

European Course on  
Pediatric Neuroradiology in  
Latin America (ECPNR-LATAM)

3<sup>rd</sup> Cycle - Module 1

# Trauma raquimedular Pediatric Spinal Trauma

Idealização:



Organização:



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Idealização:



Organização:



# Pediatric Spinal Trauma

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There is no conflict of interest in this presentation

# Learning Objectives

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- ✓ **Recognize** the anatomic and biomechanical features that make the pediatric spine unique.
- ✓ **Understand** the epidemiology and mechanisms of pediatric spinal trauma across age groups.
- ✓ **Identify** the main types of injuries, including SCIWORA.
- ✓ **Awareness** of pitfalls and normal variants.

# Pediatric Spinal Trauma

## Introduction and Context

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- **Low incidence, high severity:**
  - Represents ~1–2% of pediatric trauma cases.
  - Mortality and morbidity rates are **higher than in adults.**
- **Etiology of cervical spine trauma:**
  - **young children** (<8y): pedestrian-automobile accidents and falls.
  - **Older children:** motor vehicle accidents (MVA) or sports injuries.
- **Clinical and radiologic relevance**
  - In children, the **cervical spine is disproportionately involved**, accounting for ~60–80% of all pediatric spinal injuries.
  - Radiologists are key in **early recognition and accurate differentiation between normal variants and true injuries.**

# Pediatric Spinal Trauma

## Imaging decision rules

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### NEXUS

(all must be absent for low-risk)

- Midline cervical tenderness
- Focal neurological deficit
- Normal alertness
- No intoxication
- No painful distracting injury

- **Design:** Multicenter, prospective observational study; clinical exam recorded before imaging
- **N:** 3,065 children (0–17 years) - blunt trauma.
- **Low-risk:** NPV 100%.
- **Potential:** to reduce ~20% while maintaining safety.
- **Not powered to make definitive statements (9y).**
- **Imaging choices (RX vs CT/MRI) were at clinician discretion.**

Viccellio P, et al. N Engl J Med. 2000;343:94–99.

### PECARN

#### Pediatric C-Spine Rule

- **High-risk (CT recommended):**  
GCS 3–8 or unresponsive  
Abnormal airway/breathing/circulation  
Focal neurological deficit
- **Intermediate-risk (X-ray first):**  
GCS 9–14 or AVPU=V/P  
(Alert; Verbal; Pain; Unresponsive)  
neck pain or midline tenderness  
substantial head or torso injury
- **Low-risk (no imaging):**  
none of the above  
clinical clearance

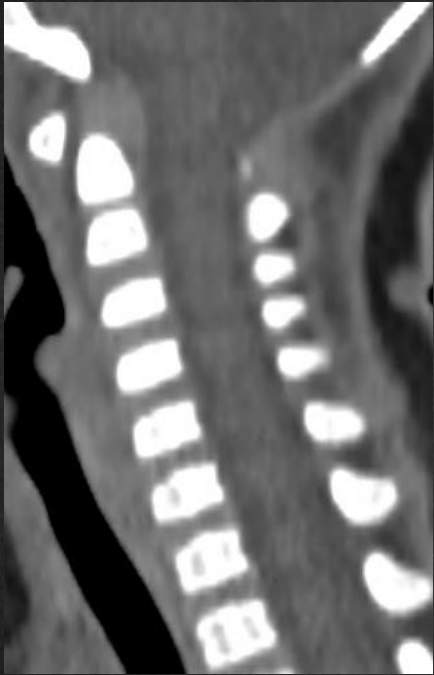
- **Design:** Multicenter, prospective observational study.
- **N:** 22,430 children (0–17 years) - blunt trauma.
- **Performance:** Sens >92%, Spec 60.4%, NPV 99.9%.
- **Potential** to reduce >50% of CT use.

Leonard JC, et al. Lancet Child Adolesc Health. 2024;8(7):482–490.

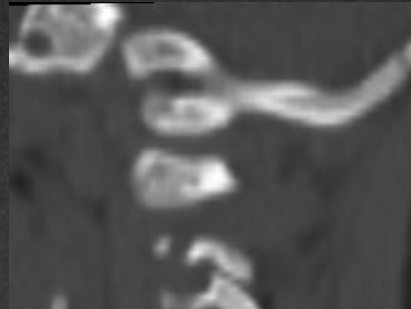
# Unique Features of Pediatric Cervical Spine

## Biomechanical Differences

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More cartilaginous spine and lax ligaments  
→ greater **mobility** and **deformability**.



Shallow occipital condyles, horizontal facet joints,  
weak neck muscles → higher **vulnerability**.



Incomplete ossification and synchondroses →  
mimic fractures, but also **weaker support**.

Large head-to-body ratio → **higher torque** at the **craniocervical junction**.

# Unique Features of Pediatric Cervical Spine

## Biomechanical Differences

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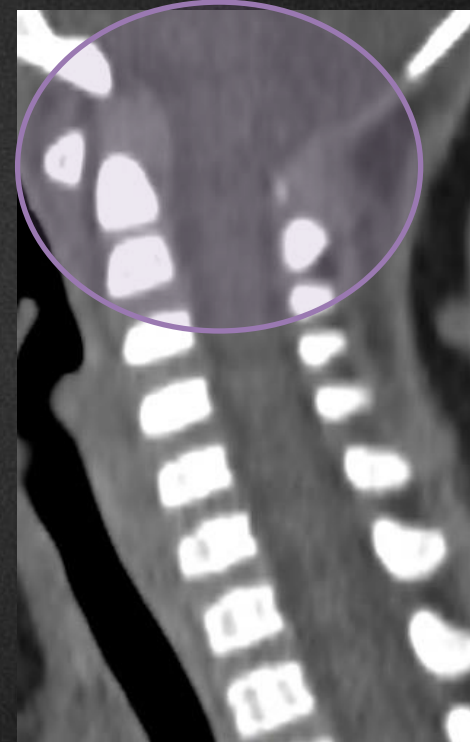
- **Age-Related Variations:**

- **<8 years:** Injuries mostly in **C1-C3** (large head-to-torso ratio).
- **>10 years:** Injuries shift to **lower cervical spine (C5-C6)** and cervicothoracic junction.

- **Injuries (<8 years):**

- Dislocations, ligamentous injuries, and epiphyseal detachments > fractures.

< 8 years



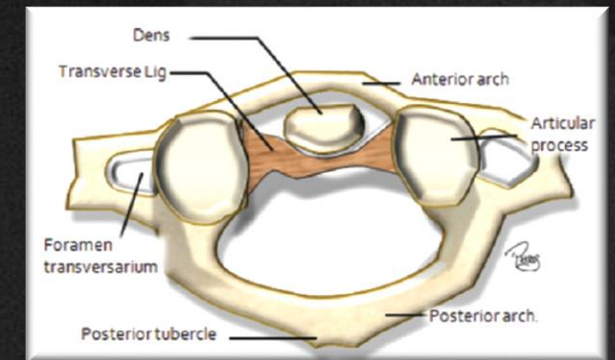
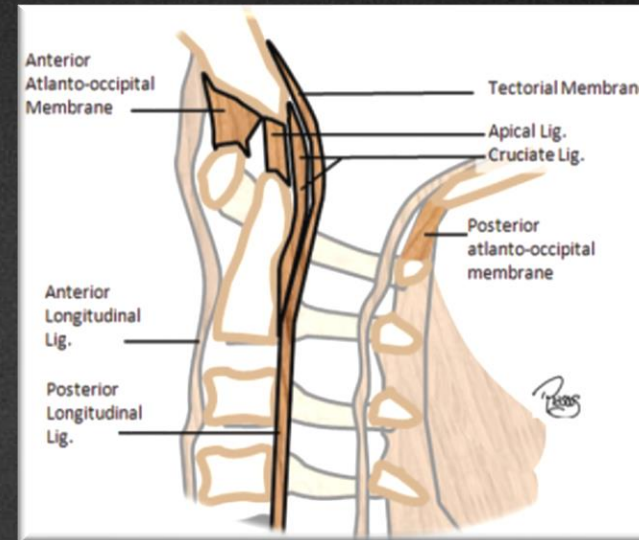
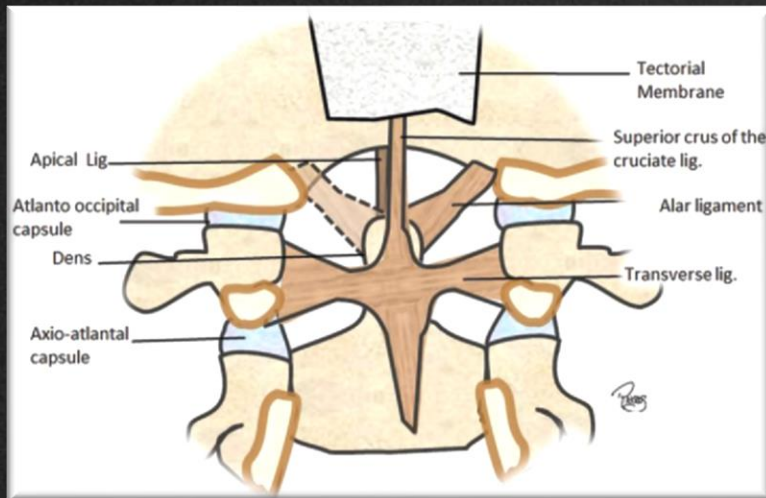
> 10 years



# Biomechanics

## Craniocervical Junction (CCJ)

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- Major stabilizers

- Atlantoaxial joint

- transverse ligament (axial rotation),
    - alar ligaments (limit excessive rotation)

- CCJ

- joint capsules (AO e AA)

- Mechanical Properties

- AO joint

- Flexion (odontoid-basion),
    - extension (tectorial membrane)

- AA joint

- axial rotation

- Disruptions of the joint capsules

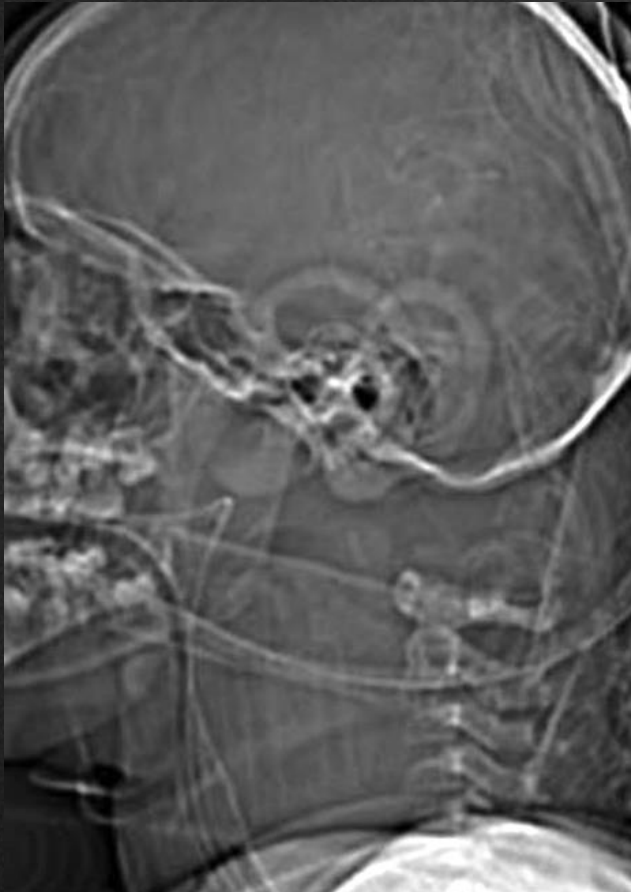
- instability - AO / AA joint

# Types of Injuries & Key Entities

- **Craniocervical injuries:**
  - Atlanto-occipital dislocation, retroclival hematoma.
  - High fatality risk, often subtle on CT → MRI essential.
- **Atlantoaxial injuries:**
  - luxation / rotatory subluxation (AARF).
  - Odontoid synchondrosis fractures (common <7 years).
- **Ligamentous injuries & SCIWORA:**
  - Spinal Cord Injury Without Radiographic Abnormality (SCIWORA).
  - Up to 35% of pediatric spinal cord injuries.
  - MRI crucial to detect edema, hemorrhage, or transection.
- **Subaxial cervical injuries:**
  - More common in adolescents (>10 years).
  - Fracture-dislocation patterns similar to adults.

# Occipital-Cervical Dislocation in Children

Most severe forms atlanto-occipital dislocation, better known as **dissociation**.



- **Epidemiology / Mechanism:**
  - Rare but often fatal injury, more frequent in children due to ligamentous laxity.
  - Usually high-energy trauma: motor vehicle accidents, falls.
- **Imaging Findings:**
  - Widening of atlanto-occipital joints.
  - Prevertebral soft tissue swelling.
  - Associated with brainstem or upper cervical cord injury.

# Normal relationships and measurements at the craniovertebral junction



## **Atlanto-Dental Interval (ADI)**

- < 8 y: 5 mm
- > 8y: 3 mm
- < 2,6 mm (TC)

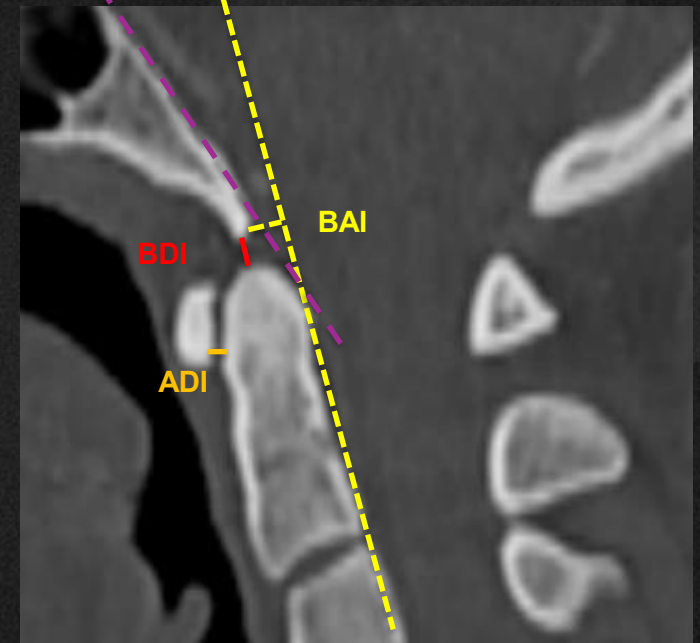
## **Basion-Dens Interval (BDI)**

- Usually <12mm
- < 9,5 mm e < 11,6 mm
- (with/without os terminale ossif)

## **Basion-Axial Interval (BAI)**

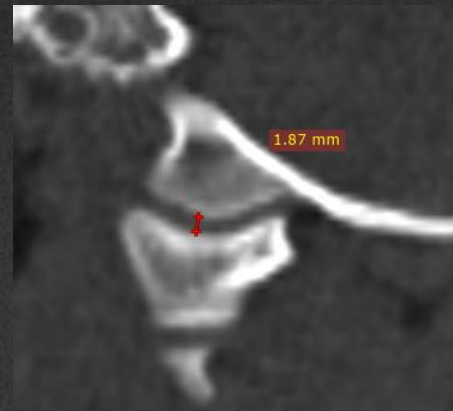
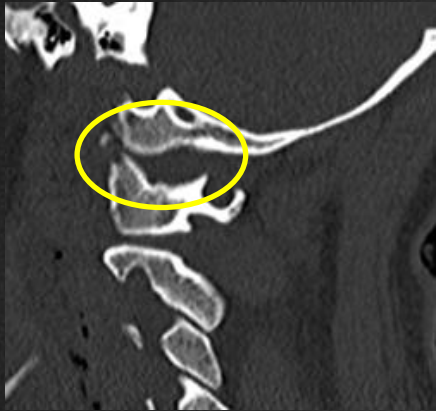
- Ant: 12 mm
- Post: 4 mm

## **Linha de Wackenheim**



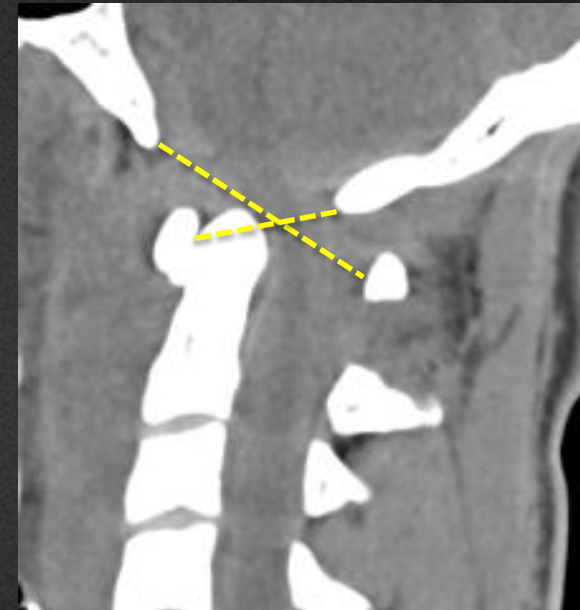
# Normal relationships and measurements at the craniovertebral junction

## Kaufman's condylar gap



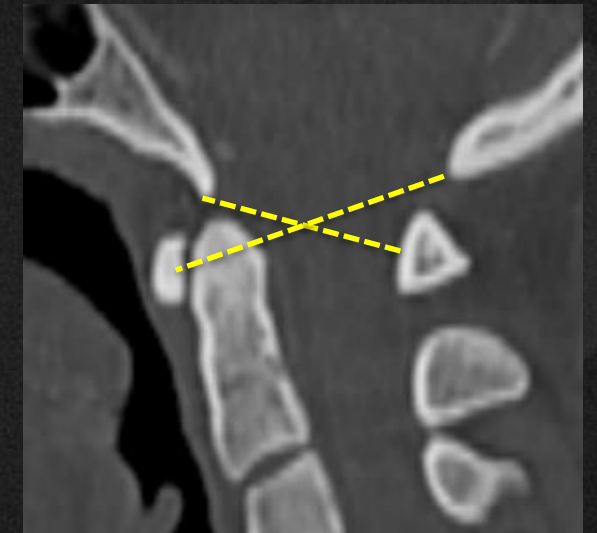
## Atlanto-Occipital dislocation

Distance between occipital condyles and condylar facets of atlas **<5 mm**.



Powers' ratio  $>1$   
**Atlanto-Occipital dislocation**

## Powers' ratio

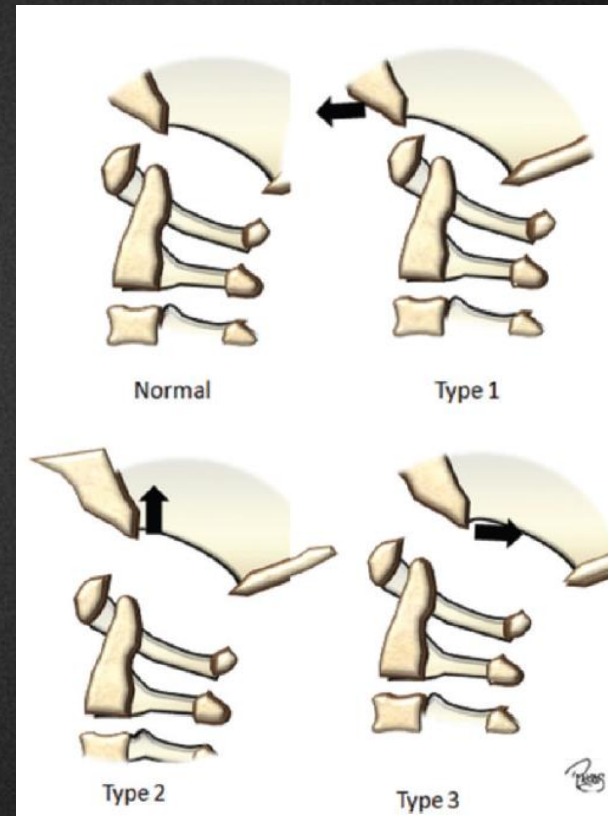
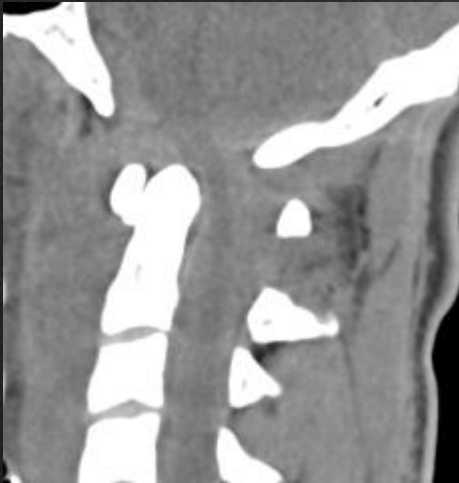


- $nl - 0,77 \pm 0,09$
- $> 1$  (AO dislocation)

Low sensitivity in detecting longitudinal distraction and posterior dislocation.

# Atlanto-occipital Dislocation (AOD)

## Traynelis classification



The most common and includes ventral dislocations of the occiput.

The most unstable and involves longitudinal distractions of the occiput.

Dorsal dislocations of the occiput.

# Occipito-Cervical Dislocation in Children

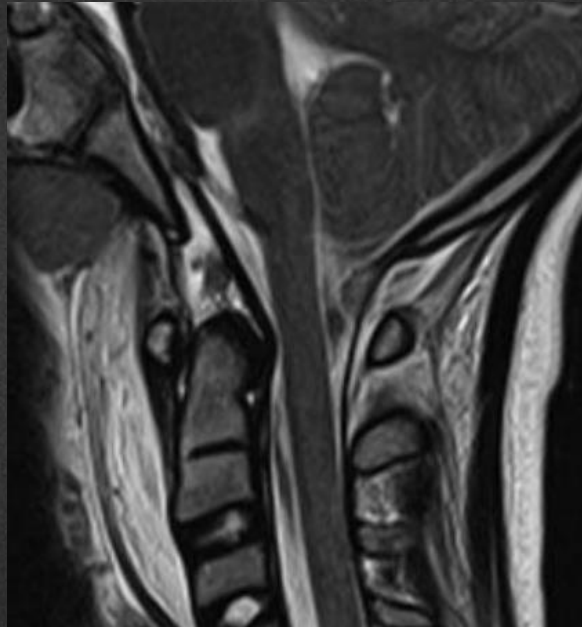
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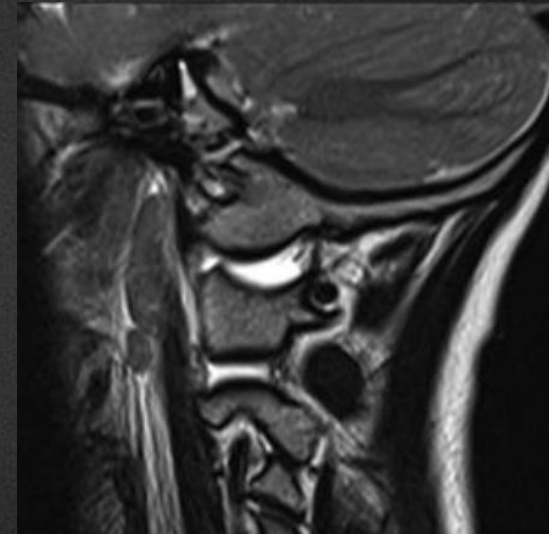
## Spectrum of craniocervical junction injuries (occiput–C1–C2)

- **Severe (CCD):**
  - complete ligament rupture (tectorial, alar, transverse, capsules) with occipital condyle–C1 displacement, fractures; often fatal.
- **Intermediate:**
  - partial ligament rupture, significant instability, variable neurological deficit.
- **Mild:**
  - Isolated ligamentous lesions, retroclival hematoma and without displacement.

# Atlanto-occipital Dislocation (AOD)

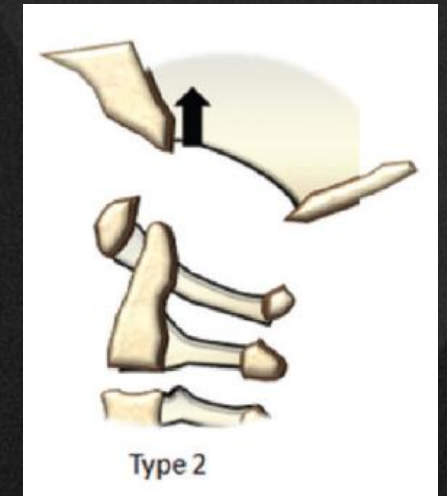


BDI



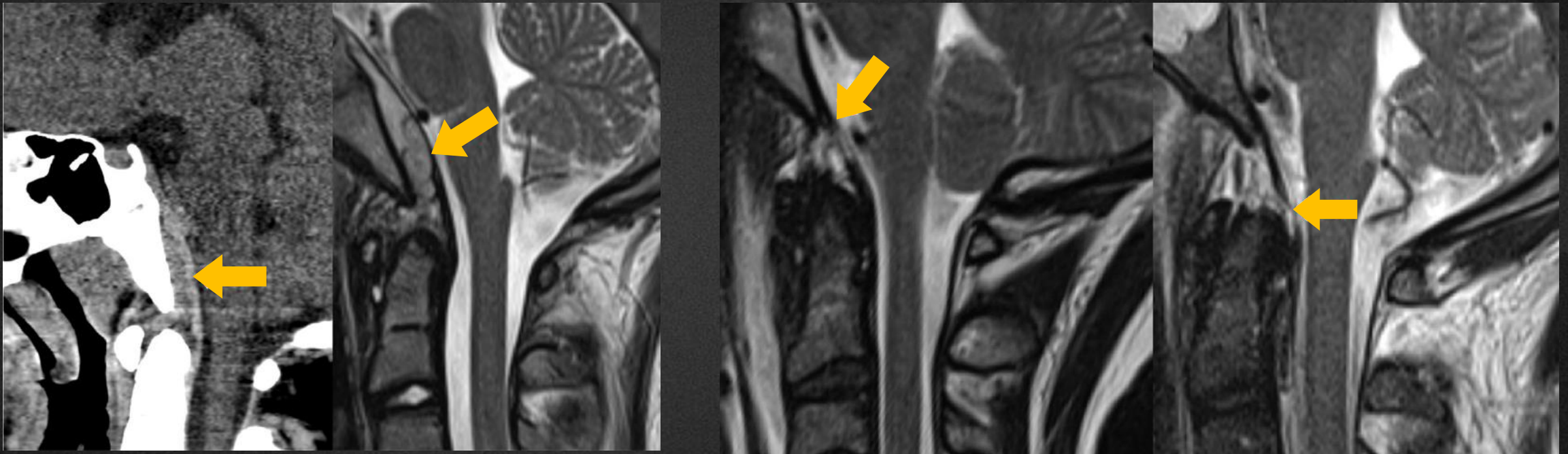
Kaufman's condylar gap

The most unstable and involves longitudinal distractions of the occiput.

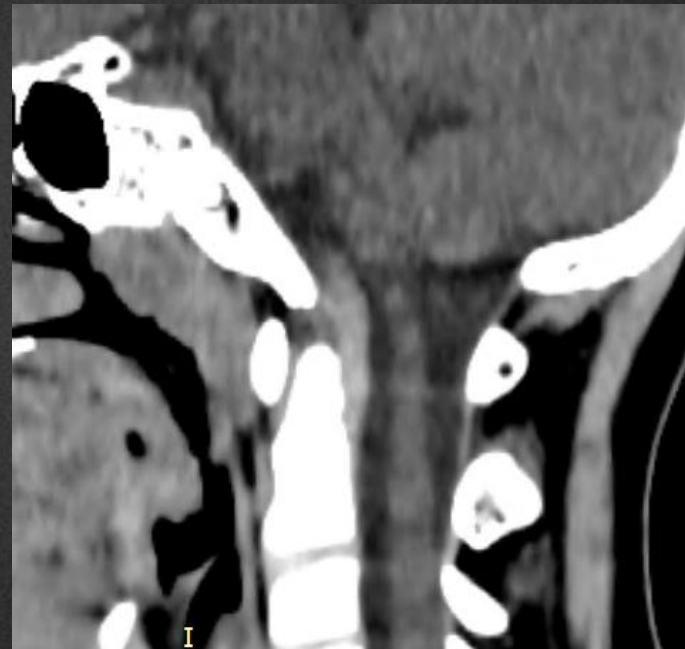


# Tectorial Membrane

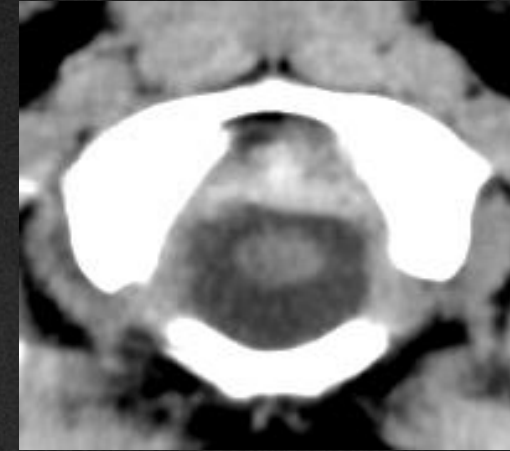
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# Tectorial Membrane



ADI – 3,0 mm  
BDI – 7,8 mm



Kaufman's condylar gap

# Spectrum of Pediatric Upper Cervical Fractures

- Pediatric cervical fractures share patterns with adults, but differ in incidence, distribution, and location.
- **Rare in children**
- Atlas (C1) fractures:
  - Jefferson fracture: axial compression (e.g., diving accidents).
  - Anterior/posterior arch fractures: focal C1.
  - Related do synchondrosis
- Axis (C2) fractures:
  - Hangman fracture: traumatic hyperextension.
  - Odontoid fractures
  - Related to synchondrosis

# Atlas - C1

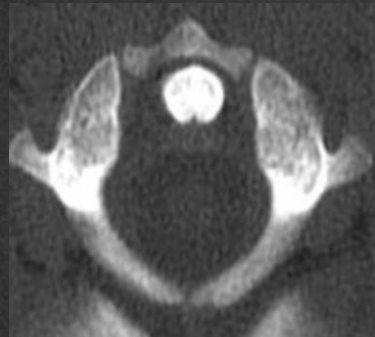
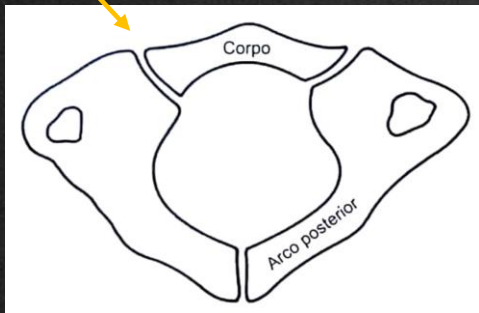
7 years

2 years-old

1 year-old

10 months-old

1 month-old



appears - 9 to 12 months of age

3 years

## **Synchondroses**

- characteristic locations
- smooth/corticated margins

## **Fractures**

- any location
- irregular and non-sclerotic margins

# Synchondrosis fracture in a pediatric patient

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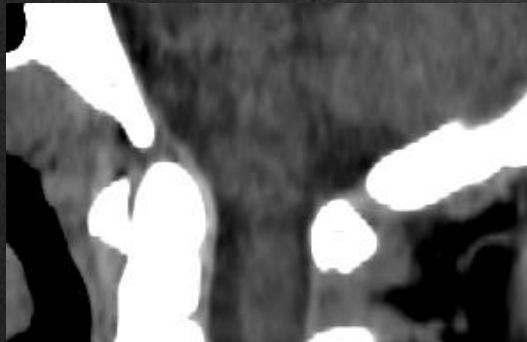
A 6-year-old boy arrived at the emergency department three days after falling 5 meters from a balcony. Bystanders said that the child appeared to have landed on his forehead. The child complained of neck pain and held his head stiffly.



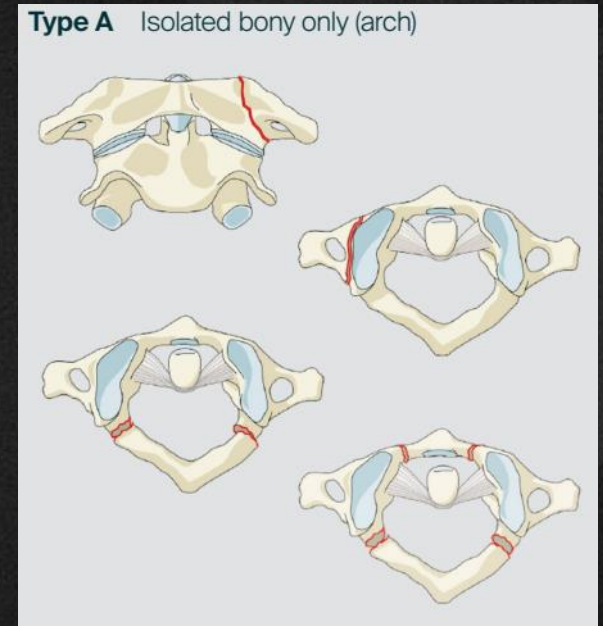
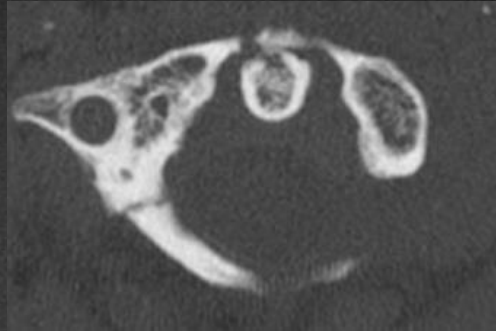
Fracture of the anterior arch of the atlas vertebra, treated with transoral closed reduction and external immobilization.

# Spectrum of C1 Fractures

12 y, boy  
MVA



15 y, boy  
MVA



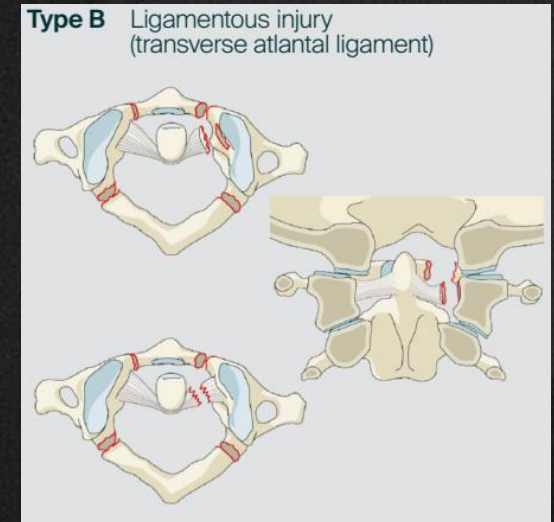
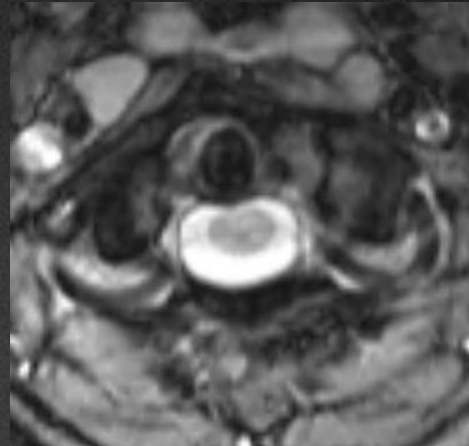
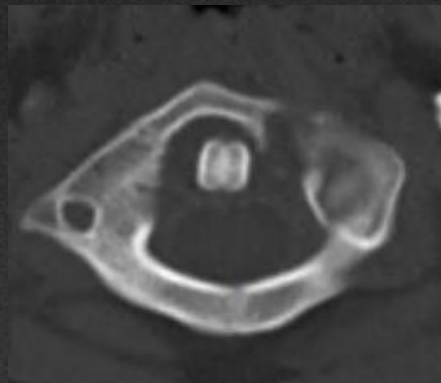
<https://media.aofoundation.org/spine/>

Atlas (C1) fractures:

- Jefferson fracture: axial compression (e.g., diving accidents).
- Ant/Post arch fracture: focal C1/2 hyperextension

# Spectrum of C1 Fractures

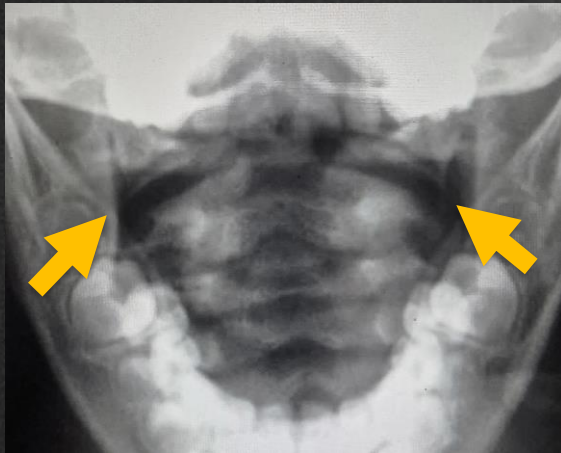
8 y, boy  
MVA



<https://media.aofoundation.org/spine/>

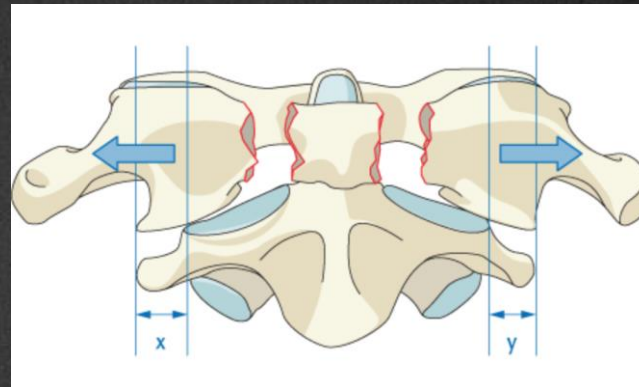
# Pseudospread of C1 on C2

open-mouth view or  
coronal reformatted CT



Children < 7 years  
Discrepancy in the growth rate  
of the atlas vs. the axis.

Mimic a Jefferson fracture



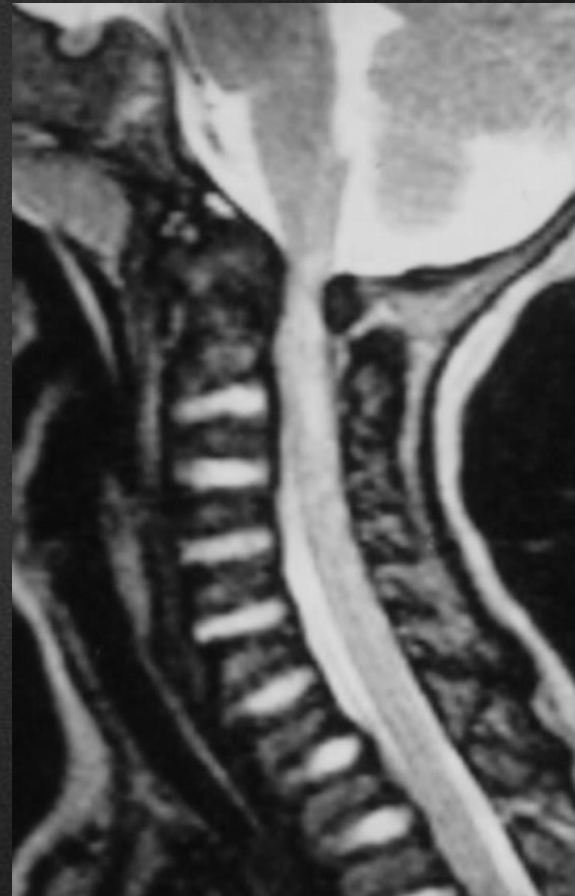
More than 6.9 mm 8,1 mm displacement of the lateral mass of C1 over  
C2 on AP view indicates a transverse ligament rupture (Spencer rule).



# Atlanto-axial dislocation

Increase the risk for injuries due to the increased ligamentous laxity / malformation.

18m, F  
fall

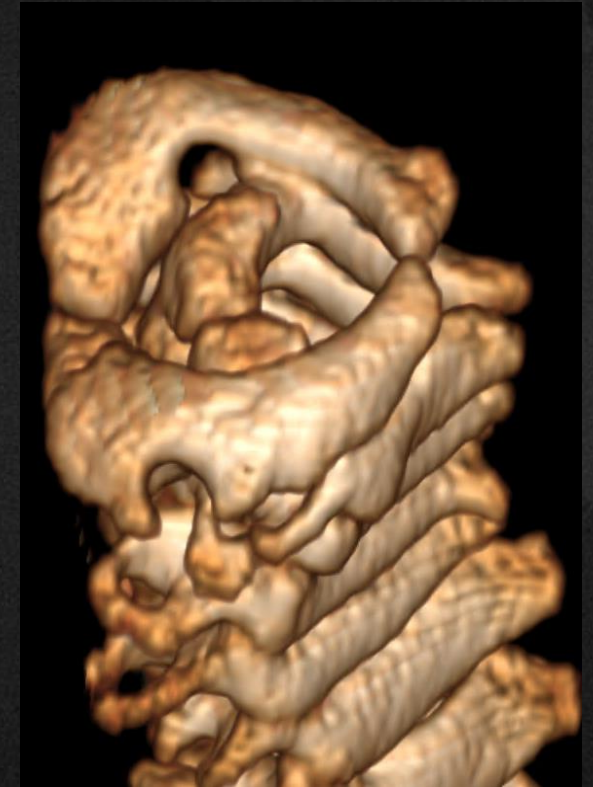
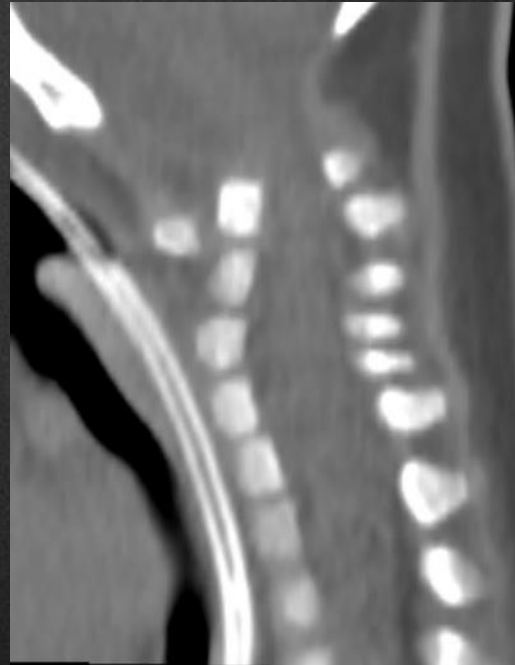
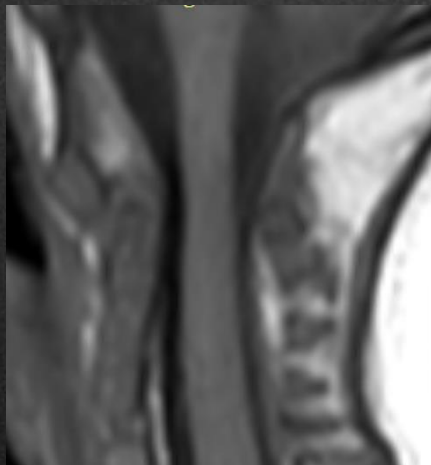
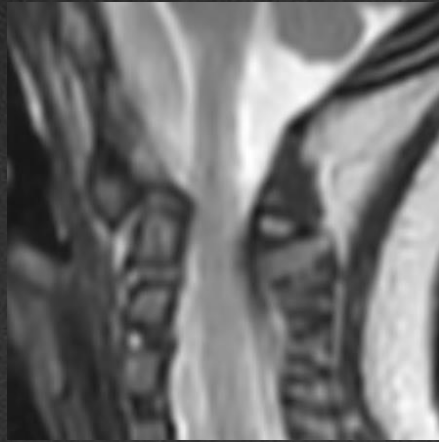


MPS

# Atlanto-axial dislocation

Increase the risk for injuries due to the increased ligamentous laxity / malformation.

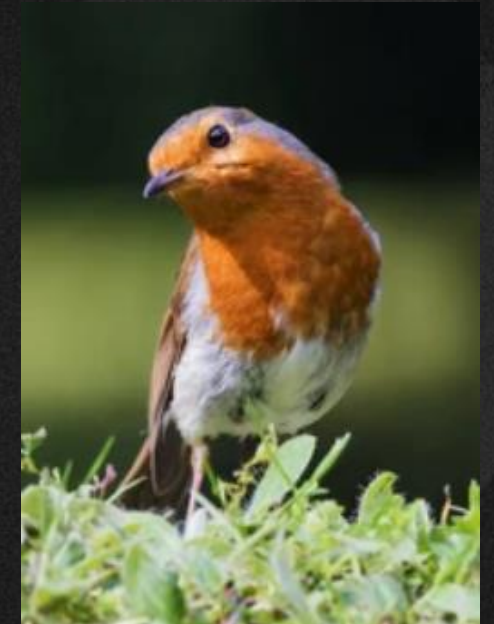
1y 8m, M



# Atlantoaxial Rotatory Fixation / Subluxation (AARF/S)

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- **Definition:**
  - Pathological fixation of C1 on C2 in abnormal rotation, often presenting with torticollis (“cock robin” position).
- **Clinical Presentation:**
  - Sudden painful torticollis, limited range of motion, head tilt with chin rotated to one side.
- **Etiology:**
  - Trauma (minor falls), infection/inflammation (Grisel syndrome), congenital anomalies, or post-surgical changes.

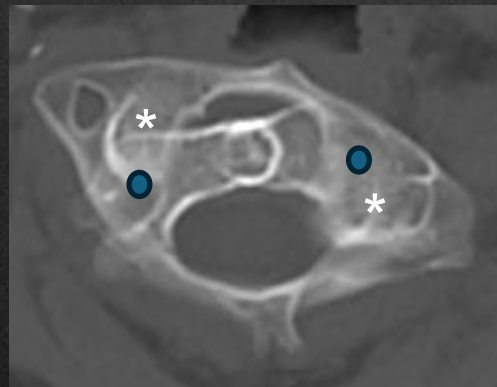
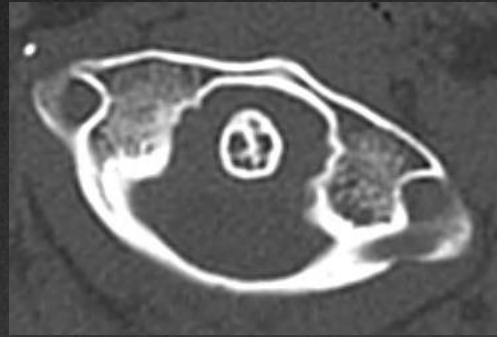


“pisco-de-peito-ruivo”

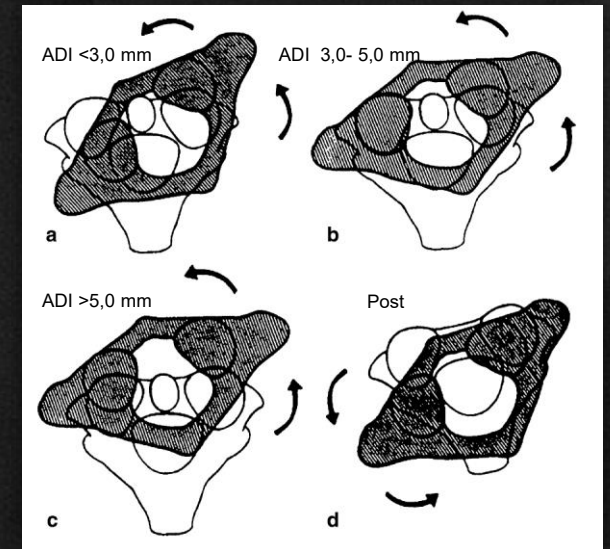
# Atlantoaxial Rotatory Fixation / Subluxation (AARF/S)

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9y, M  
Minor trauma



AA rotatory subluxation classified 4 types  
**Fielding and Hawkins.**

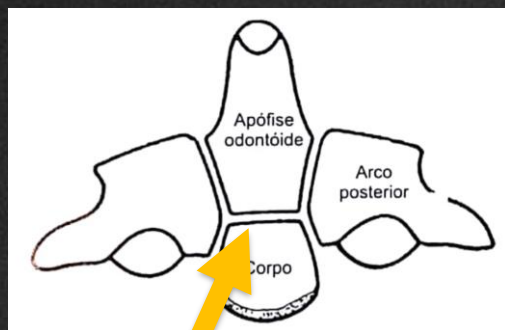


Khanna G, El-Khoury GY. *Skeletal Radiol.* 2007;36(6):477-494.

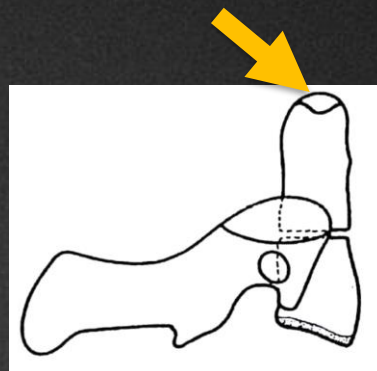
# Axis (C2) fractures in children

- **Rare in children**
- Axis (C2) fractures:
  - Anderson fracture: traumatic hyperflexion.
  - Hangman fracture: traumatic hyperextension.
  - Odontoid fractures (most common fracture of cervical spine in children)

# Axis (C2)



Fuses 3-6 years  
Visible up to 11 years



Os. terminale  
appears -3-6 years  
Fuses - 12 years



*Ossiculum terminale*

- **Rare in children**
- Axis (C2) fractures:
  - Anderson fracture: traumatic hyperflexion.
  - Hangman fracture: traumatic hyperextension.
  - **Odontoid fractures** - **most common** fracture of cervical spine in children

# Axis (C2) fractures - synchondrosys

Odontoid fracture  
(young children)

16 m, F



Odontoid process - subdental synchondrosis



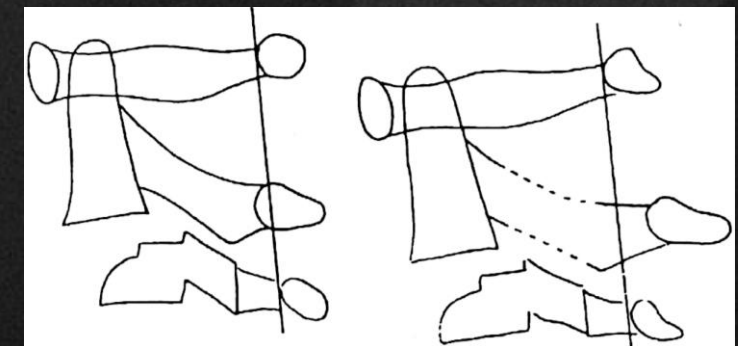
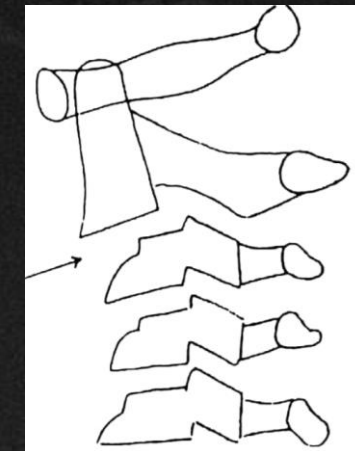
C1-C2 interspinous distance < 12mm

4y, M



# Pseudosubluxation C2/C3

4y, M

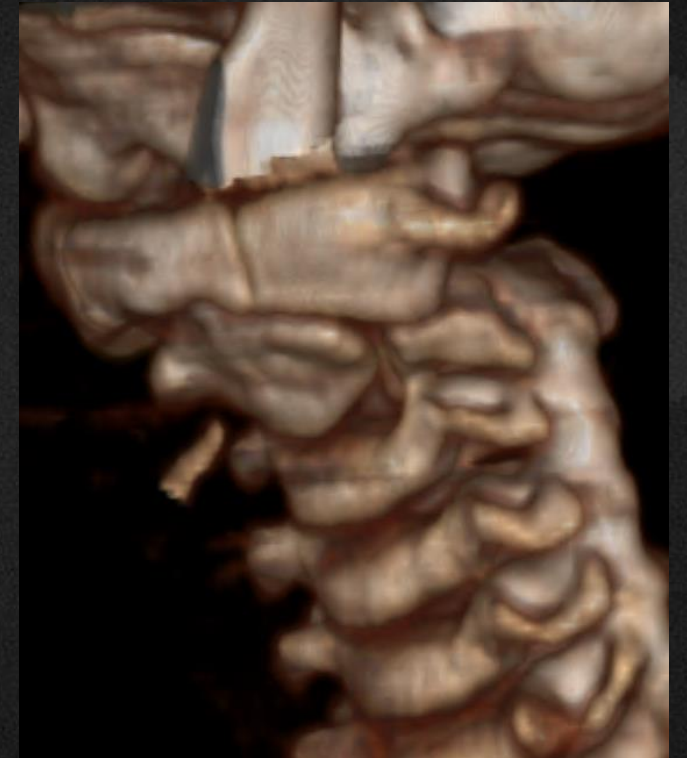
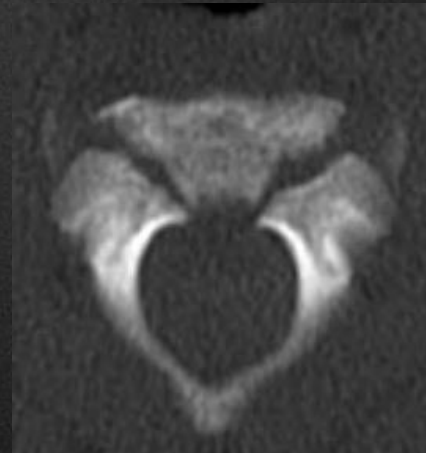
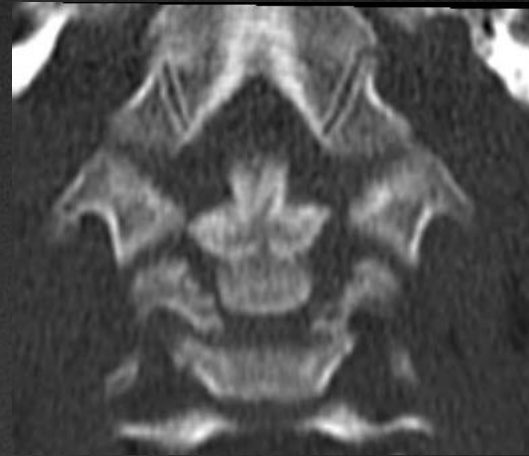
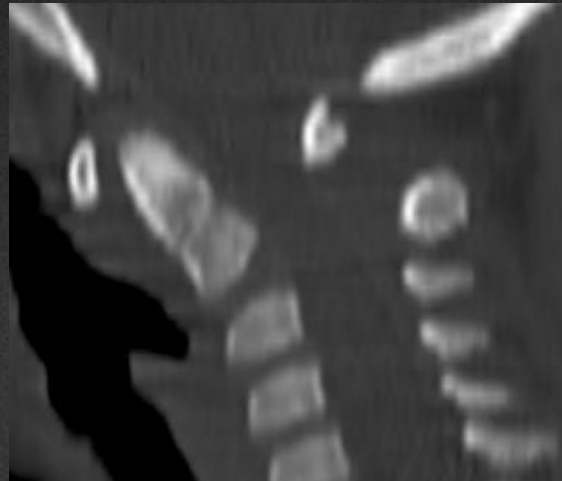


**Posterior cervical line:** along the posterior arches of C1 and C3,  
Normal: posterior arch of C2 lies **within 1.5 mm** of the posterior cervical line.

# Axis (C2) fractures - synchondrosys

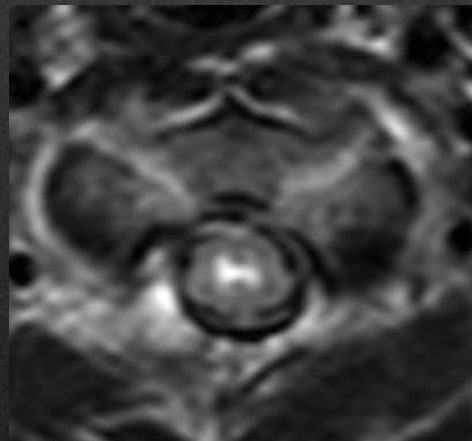
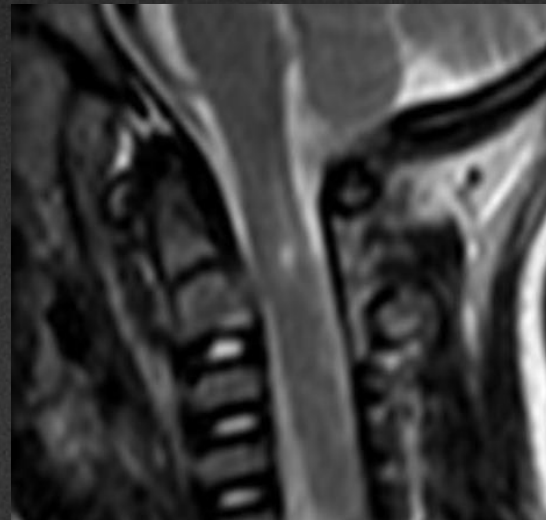
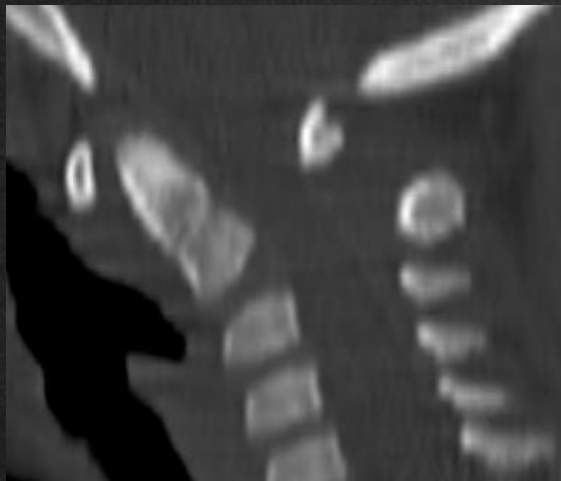
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4y, M

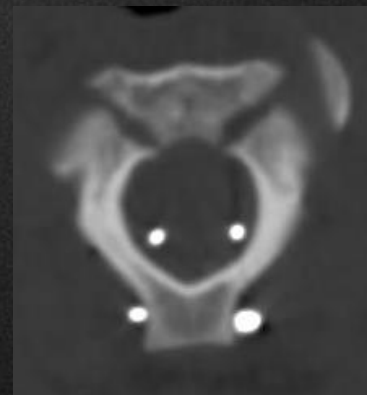


# Axis (C2) fractures - synchondrosys

4y, M



20 d P.O.

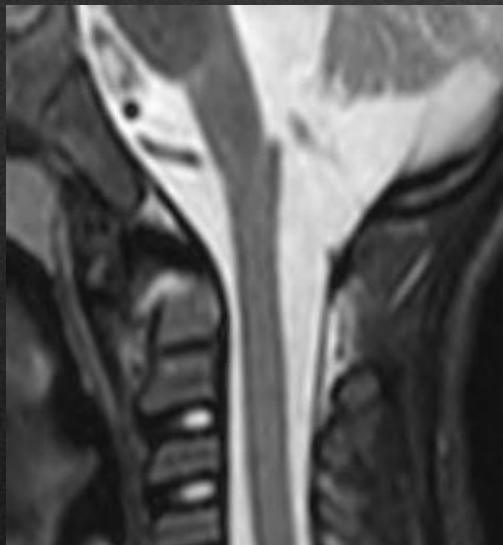
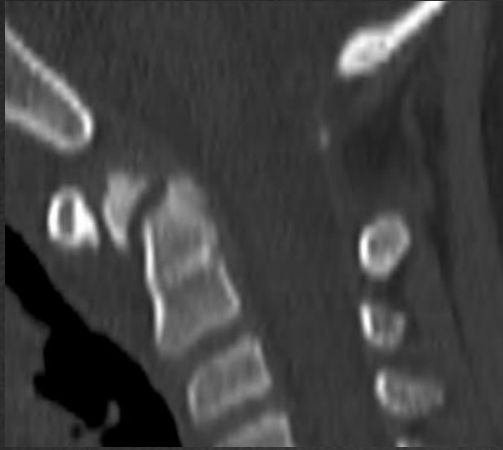


4 y P.O.

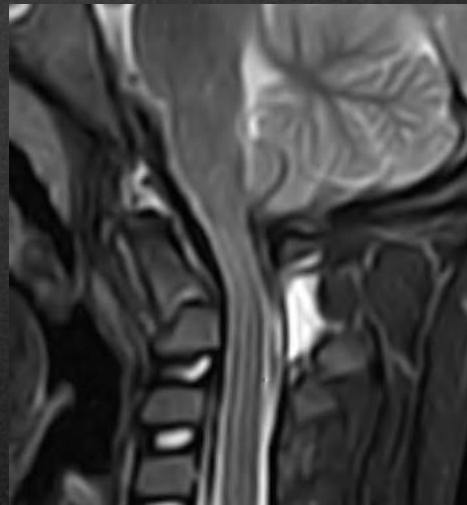


# Odontoid fractures

7 y, M



8 y, M



## Grauer's Classification

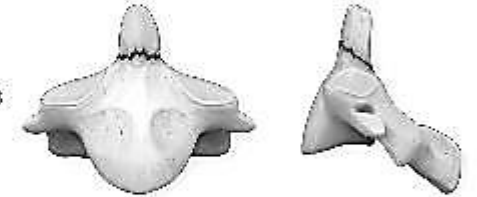
Type I



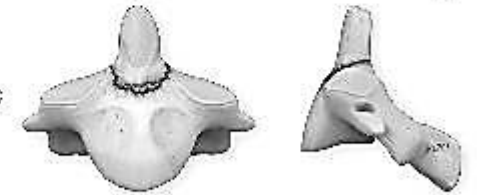
Type II A



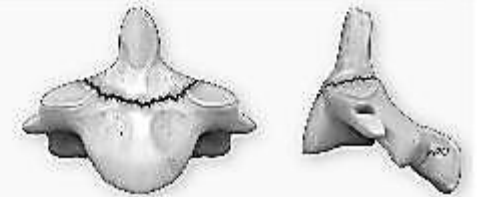
B



C



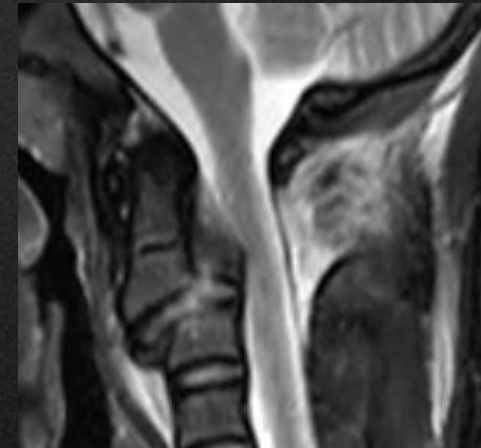
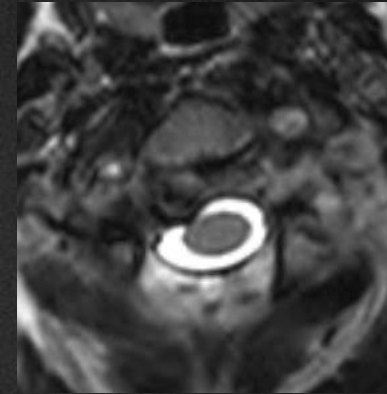
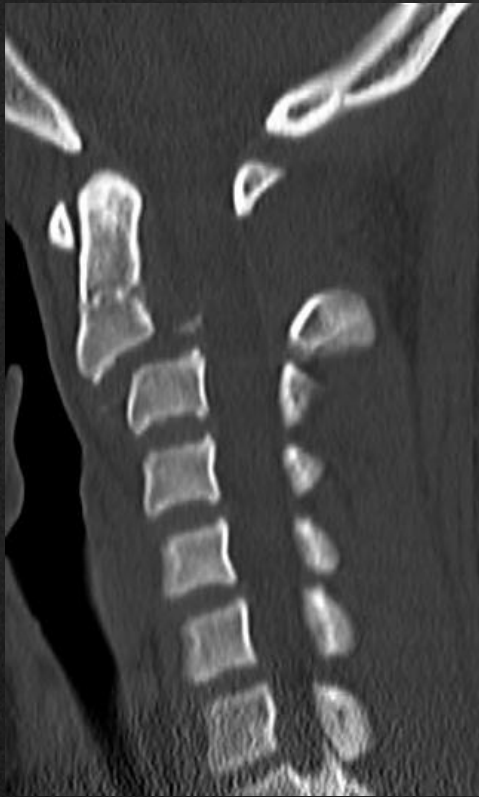
Type III



# Axis (C2) fractures in children

12y, F  
MVA

## Hangman's fracture



# SCIWORA

spinal cord injury without radiographic abnormality

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**Acronym** – “SCIWORA” - **1982** by Pang and Wilbarger

- pediatric patients - traumatic myelopathy
- no fractures, dislocations, or malalignment of the spinal column

**Most cases:**

- upper cervical in children <8 years

**Pathophysiology and Biomechanics**

- **Increased laxity and elasticity** of the developing cervical spine.
- maximal spinal cord stretch: 6 mm
- maximal spinal stretch: up to 5 cm
- **Cord stretching** - cord contusion, ischemia or rupture.

**J Neurosurg 57:114–129, 1982**

**Spinal cord injury without radiographic abnormalities in children**

**DACHLING PANG, M.D., F.R.C.S.(C), AND JAMES E. WILBERGER, JR., M.D.**

*Department of Neurosurgery, University of Pittsburgh School of Medicine, Pittsburgh, Pennsylvania*

# SCIWORA

spinal cord injury without radiographic abnormality

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- **Mechanisms of injury**

- often related to **motor vehicle accidents, falls, or sports trauma.**

- **Symptoms:**

- immediately after trauma
- can be delayed up to 48 h after initial injury
  
- Complete deficit – poor prognosis
- Better outcome – incomplete lesions

- **Diagnosis – MRI**

- Edema, contusion and hemorrhage

- **Prevention:**

- proper use of restraints in motor vehicles
- protective gear in sports.

5y, M  
MVA

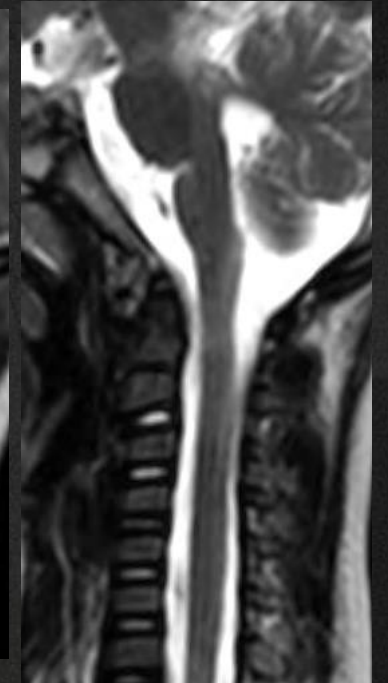
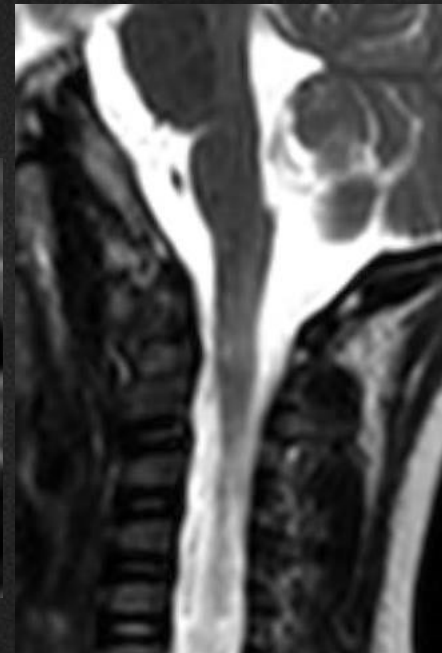
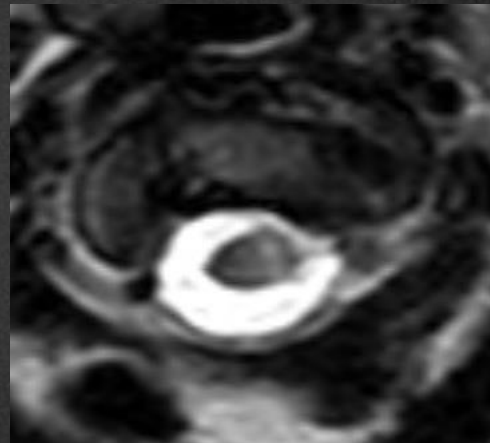


# SCIWORA

spinal cord injury without radiographic abnormality

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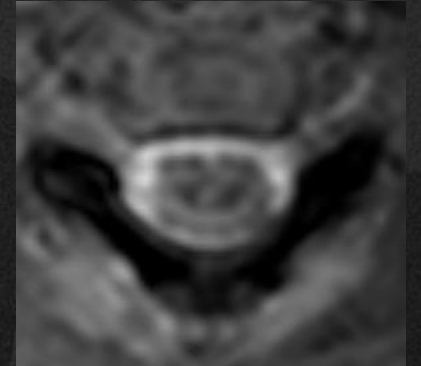
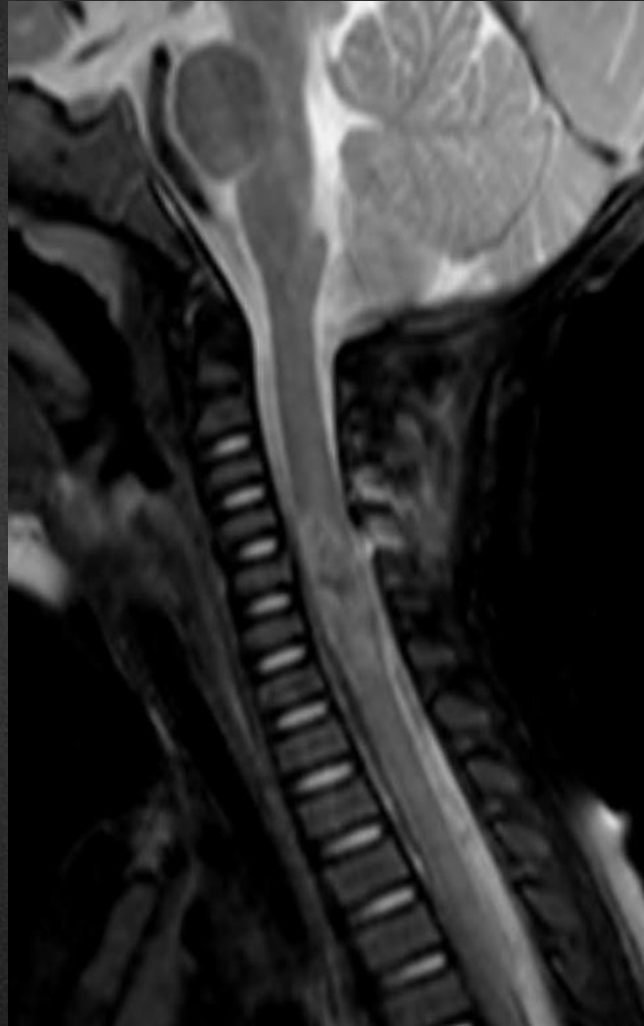
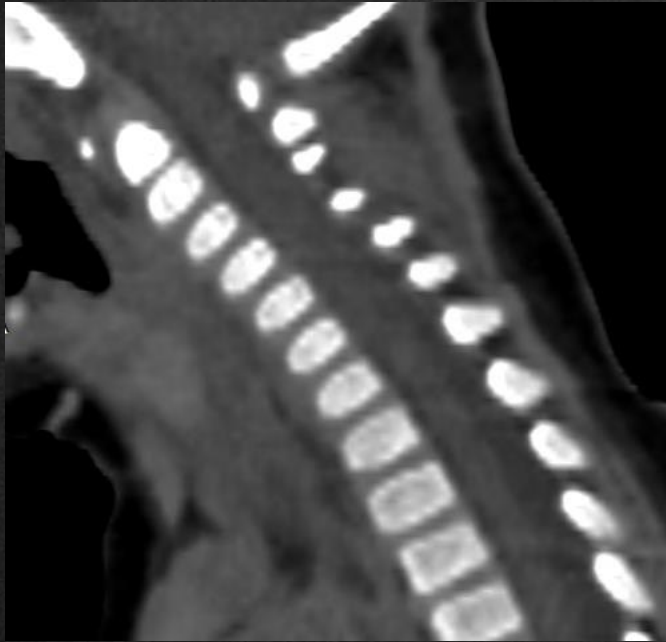
4y, F  
MVA



# SCIWORA - mimic

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1y, F  
fall

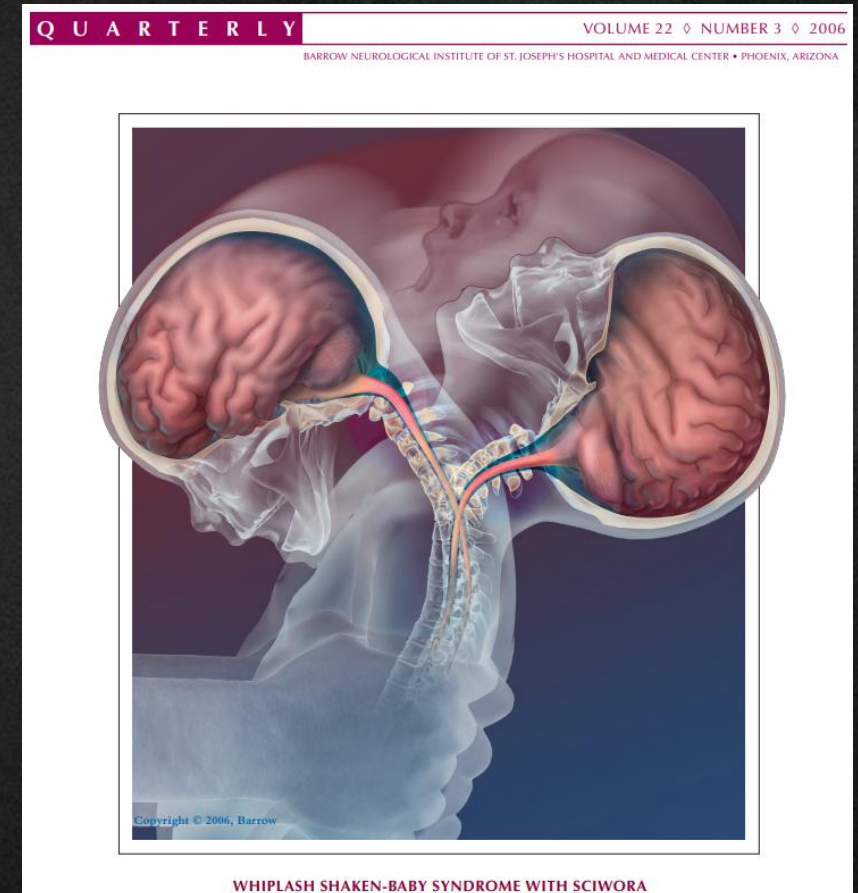


# Non-Accidental Pediatric Spinal Trauma

## (Epidemiology & Mechanisms)

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- **Epidemiology & Severity**
  - Literature is **limited**, but cases are well documented.
  - Spinal injury in child abuse = **severe form** with **high risk of long-term neurological impairment**.
- **Age & Patterns**
  - **Younger infants (≈5 months)**: cervical injuries → impaired consciousness, respiratory distress.
  - **Older infants (≈13.5 months)**: thoracolumbar injuries → spinal deformity, focal neurologic deficits.
  - **No pathognomonic patterns**; diagnosis requires full work-up (skeletal survey, clinical exam, psychosocial evaluation).



# Subaxial Cervical, Thoracic and Lumbar Spine Injuries

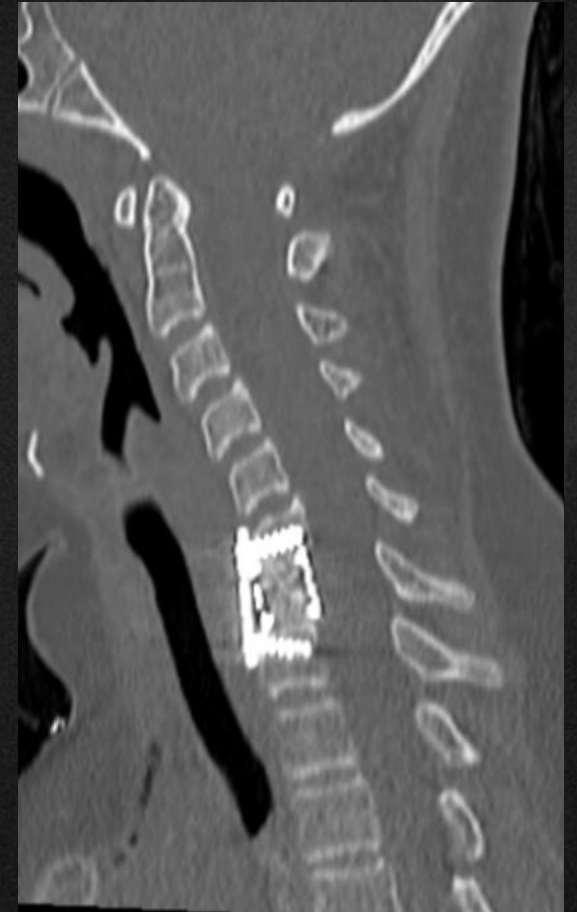
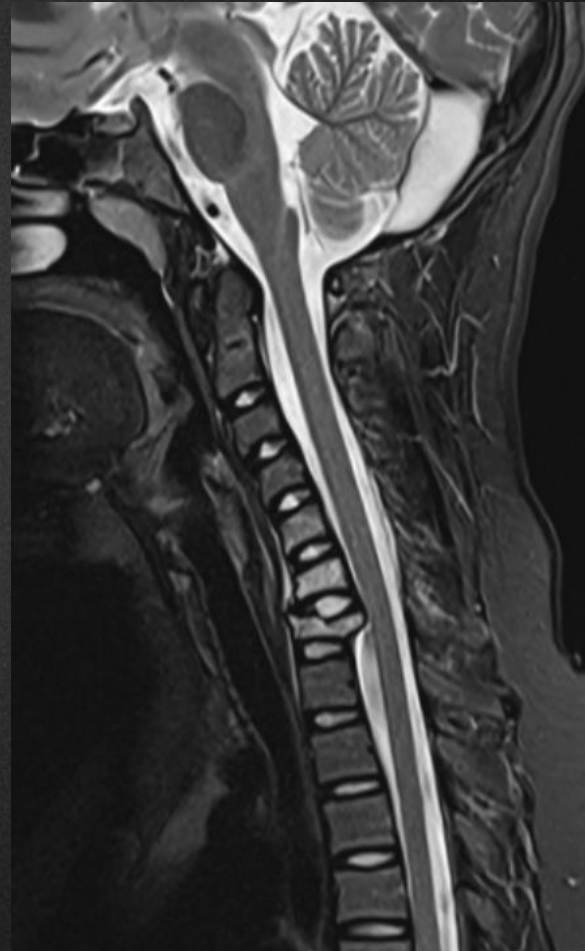
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- In children >10 years, injury location shifts to subaxial, thoracic and lumbar spine.
- Injuries resemble adult patterns.

# Subaxial Cervical Spine Fractures in Children

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12y, F  
MVA



# Take home messages

- The pediatric cervical spine has unique anatomic and biomechanical features with a higher fulcrum of motion at C2–C3.
- These characteristics predispose children < 8 years to upper cervical and craniocervical injuries.
- SCIWORA and purely ligamentous injuries are common in this age group.
- Normal variants (pseudosubluxation, synchondroses, wedging) can mimic trauma and represent major pitfalls in imaging interpretation.
- Neurologic morbidity and mortality are higher, emphasizing the need for cautious evaluation and awareness of these pitfalls.

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## Contact



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Idealização:



Organização:

