Head, shoulders, knees, and toes: How pediatric anatomy affects injuries

Julie Mansfield, PhD
Research Assistant Professor
The Ohio State University

INJURY BIOMECHANICS RESEARCH CENTER
THE OHIO STATE UNIVERSITY

1

Key idea

Children are not small adults!

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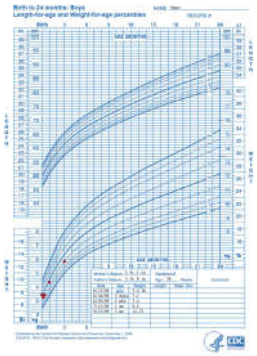
Key idea

- Children grow and change very quickly!



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Overview

Main body regions for today's discussion:

- Head and brain
- Cervical spine (neck)
- Lower extremities (legs)

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Overview

Important factors for protecting children in crashes:

- Physical geometry/proportions
- Bone and tissue strength
- Developmental rate
- Injury outcomes

- **How can CPSTs use/share this knowledge at seat checks?**

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Topic 1: Head and Brain

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Image: shutterstock

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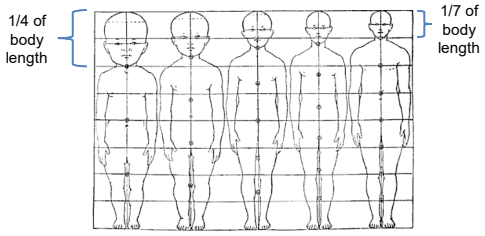
Head: Geometry



A child's head is proportionally larger than an adult's, in terms of both size and mass.

7

Image: marxists.architexturez.net

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Brain: Tissue strength

- **Children's brains change with age**
- Myelin: Phospholipid (fat) layer which surrounds the axons of neurons
- Lipids in myelin deform easily

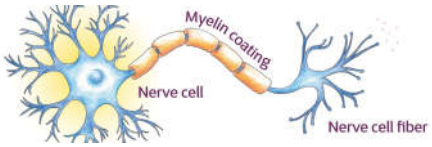

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Image: mssociety.org.uk

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Brain: Tissue strength

- **Children's brains change with age**
- Myelin:

Birth: 34% of adult levels → 5 years: Nearly equal to adult levels

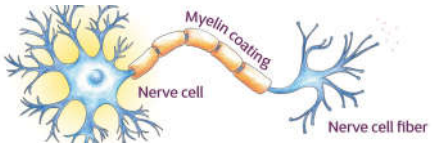

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Image: mssociety.org.uk

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Brain: Tissue strength

- **Children's brains change with age**
- Water:

Birth:
Brain is 88% water

→

Adult:
Brain is 78% water

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Image: prominent.com

10

Brain: Tissue strength

- Data suggest that children's brains are stiffer than adults' brains when exposed to large forces (i.e., crash forces)

11
Prange and Margulies, 2002. Image: freecoast.org

11

Brain: Developmental rate

- To further complicate things:
  - Age-related changes are not linear, but happen rapidly during the first few years of life and more gradually throughout early childhood.

12
Margulies and Coats, 2013. Image: medium.com

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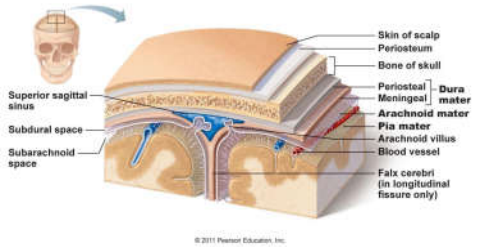
Brain: Regions

- To further complicate things:
  - Brain response to impacts can vary by region

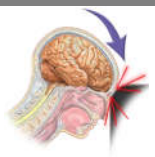


13
Margulies and Coats, 2013. Image: Wyoming Spine and Neurosurgery

13

Brain: Injury outcomes

- Severe TBI:
  - Younger children (3-7 years old) had minimal, if any, recovery of cognitive performance.
  - Older children (8-12 years old) had better recovery outcomes.
- Moderate TBI:
  - Infants showed poorer outcomes compared to older children.
- Mild TBI:
  - Cognitive recovery not well predicted by age.
- The trend reverses for adults: Older adults have worse recovery outcomes.



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Margulies and Coats, 2013. Image: medlineplus.gov

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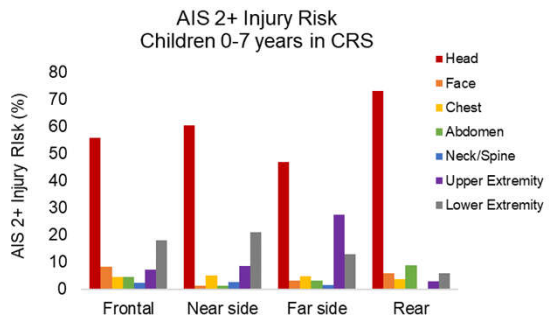
Head injuries in crashes



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Arbogast and Durbin, 2013

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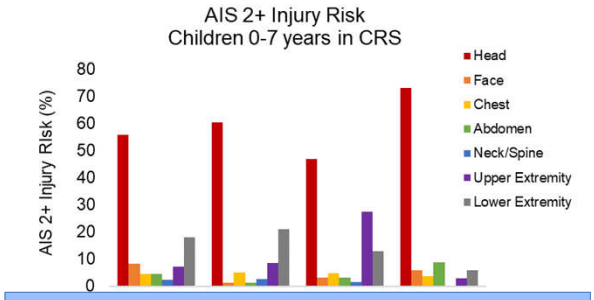
Head injuries in crashes



Goal: Prevent head injuries by preventing head contact

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Head injuries: Tips for CPSTs

- **CPST Tips for Rear-Facing CRS:**
  - Tight, proper installation
  - Proper space between back of CRS and front row seat (manufacturer's recommendations)
  - Appropriate weight and height of child

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Head injuries: Tips for CPSTs

- **CPST Tips for Rear-Facing CRS:**
  - Tight, proper installation
  - Proper space between back of CRS and front row seat (manufacturer's recommendations)
  - Appropriate weight and height of child
    - Ensure that the child's head is at least 1 inch below the top of the RF CRS "shell" (or follow manufacturer's guidelines, if different guidelines are given).

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Head injuries: Tips for CPSTs

12 month old dummy

Less space above head: Head contact

More space above head: No head contact

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Head injuries: Tips for CPSTs

12 month old dummy

Less space above head: Head contact

More space above head: No head contact

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Head injuries: Tips for CPSTs

- **CPST Tips for Forward-Facing CRS:**
  - Tight, proper installation
  - Tight harness with chest clip in proper position
  - Encourage top tether use!
    - Reduces head excursion by 4-6 inches

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Head injuries: Tips for CPSTs

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Image: Buckle Up with Brutus

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Topic 2: Cervical Spine

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Image: shutterstock

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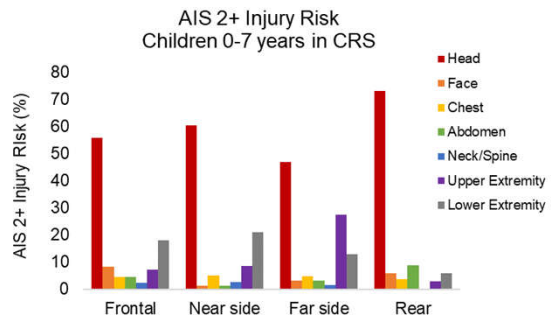
Spine injuries in crashes



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Arbogast and Durbin, 2013

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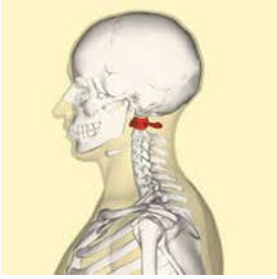
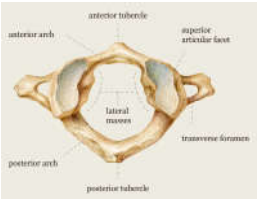
Cervical Spine: Geometry & Development

Atlas (C1 vertebra)





Adult

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Image: Wikipedia.org

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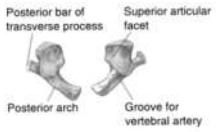
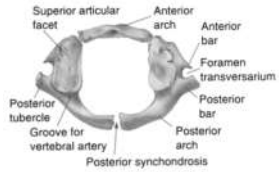
Cervical Spine: Geometry & Development

Atlas (C1 vertebra)



Newborn

Two lateral bony regions connected by cartilaginous regions



~3 years old

Third ossification region develops in anterior portion

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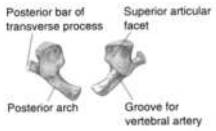
Scheuer and Black 2004; Nightingale and Luck, 2013

26

Cervical Spine: Geometry & Development

Atlas (C1 vertebra)



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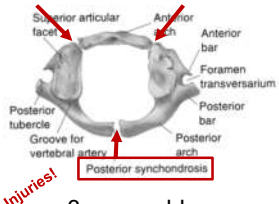

~3 years old

Third ossification region develops in anterior portion

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Scheuer and Black 2004; Nightingale and Luck, 2013

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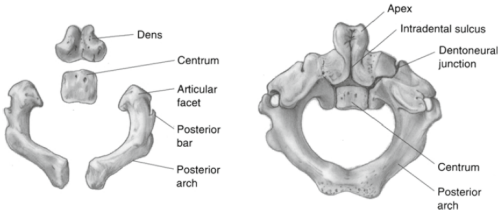
Cervical Spine: Geometry & Development

Axis (C2 vertebra)



Newborn ~3 years old

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Scheuer and Black 2004; Nightingale and Luck, 2013

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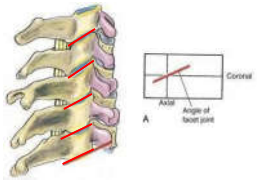
Cervical Spine: Geometry & Development

- Facet angles



Adult:
- Facet angles are **deeper** and **diagonal**

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Image: Psico-Motricidade

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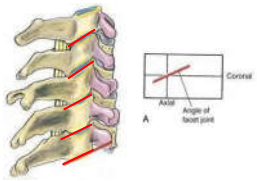
Cervical Spine: Geometry & Development

- Facet angles



Adult:
- Facet angles are **deeper** and **diagonal**

Pediatric:
- Facet angles are **shallow** and **horizontal**

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Kim et al. 2008; Image: Psico-Motricidade

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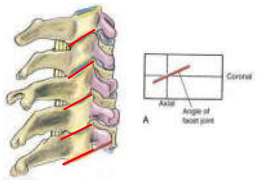
Cervical Spine: Geometry & Development

- Facet angles



Adult:
- Ligaments connecting vertebrae are **stiffer** and **less yielding**

Pediatric:
- Ligaments connecting vertebrae are **dynamic** and **yielding**

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Kim et al. 2008; Image: Psico-Motricidade

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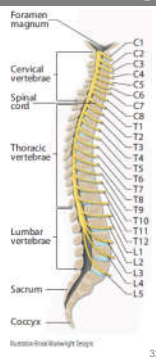
Cervical Spine: Tissue Strength

- Child's vertebral column can stretch up to 2 inches without skeletal or ligamentous injury.
- Spinal cord (inside the column) can stretch only 0.25 inches without injury.



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Leventhal 1960; Image: Brook Wainwright Designs

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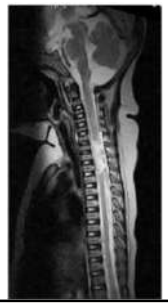
Cervical Spine: Tissue strength

Result: Spinal cord injury without radiological abnormality (SCIWORA) in surrounding bony and ligamentous structures.



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Images: Basu 2012

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Cervical Spine: Injuries in crashes

- **Non-contact neck injuries**
  - Called 'inertial' neck injuries

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Cervical Spine: Injuries in crashes

- **Non-contact neck injuries**
  - Called 'inertial' neck injuries
  - **This type of neck injury is rare**, but some have been reported.
  - Risk is higher in children than adults due to:
    - Large heads
    - Undeveloped spine
    - Flexible neck ligaments

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Cervical Spine: Injuries in crashes

- Spine injury due to <u>head contact</u> is the more common cause.
  - Neck stretches during deceleration (i.e., neck is in tension), which makes it more vulnerable to injury
  - <u>Contact</u> against seat back or side door can cause vertebral fractures, dislocations, spinal cord injuries

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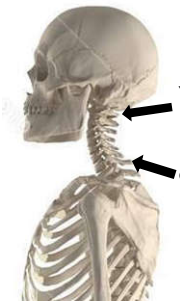
Cervical Spine: Injury outcomes



Younger children tend to have more **upper** cervical spine fractures
-Higher risk of fatality
-Especially atlanto-occipital dislocations

Older children and adults tend to have more **lower** cervical spine fractures
-Still serious but not as deadly

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Nightingale and Luck, 2013

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Cervical Spine: Tips for CPSTs

- **CPST Tips for preventing neck injuries:**
  - Encourage rear-facing for as long as possible!

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Cervical Spine: Tips for CPSTs

- **CPST Tips for preventing neck injuries:**
  - Encourage rear-facing for as long as possible!

Rear-facing CRS reduce neck forces!

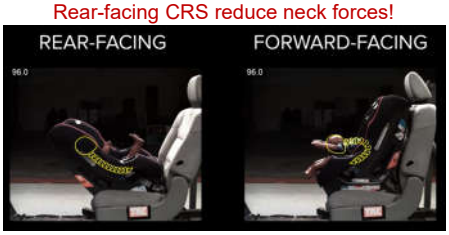

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Image: Buckle Up with Brutus

39

Cervical Spine: Tips for CPSTs

- **CPST Tips for preventing neck injuries:**
  - Encourage rear-facing for as long as possible!
  - Encourage top tether attachment
    - Prevents head contact

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Cervical Spine: Tips for CPSTs

- **CPST T** **es:**
  - Enco
    poss
  - Enco
    - Pre

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Image: Buckle Up with Brutus

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Topic 3: Lower Extremities

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Image: dreamstime.com

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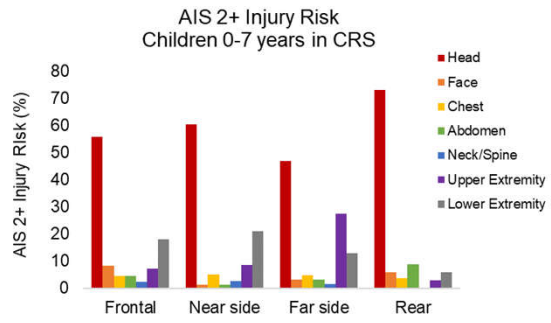
Lower extremity injuries in crashes



43
Arbogast and Durbin, 2013

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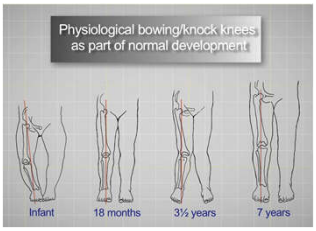
Legs: Geometry and Development

- Rapid growth rate in infancy, plateau in early childhood, rapid acceleration in adolescence.
- Limb segments grow at different rates.
- Knee caps are cartilage until becoming fully ossified (i.e., turned to bone) around 3-5 years old.



44
Whitaker and Vuillermin 2016; Image: pmmonline.org

44

Legs: Tissue strength

- **Growth plates**
  - "Epiphyseal plates" or "physes"
  - Areas of cartilage
    - Weaker than the surrounding bone, ligaments, and tendons
  - Last portion of the child's bone to ossify (harden) around age 15

45
Source: Mayoclinic.org

45

Legs: Injury outcomes

- **Growth plates**
  - Most growth plate injuries heal with no complications.
  - Some growth plate fractures can increase the risk of crooked, accelerated, or stunted bone growth.
    - Severity of injury
    - Age of the child
    - Location of the injury
      - Knees are most sensitive

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Source: Mayoclinic.org

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Legs: Injuries in crashes

Which is safer for the legs:
Rear-facing or Forward-facing?

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Legs: Injuries in crashes

Which is safer for the legs:
Rear-facing or Forward-facing?

Caregivers are often concerned about the legs in rear-facing mode.

"They're bent!"
"They're squished!"
"They're touching the seat back!"
"Is this dangerous?"

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Image: Consumer Reports

48

Legs: Injuries in crashes

Which is safer for the legs:
Rear-facing or Forward-facing?

Caregivers are often concerned about the legs in rear-facing mode.

Response:
We don't have much data...

... The data that we DO have shows risk of leg injuries in FORWARD-facing mode, too.

49
McMurry et al. 2017

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Legs: Injuries in crashes

Which is safer for the legs:
Rear-facing or Forward-facing?

Caregivers are often concerned about the legs in rear-facing mode.

Response:
We don't have much data...

... The data that we DO have shows risk of leg injuries in FORWARD-facing mode, too.

Rate of Lower Extremity Injury

Age	Rear Facing	Forward Facing
0-11 months	0.1%	0.3%
12-23 months	0.1%	0.3%

50
McMurry et al. 2017

50

Legs: Injuries in crashes

- In forward-facing CRS:
  - Usually due to interaction with the back of the front row seat
  - Injuries most often occur below the knee

51
Arbogast and Durbin, 2013. Image: Buckle Up with Brutus

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Legs: Injuries in crashes

- In forward-facing CRS:
  - Usually due to interaction with the back of the front row seat
  - Injuries most often occur below the knee

Crash Analysis of Lower Extremity Injuries in Children Restrained in Forward-facing Car

Lower Extremity Injuries in Children Seated in Forward Facing Child Restraint Systems

Jessica S. Jermakian, Caitlin M. Locey, Lexie J. Ha

INJURIES TO CHILDREN IN FORWARD FACING CHILD RESTRAINTS

Kristy B. Arbogast*, Rebecca A. Cornejo+, Michael J. Kallan+, Flaura K. Winston*, Dennis R. Durbin*+
*The Department of Pediatrics
The Children's Hospital of Philadelphia
+The Center for Clinical Epidemiology and Biostatistics
The University of Pennsylvania School of Medicine
Philadelphia, Pennsylvania

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Legs: Tips for CPSTs

- Encourage RF for as long as possible!
- Ensure tight installation of FF CRS
  - Keeps child (and legs) away from front row seat back

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Applications

- Pediatric Anthropomorphic Test Devices (ATDs)


CRABI 12mo


Hybrid III 3yo


Hybrid III 6yo


Hybrid III 10yo

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Images: Humanetics

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Applications

- Pediatric Anthropomorphic Test Devices (ATDs)

TABLE C5. Failure Stress, Anthropometry, Scale Factors and Relationships for N_{ij} Intercepts for OOP and In-Position Testing.

Size & Age	Failure Stress		Neck Circum.				N_{ij} Intercepts for OOP				N_{ij} Intercepts for In-Position			
	σ N/mm^2	λ_σ	C mm	λ_C	λ_F [1]	λ_M [2]	F_T (N)	F_C[3] (N)	M_E (Nm)	M_F[4] (Nm)	F_T[5] (N)	F_C[6] (N)	M_E[5] (Nm)	M_F[6] (Nm)
6 Mo	36.8	0.79	221	0.906	0.648	0.588	1380	1380	15.8	39.5	1510	1380	17.3	39.5
12 Mo	38.2	0.82	224	0.918	0.691	0.634	1470	1470	17.0	42.5	1610	1470	18.6	42.5
18 Mo	41.0	0.88	226	0.926	0.755	0.699	1610	1610	18.7	46.8	1760	1610	20.4	46.8
3 Yr	46.6	1.00	244	1.000	1.000	1.000	2130	2130	26.8	67.0	2330	2130	29.3	67.0
6 Yr	52.6	1.13	264	1.082	1.323	1.431	2820	2820	38.4	96.0	3080	2820	42.0	96.0
10Yr	53.8	1.15	287	1.176	1.590	1.870	3390	3390	50.1	125	3710	3390	54.8	125
S. Fem	54.9	1.18	304	1.246	1.832	2.283	3900	3900	61.2	153	4260	3900	66.9	153
M. Male	54.9	1.18	383	1.570	2.909	4.566	6200	6200	122	305	6780	6200	133	305
L. Male	54.9	1.18	421	1.725	3.511	6.057	7480	7480	162	405	8180	7480	177	405

Notes:
1. $\lambda_F = \lambda_\sigma \lambda_C^2$
2. $\lambda_M = \lambda_\sigma \lambda_C^3$
3. $F_C = F_T$
4. $M_F = 2.5\ M_E$
5. For OOP tension and extension, $N_{TE} = 1.093$ for 5 percent risk, Figure B6. Thus, for in-position, the 5 percent risk curve passing through $N_{TE} = 1$ has intercepts of $F_T = 1.093\ F_E$ and $M_E = 1.093\ M_E$, where F_E and M_E are the F_T and M_E intercepts for the OOP risk curve.
6. For compression and flexion, the in-position intercepts are the same as the OOP intercepts.

Mertz et al. 2016

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Applications

- Pediatric Anthropomorphic Test Devices (ATDs)

CRABI 12mo | Hybrid III 3yo | Hybrid III 6yo | Hybrid III 10yo

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Images: Humanetics

56

Applications

- Pediatric Anthropomorphic Test Devices (ATDs)

Q-Series: Q0, Q1, Q1.5, Q3, Q3s, Q6, Q10

Side impact!

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Images: Humanetics

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Summary

- Children are not small adults!
  - They grow and change rapidly in terms of geometry, proportions, and tissue strength.
  - These factors all affect crash outcomes.
  - Scientists and researchers are still learning more about children to help them design better tools and CRS.

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Conclusions:
Strange Planet by Nathan Pyle

Contact me: Julie.Mansfield@osumc.edu

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Head, shoulders, knees, and toes: How pediatric anatomy affects injuries

Julie Mansfield, PhD
Research Assistant Professor
The Ohio State University

INJURY BIOMECHANICS RESEARCH CENTER

THE OHIO STATE UNIVERSITY

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