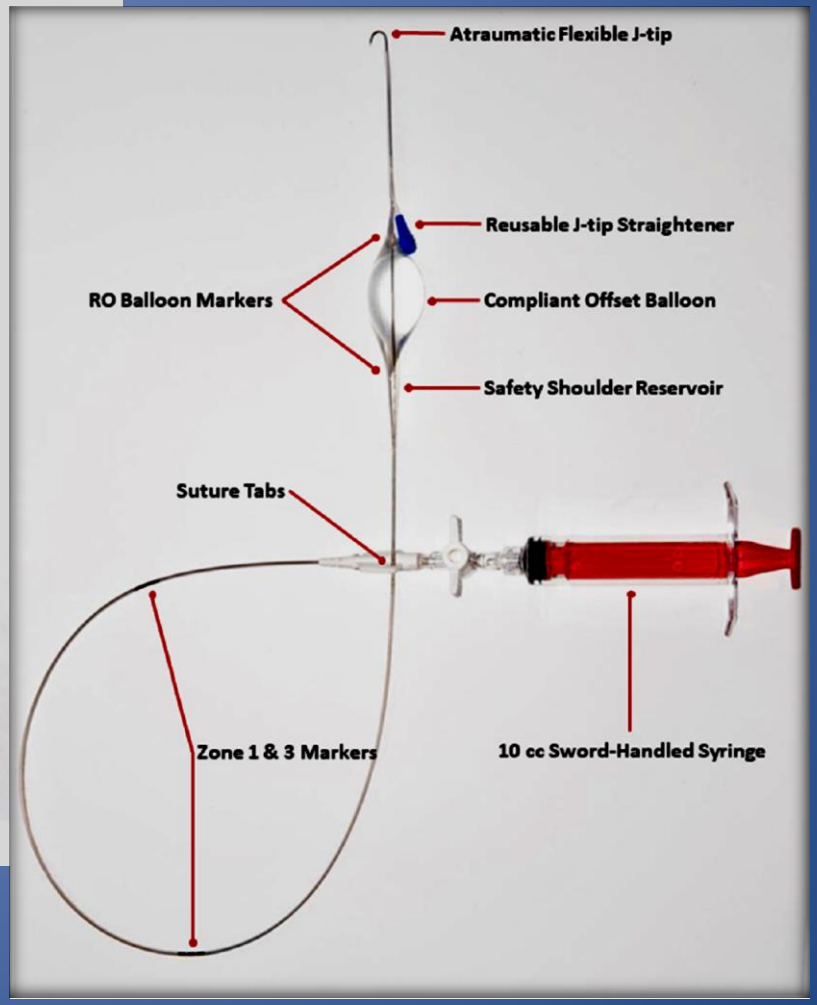
R ADAMS COWLEY
SHOCK TRAUMA CENTER
UNIVERSITY OF MARYLAND

REBOA Innovations in Peds Trauma

COBRA-OS

- 4Fr sheath
- Wire-free
- Compliant

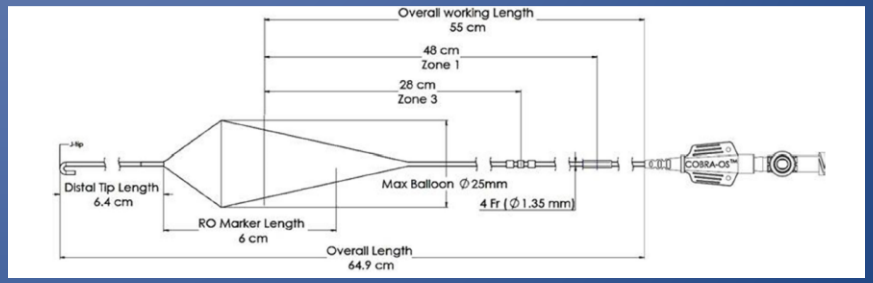




Size matters: first-in-human study of a novel 4 French REBOA device

Adam Power,[1] Asha Parekh,[1] Oonagh Scallan,[1] Shane Smith,[1] Teresa Novick,[1] Neil Parry,[1] Laura Moore[2]

- Feasibiity study for COBRA-OS new 4 French REBOA device in humans immediately prior to organ donation
- Inclusion criteria were brain death organ donors (N=7) over the age of 18
- Single vascular surgeon performed all procedures
  - Bilateral 4 French introducer sheaths placed in CFA and device advanced and deployed in Zone 1
  - Once aortic occlusion confirmed via left Aline, the device was deflated and repositioned at Zone 3
- COBRA-OS was able to occlude the aorta in Zones 1&3 in all patients
- Mean time of Zone 1 deployment: 70.1 seconds
- Mean balloon fill volumes were 15 cc for Zone 1 and 9 cc for Zone 3
- No complications and post-donation of the aorta revealed no injury.



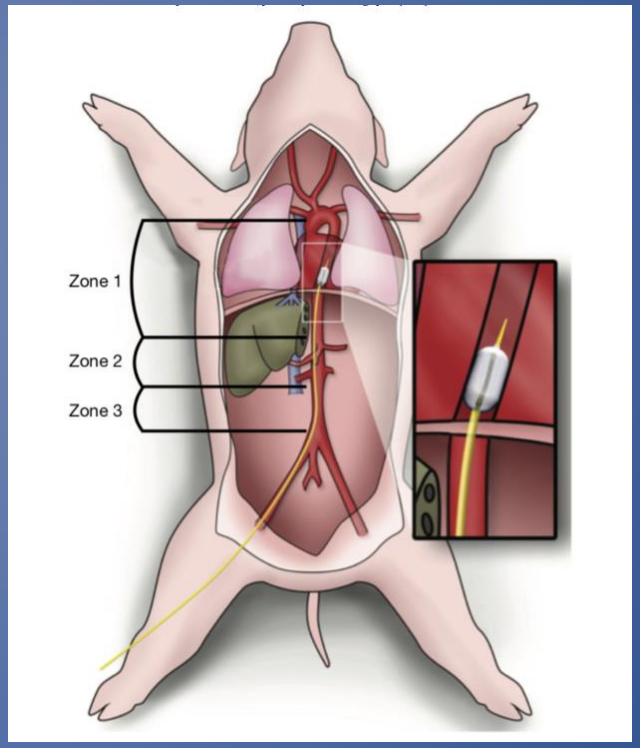
Trauma Surg Acute Care Open (2021) 6: e000617

Resuscitative endovascular balloon occlusion of the aorta (REBOA) in a pediatric swine liver injury model: A pilot study

Kaeli J. Yamashiro [a,b,*,1], Andrew M. Wishy [a,c,1], Carl A. Beyer [a,b], Harris W. Kashtan [a,b], Laura A. Galganski [a], J. Kevin Grayson [b], M. Austin Johnson [b,d], Jacob T. Stephenson [a,b], A. Francois Trappey [a,b]

[a] Department of Surgery, University of California-Davis, Sacramento, CA
[b] Clinical Investigation Facility, David Grant USAF Medical Center, Travis Air Force Base, Fairfield, CA
[c] Department of Vascular Surgery, University of California-Davis, Sacramento, CA
[d] Department of Emergency Medicine, University of California-Davis, Sacramento, CA

- Pediatric swine randomized to zone 1 REBOA (n=6) or no intervention (n=5)
- Underwent partial liver amputation to simulate a grade IV liver injury and free hemorrhage (5 min) followed by REBOA (5.5 Fr Fogarty) or no intervention for 30 minutes
- To simulate a period of transport, they were resuscitated with Plasmalyte during that time
- Damage control laparotomy and critical care for 4 hours



Yamashiro et al. *J Pediatric Surg* (2020) 55:346-352

Resuscitative endovascular balloon occlusion of the aorta (REBOA) in a pediatric swine liver injury model: A pilot study

Kaeli J. Yamashiro [a,b,*,1], Andrew M. Wishy [a,c,1], Carl A. Beyer [a,b], Harris W. Kashtan [a,b], Laura A. Galganski [a], J. Kevin Grayson [b], M. Austin Johnson [b,d], Jacob T. Stephenson [a,b], A. Francois Trappey [a,b]

[a] Department of Surgery, University of California-Davis, Sacramento, CA
[b] Clinical Investigation Facility, David Grant USAF Medical Center, Travis Air Force Base, Fairfield, CA
[c] Department of Vascular Surgery, University of California-Davis, Sacramento, CA
[d] Department of Emergency Medicine, University of California-Davis, Sacramento, CA

- Trend toward survival: all REBOA piglets survived whereas 2 control piglets died
- REBOA piglets had less blood loss and higher end Hct, but signs of end organ injury with higher Cr and liver enzymes than controls
- REBOA piglets required increased vasoactive support following balloon deflation during the critical care portion

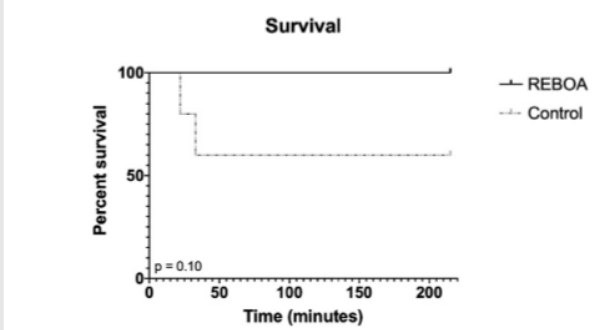


Fig. 3. A Kaplan–Meier curve demonstrating time until death or study completion of the piglets. None of the REBOA piglets died, while 2 of the 5 control piglets died during the intervention phase. There was a trend towards survival with REBOA; however, the difference in survival time was not significant, $p = 0.10$.

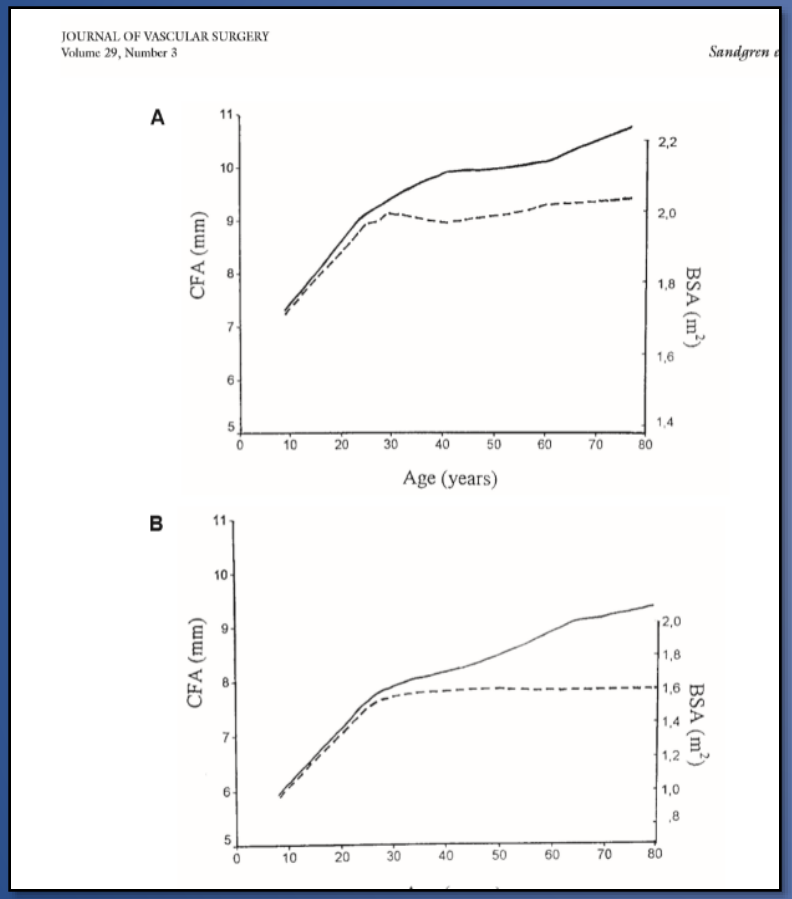
Table 3
Total fluids and vasoactive support needed by the piglets.

Variable	REBOA ($n = 6$)	Control ($n = 5$)	p
Blood Loss (mL/kg)	**34.0 ± 1.6**	**61.3 ± 2.5**	**<0.01**
Norepinephrine Given (mg/kg)	**1.4 ± 0.3**	**0.3 ± 0.3**	**0.04**
Fluids Given (mL/kg)	84.8 ± 12.1	83.4 ± 17.9	0.95
Urine Output (mL/kg)	29.0 ± 7.6	14.2 ± 3.2	0.13

Values are presented as mean and standard error of the mean. REBOA piglets had less overall blood loss but required more norepinephrine during critical care compared to control piglets. There were no differences in fluids given or urine output.

Yamashiro et al. *J Pediatric Surg* (2020) 55:346-352

CFA Diameter in Children and Adolescents

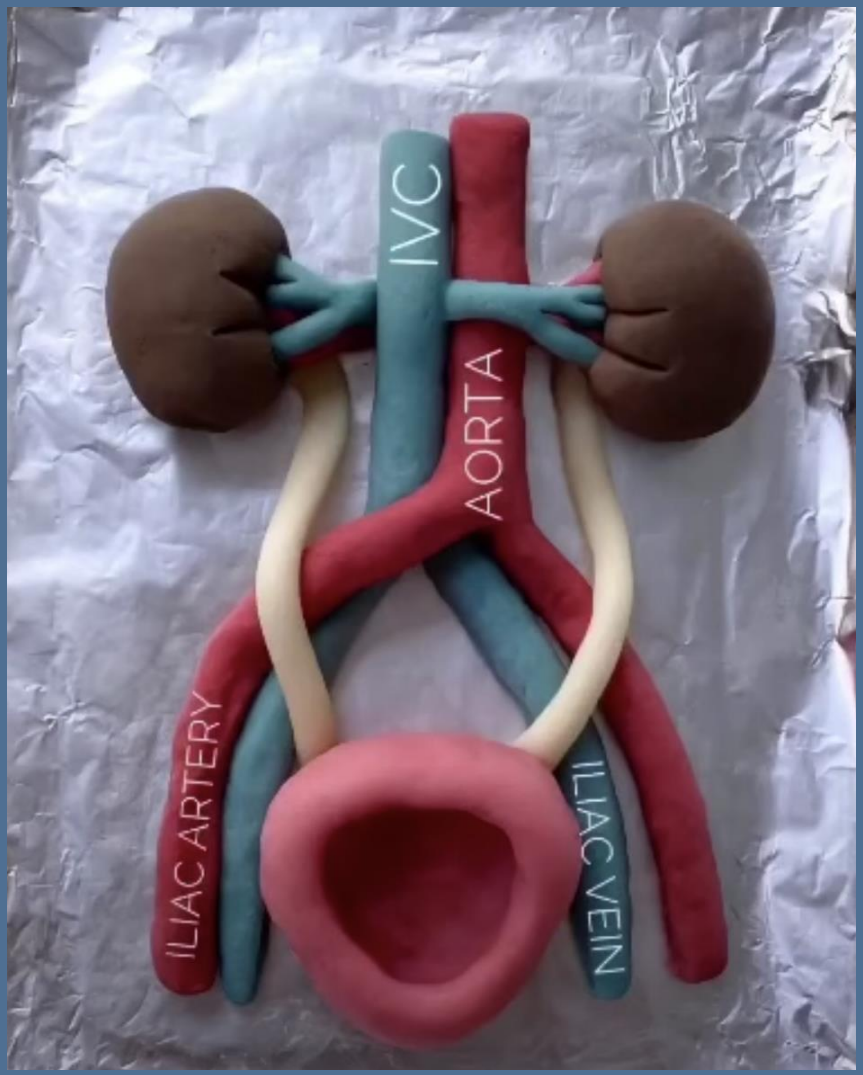


- When is the caliber of the CFA comparable to an adult?
- CFA diameter increases in size with age not only during growth as a child and adolescent, but also significantly during the adult years
- Gender and BSA also play significant roles in the size of the CFA
- Mean size of CFA was 9.8 mm in male subjects and 8.2 mm in female subjects.
- Interpretation of graphs indicate that the CFA reaches mean size during the late adolescent years.

Sandgren et al. *J Vasc Surg (1999) 29: 503-510.*

-
-

Renal Injuries



- Renal injuries are more common in children than in adults
  - Anatomic reasons: less perinephric fat, less abdominal musculature, less ossified thorax
- Injury to the kidney is the most common injury to the GU tract
- 90% of renal injuries are from blunt trauma
- Renal injury occurs in about 10% of all blunt abdominal trauma

https://www.youtube.com/watch?v=CFckvwct4go&ab_channel=TheBreakfasteur

The Journal of Trauma and Acute Care Surgery

Pediatric blunt renal trauma practice management guidelines: Collaboration between the Eastern Association for the Surgery of Trauma and the Pediatric Trauma Society

Judith C. Hagedorn, MD, Nicole Fox, MD, Jonathan S. Ellison, MD, Robert Russell, MD, Cordelie E. Witt, MD, Kristen Zeller, MD, Paula Ferrada, MD, *and* **John M. Draus, Jr, MD**, *Seattle, Washington*

- Published in February 2019. Meta-analysis based on literature review from publications between 1990 and 2016, including 51 articles
- Guidelines for management developed based on PICO methodology (Population, Intervention, Comparator, Outcome).

Pediatric Blunt Renal Trauma Practice Guidelines

1. *Strong recommendation* for nonoperative management of hemodynamically stable pediatric trauma patients with blunt renal trauma of all grades (goal = avoid nephrectomy)
   - Similar ED/hospital management strategy as liver/spleen injuries
2. *Strong recommendation* for IR embolization (vs OR) for hemodynamically stable patient with high-grade injury (AAST grade 3-5) and need for recurrent blood transfusions
   - Even if a main renal artery is embolized, some renal parenchyma can be saved
   - When to operate?
     - Unstable in ED or become unstable in ICU (ie due to excessive bleeding), or Grade V injury with UPJ disruption
3. *Strong recommendation* for routine blood pressure checks in pediatric patients with blunt renal trauma to evaluate for posttraumatic renal hypertension

- Follow up?
  - Need routine BP checks with pediatrician to evaluate for renal hypertension

BROWN
Alpert Medical School

https://journals.lww.com/jtrauma/Abstract/2019/05000/Pediatric_blunt_renal_trauma_practice_management.23.aspx

High-Grade Pancreas Injury

- Overall a RARE injury; even in high-volume centers, maybe see 1-2 per year (Grade III or higher)
- In pediatric patients, pseudocysts, fluid collections, etc., do not lead to long term sequela, and fistulas are extremely rare
- Treatment is *variable*; initiation of TPN/J-tube feeds, MRCP, ERCP with sphincterotomy, drain placement for pseudocysts, multiple ultrasounds/MRCPs, even home with TPN/J-tube feeds are all done across the country
- What does the data suggest we do?

https://www.youtube.com/watch?v=fSexloRdlEk

Pancreas Injury Grading

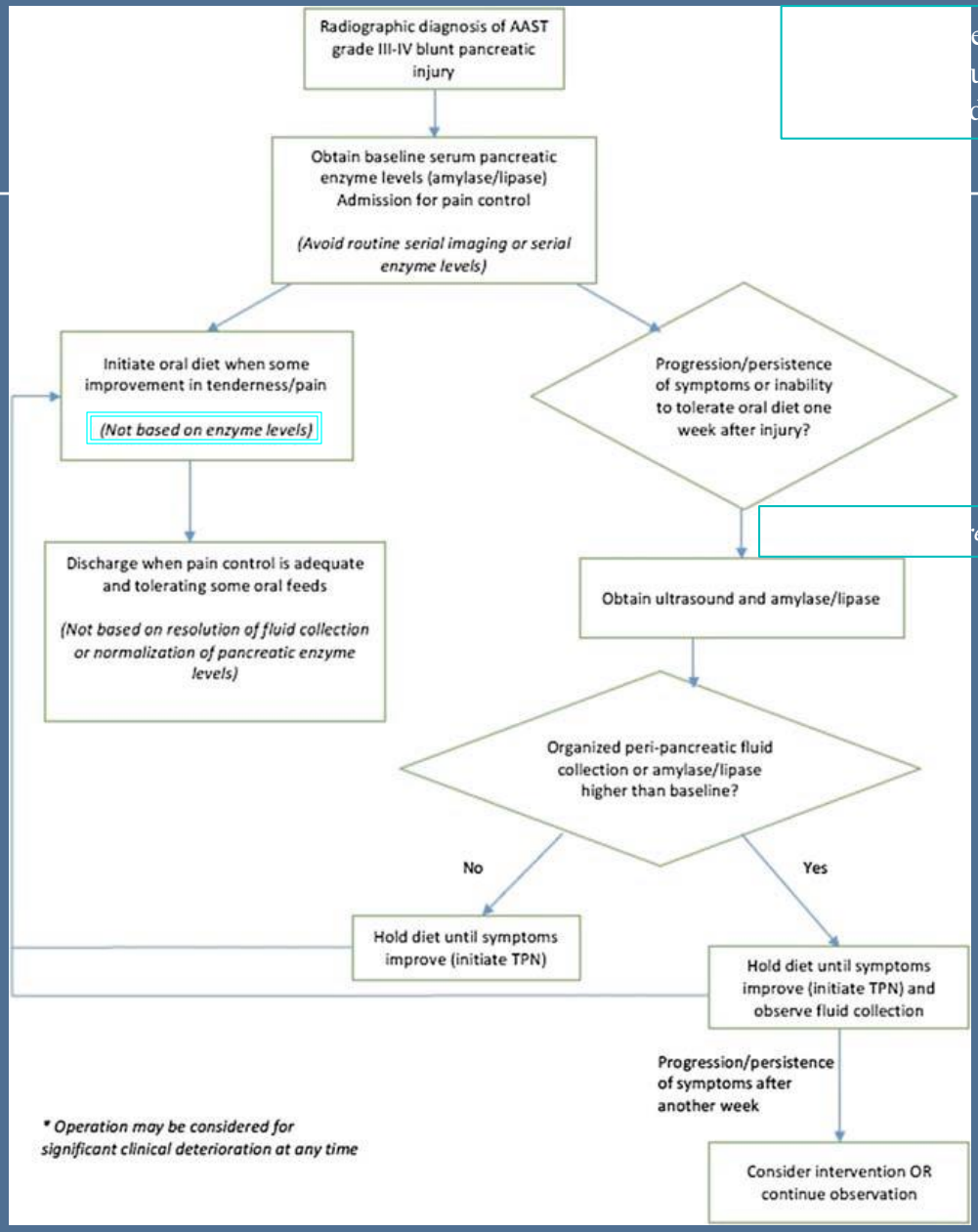
Pancreas Injury Scale

Grade*	Type of Injury	Description of Injury	ICD-9	AIS-90
I	Hematoma	Minor contusion without duct injury	863.81-863.84	2
	Laceration	Superficial laceration without duct injury		2
II	Hematoma	Major contusion without duct injury or tissue loss	863.81-863.84	2
	Laceration	Major laceration without duct injury or tissue loss		3
III	Laceration	Distal transection or parenchymal injury with duct injury	863.92/863.94	3
IV	Laceration	Proximal[?] transection or parenchymal injury involving ampulla	863.91	4
V	Laceration	Massive disruption of pancreatic head	863.91	5

*Advance one grade for multiple injuries up to grade III. *863.51,863.91 - head; 863.99,862.92-body;863.83,863.93-tail. [a]Proximal pancreas is to the patients' right of the superior mesenteric vein.
From Moore et al. [6]: with permission.

eeded to diagnose
ury, decision to scan
dard criteria for BAT

- *Emphasis on NOT obtaining routine enzyme levels*
- *No correlation of enzyme level with injury grade or adverse outcomes*
- *Enzyme levels tend to peak at post-injury day 2, then fall*
- *Symptom-driven management*



eimage

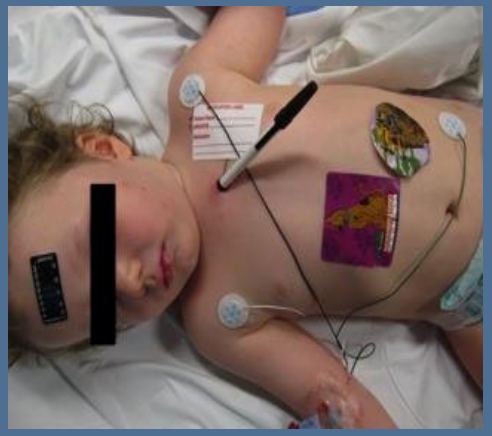
Recommended to observe and treat nonop even if fluid collection is identified

BROWN
Alpert Medical School

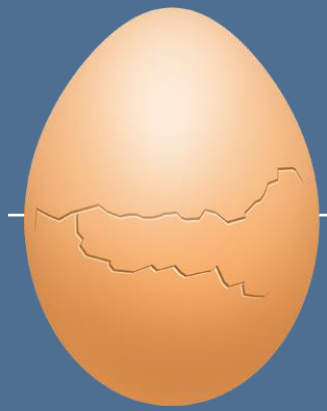
Conclusion: *Majority of patients can be treated nonoperatively*

Pediatric Thoracic Trauma

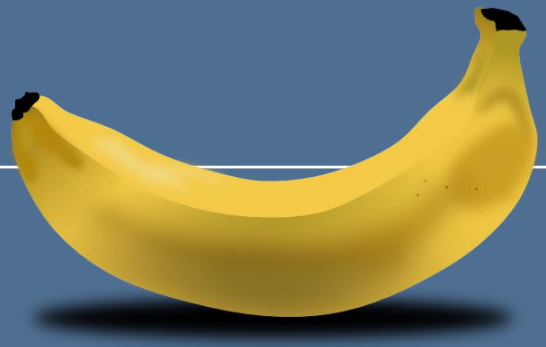
- Thoracic injuries in children are less common than in adult trauma, but carry a disproportionate percentage of morbidity and mortality compared to other traumatic injuries
- 92% of traumatic thoracic injuries due to blunt mechanisms
  - MVC
  - Pedestrian struck
  - Bicycle accidents
  - Falls
  - Non-accidental trauma
- <10% due to penetrating chest injury
  - Incidence increasing over past decade due to rising gun violence



Children's Healthcare of Atlanta



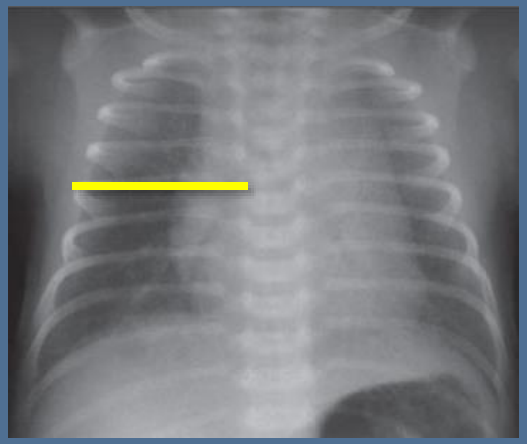
VS



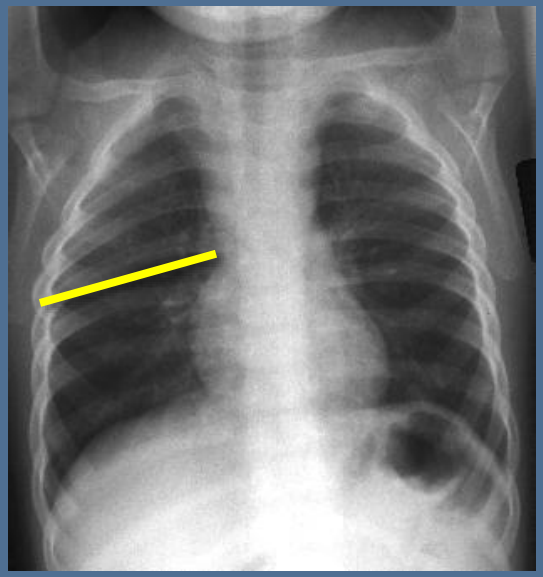
- Adult/Adolescent
  - Chest wall protective
  - Energy absorbed → rib fractures
  - Lower risk of organ injury
  - Sternum fully ossified
  - Shields
- Children
  - Chest wall (ribs, sternum) NOT protective
  - Ribs BEND and transmit energy
  - HIGHER risk of organ injury (lungs, heart, diaphragm)
  - Can have injuries with minimal bruising

Children's Healthcare of Atlanta

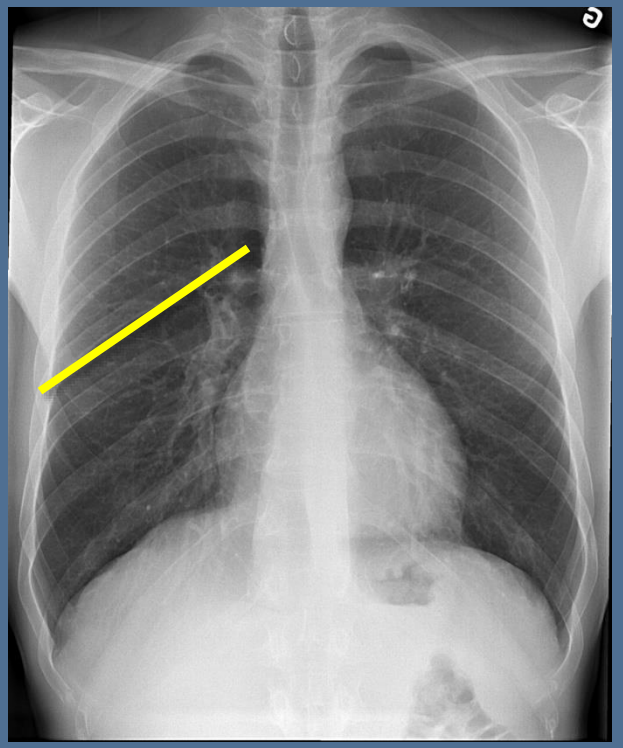
Rib Orientation Neonate to Adult



1 day old infant



6 year old



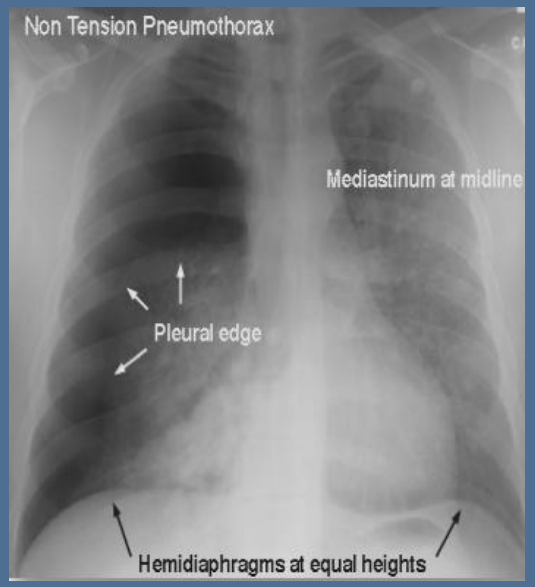
18 year old

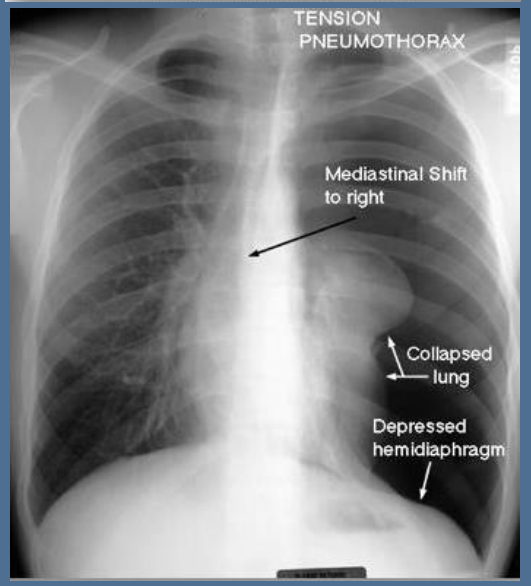
Children's Healthcare of Atlanta

Kent R, Ch 13. Experimental Injury Biomechanics of Pediatric Thorax and Abdomen. In Crandall JR. Pediatric Injury Biomechanics: Archive and Textbook. 2013. Springer Science, New York

Traumatic Pneumothorax (PTX)

- 2nd most common thoracic injury in children
  - 1/3 of children that sustain a thoracic injury will develop a PTX
  - 2/3 of PTX associated with additional intra- and extra- thoracic injuries
- 25% of children with a PTX display tension physiology due to increased mobility of the pediatric mediastinum
- Decreased incidence of tension PTX with age as mediastinum becomes fixed later in life



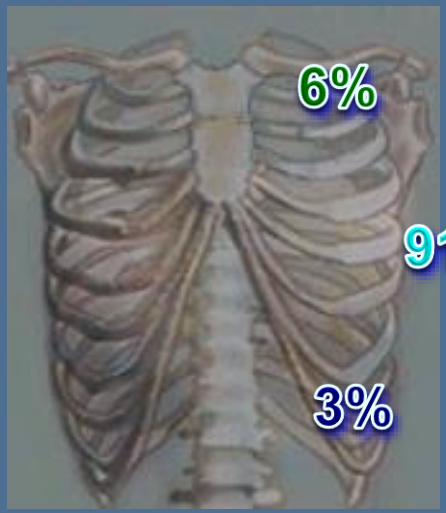


Children's Healthcare of Atlanta

Rib Fractures and Thoracic Trauma

- Fractures in children are a marker of injury severity
- National Pediatric Trauma Registry
  - Rib fractures found in 1% of traumatically injured children
  - Rib fractures had a 20-40% associated mortality rate compared to injured children without fractures (2%)
  - Represent a sign that a significant mechanical force delivered and therefore a sign of severe internal injuries
- Chest wall fractures often associated with other thoracoabdominal injuries in children
- Rib fracture associated morbidity and mortality
  - Incidence of associated head, thoracic, and abdominal solid organ injuries in children with rib fractures is significantly higher than in adults
  - Rib fracture + head injury = 70% mortality

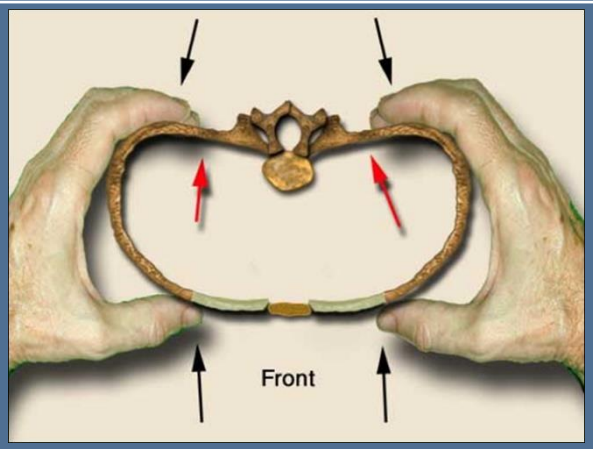
LOCATION is related to mechanism



Children's Healthcare of Atlanta

Garcia VF, et al. Rib fractures in children: a marker of severe trauma. J Trauma Inj Infect Crit Care (1990) 30:695–700

Rib Fractures from Abuse



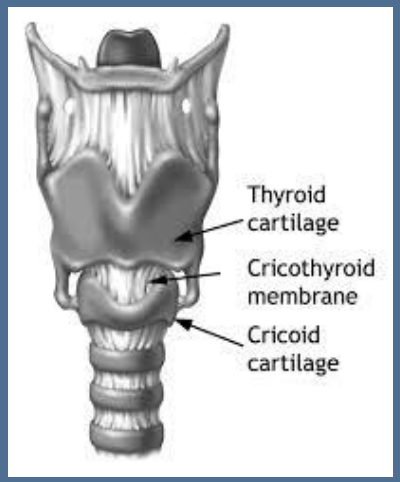
- Non Accidental Trauma (NAT) pattern of injury
  - Direct grasping
  - Multiple POSTERIOR/ANTERIOR fractures
  - Often find in multiple stages of healing
- A child with rib fractures has a 7 in 10 chance of having been abused
- Majority of rib fractures under the age of 3 due to NAT

Children's Healthcare of Atlanta

6. Kemp AM et al. Patterns of skeletal fractures in child abuse: systematic review. BMJ 2008; 337

Emergency cricothyroidotomy contraindicated below the age of 10

- Surgical airway indicated when endotracheal intubation unsuccessful
- Cricothyroidotomy preferred in adolescents and preteens over the age of 10 years
- In younger children, larynx pliable and mobile with a small cricothyroid membrane→ technically difficult to perform a cric without serious injury to the larynx
- Needle cricothyroidostomy in younger children
- Definitive tracheostomy indicated in both age groups



Children's Healthcare of Atlanta