Radiographic atlas of pediatric cervical spine in emergency: normal anatomy, variants and pitfalls

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Learning objectives

To describe the normal anatomy and variants of the pediatric cervical spine.

To be familiar with and to recognize the main radiographic features of the cervical spine of the children

To obtain the key-elements and landmarks to interpret correctly a plain radiograph following trauma

Background

Several normal anatomic variants and synchondroses may be encountered on a standard cervical in children

Knowledge of the normal embryologic development and anatomy of the cervical spine is important to avoid mistaking synchondroses for fractures in the setting of trauma

Variants include, in general, pseudosubluxation C2-C3, absence of cervical lordosis, wedging of C3 vertebra, widening of the predental space and the prevertebral soft-tissue

This atlas provides the main signs to aid in the correct interpretation of radiographs

Findings and procedure details

Cervical spine injuries in children are uncommon

By the time a child is 8-10 years old, the cervical spine reaches adult proportions
Under 8 years, radiologic « abnormalities » and injuries are usually seen in the upper cervical region (C1#C3) owing to its particular biomechanics and anatomic characteristics.

Beyond 8 years, lesion are most seen in the lower cervical region (C3# C7).

Under 13 years of age, atlantoaxoid subluxation is more common. After this age, odontoid fracture become more seen (frequently associated with neurologic lesions).

Analysis of pediatric cervical spine X-Rays can be challenging because of:
- Initial radiographs are almost always technically imperfect because of the painful contracture
- Epiphyseal variants, unique vertebral architecture, incomplete ossification of synchondroses and apophyses
- Hypermobility because of ligamentous laxity especially between C2 and C3.

A- ANATOMY:

C1: (Fig 1 and 2)

Features:

- Absence vertebral body; replaced by an anterior arch.

- Atlas is formed by three primary ossification centers, separated by synchondroses:

  1- Two posterior neural arches (ossified at birth)

  2- One anterieur arch (it is ossified in only 20% of cases at birth).

The neural arches fuse posteriorly by 3-4 years of age.

The anterior arch fuses with the neural arches by 7 years of age.

C2 (Fig 3 and 4):
Features:

- C2 is formed by four primary ossification centers:
  1 for each neural arch
  1 for the body
  1 for odontoid process (#). This center forms, in utero, from two separate secondary ossification centers that fuse in utero; and from a third secondary center that appears at the apex of odontoid process (os terminale) between 3-6 years.

- The body of C2 fuses with odontoid process by 3-6 years of age.

- Neural arches fuse posteriorly by 2-3 years, and with the body od odontoid process between 3-6 years.

- Os terminale fuse totally by age 12 years

Subdental synchondrosis (between body of C2 and odontoid process) can be seen until 11 years (may be confused with a Type II fracture of odontoid process)

A non fusion of the two secondary ossification centers of the odontoid process can be seen and may be confused with a longitudinal fracture (very rare)

C3 to C7 (Fig 5)

Features:

- Three ossification centres are present:
  1 for the body
  1 for each neural arch

- Neural arches fuse posteriorly by age 2-3 years and with the body between 3-6 years of age.
Secondary ossification centers (uncus) can also appear at the superior and inferior aspects of the cervical vertebral bodies and remain unfused until early adulthood (9-10 years).

- additionally, secondary ossification centers may be seen at the tips of the transverse processes and spinous processes that may persist until early in the 3rd decade of life.

Secondary ossification centers can be unfused, and not to be taken for fractures.

On antero-posterior radiograph, posterior synchondroses may like a radiolucent thin line crossing the vertebral bodies (they should be recognized as smooth and regular lines with sclerotic border).

**B- ANALYSIS:**

1- **Lateral View:** (Fig 6)

Verify:

- *Cervical lines,* should be aligned and paralleled:
  - **Anterior cervical line** (drawn between the anterior faces of vertebral bodies),
  - **Posterior cervical line** (drawn between the posterior faces of vertebral bodies),
  - **Spinolaminar line** (drawn between the anterior aspect of spinous processes),

  [*IT IS THE MOST IMPORTANT LINE*]

- **SWISCHUK line** between the anterior aspect of spinous process from C1 to C3.

- **Atlantodens interval:** This distance should be **5 mm** until 1 year of age, **4 mm** until 8 years and **3 mm** beyond 8 years.

- **Prevertebral soft-tissues**

A prevertebral space of **7 mm** at the level of C4 is considered normal in children.

Under C4, prevertebral space should be **14 mm**.
In children, widening of the prevertebral soft tissues can be a normal finding that is related to expiration.

When lateral radiography in an infant with possible spinal injury shows wide prevertebral soft tissues, repeat lateral radiography in mild extension and in inspiration should be performed to determine if the apparent soft-tissue abnormality is real.

- Harris' ring (dotted line) is a ring-like structure resulting of projection of the lateral masses of C2 on its body

- Criterion of success radiograph on Lateral view:
  - Superposition of the mandibular angle and articular processes
  - Absence of duplication of posterior wall
  - All intervertebral discs and posterior articular interline are visible
  - All vertebrae are visible from the skull base to T1.

2- Anteroposterior view: (Fig 7)

Verify:

- parallelism and equidistance of 5 lines:
  
  transverse process lines, uncinate lines and spinous line.

- Lateral margins should be intact and smoothly undulating

- Height of the vertebral bodies should be approximately equal

- The spinous processes are spaced approximately evenly.

- The spinous processes should all align and lie in the midline.
If one of the spinous processes is off to one side, a facet dislocation may be present.

vertebral endplates are parallel and intervertebral disk-space are uniform.

Interspinous distance of two adjacent segments must not differ by more than 2 mm.

A widening of interspinous space evokes a flexion injury and may also be present in the lesions by axial compression.

**Criterion of success radiograph on Antero-Posterior view:**

- Trachea lie in the midline.
- Spinous processes should all align and lie in the midline.
- Mandibles should be symmetric.
- Good visibility of the articular interline C3-C4 to C7-T1.

**3- Open-mouth view:**(Fig 8)

Verify:

- alignment of the lateral processes of C1 and C2.

- distance between the *processus odontoïde* and the lateral masses of C1 should be equal on each side.

- symmetric position of lateral masses of C1 and C2:
  - Pseudospread of the atlas on the axis can be seen.
  - Up to 6 mm of displacement of the lateral masses relative to the dens is common in patients up to 6 years.
  - Above 6 mm, a C1 fracture with transverse ligament rupture should be suspected, and confirmed by CT.
- Any asymmetry is suggestive of a fracture, **BUT it may also be caused by tilting of the head and secondary to torticollis**

• the line drawn (blue line) from the *odontoid process* should be line up with the spinous process of C2

• no bone fragment between odontoid process and one of the lateral masses of C1 (no bone avulsion of the transverse)

4- Dynamic view: (Fig 9)

- They are usually most helpful in detecting ligamentous injury

- Radiographs are in general technically imperfect because of the painful contracture

- typically, this view is ordered at 7 to 10 days post injury when the cervical spine is less painful

- Should be realized in case of absence of osseous lesions in the static views (AP, Lateral, open-mouth)

- patient flexes and extends their own neck under the supervision of the requesting physician

- no manual flexion/extension should be applied

- Contraindications:

  * altered state of consciousness;
  * documented neurologic deficit;
  * inability of patient to flex and extend the neck w/o assistance

*Dynamic view is particularly useful before 8 years of age to study C2-C3, to avoid over- or under-estimated a pseudosubluxation. Reduction of subluxation with neck extension help to differentiate this from more serious disorders*
C- MEASUREMENTS AND LANDMARKS:

1- Swischuk Line: (Fig 10)

- It is the line drawn between the anterior edges of the spinous processes from C1 to C3.
- The anterior edges of the spinous processes of C1, C2 & C3 should line up within 1 mm of each other on both flexion and extension radiographs

anterior aspect of posterior arch of C2 should be within 1-2 mm of this line:

> 2mm # true luxation C2 on C3

< 2mm # bilateral interarticularis fracture

2- Atlantodens (predental) space C1-C2 (Fig 11)

<5 mm until 1 year of age.

<4 mm until 8 years of age.

<3 mm beyond 8 years of age.

An increase in this space may be visible in case of:

- Ligamentous disruption.
- Atlantoaxial subluxation.
- Jefferson fracture Type C1.

The tangent to the cartilage growth (subdental synchondrosis) of the dens must pass through the superior articular facet of C2

3- Spinal columns and lines: (Fig 12)

- These landmarks are applicable when pediatric cervical spine reaches adult proportions (> 8 years)
- Normally there will be no abrupt step offs or breaks in continuity in these lines.

**Anterior spinal line**
Along the anterior vertebral body cortex

**Posterior spinal line**
Along the posterior vertebral body cortex

**Spinolaminar line**
formed by the anterior edge of the spinous processes

- anterior and posterior lines should be traced to the superior aspect of the dens

- prevertebral soft-tissue : the law of 7:
  
  # 7 mm (above C4)
  
  # 14 mm (below C4)

**D- PITFALLS:**

1- **Pseudo-subluxation C2 on C3: (Fig 13 and 14)**

In normal circumstances, This anterior displacement occurs in neutral lateral view and flexion view, and should disappear in extension

It occurs because of increased ligamentous laxity, more horizontal nature of facet joints.

Reduction of subluxation with neck extension help to differentiate this from more serious disorders

Pseudo-subluxation is reduced in extension, unlike in case of trauma

spinal-laminar line and Swischuk lines should remain intact
2- False fractures

2a- failure of fusion of synchondroses: (Fig 15)

2b- absence of primary ossification center: (Fig 15)

2c- neurocentral synchondrosis: (Fig 16)

between the vertebral body and neural arches

- Fuse between 3-6 years of age.

- They appear like a smooth and regular radiolucent line with sclerotic border

- Closure proceeds in a craniocaudal progression. It must be symmetric to maintain the normal spine alignment

- Sometimes, closure is non symmetric et may be confused with fracture, especially at 6-7 years of age.

- The difference with fractures will be by distinguishing a sclerosis always bordering synchondroses.

2d- pseudo-Jefferson fracture: (Fig 17)

- It is a pseudospread of the atlas on the axis. Ossification of lateral masses may precede that of the body of C2, causing an apparent lateral displacement of the masses in relation to C2.

- True Jefferson fracture is rare before the age of 10.

- It is present in 90% of children of 2 years of age and usually normalizes by 4-6 years

- Up to 6 mm of displacement of the lateral masses relative to C2 is common in patients up to 4-6 years old

- Above 6 mm, a C1 fracture with transverse ligament rupture should be suspected, and confirmed by CT.
- Beyond 6 years of age, the lateral masses of C1 and C2 should be perfectly symmetrical.

_The interest of the open-mouth radiograph remains discutable because:_

- Jefferson fractures are rare and secondary to severe trauma where radiography is replaced by a CT-Scan.
- This pseudo-fracture is present in 90% of children of 2 years of age and usually normalizes by 4-6 years.

2e- persistence of subdental synchondrosis: (Fig 18)

- It usually fuses between 3-6 years of age.
- This fusion line (subdental synchondrosis), or the remnant of the cartilaginous synchondrosis, can be seen until 11 years of age.
- The synchondrosis is always surrounded by a thin and regular sclerotic margins
- Knowledge of this variant is important to avoid mistaking it for fracture following trauma.

2f- interdental space and laryngo-tracheal airways: (Fig 19)

2g- Pseudo-widening of prevertebral soft-tissue: (Fig 20)

Normal 0 21 false false false MicrosoftInternetExplorer4

- In pediatric patients, widening of the prevertebral soft tissues can be a normal finding that is related to expiration.
- We have to repeat lateral radiography in mild extension and in inspiration to determine if the apparent soft-tissue abnormality is real.
- A prevertebral space of less than 7 mm at the level of C3 is considered normal in children

_TAKE HOME MESSAGE: (Fig 21)_

_Images for this section:_
Fig. 1: anatomy of C1 (1)
**Fig. 2:** anatomy of C1 (2)

Axial CT Scan with 3D Reconstruction in another child (21 months old) admitted to emergency unit for a violent accident
All of primary ossification centers and first three cervical vertebrae (C1, C2, C3) are visible without fracture or subluxation

Axial computed tomography (CT) with 3D reconstruction of C1 vertebrae (Fig 2a, b). We observe the neural arch (arrow) and the inmanuul + posterior arch synchondrosis (double arrow) with the absence of the anterior arch of C1.

3D Reconstruction (Fig 2c), allow to visualize the symmetric and central position of C1 in relation to other vertebrae especially C2. So, we can confirm that there is no a rotary subluxation.

Lateral radiograph (Fig 1): anterior arch of C1 is not ossified (do not forget that it is not ossified at birth in 85% of cases).

4 days-old child admitted in emergency unit for a high energy trauma.
**Fig. 3:** anatomy of C2 (1)
Fig. 4: anatomy of C2 (2)

Development of C2 vertebra

- Standard radiographs centered on C1-C2 (Fig 1) and coronal CT (Fig 2a, b, c) show the different ossification centers (●) of C2 separated by synchondroses (neuro-central = arrow) and subdental (dotted line) that fuse with age.

- 3D reconstruction (Fig 3a, b) allows to verify the good alignment and symmetric position of different cervical vertebra, especially C1 et C2.

Development of Os Terminale of C2

- Open-mouth radiograph centered on C1-C2

- In Fig 3a we observe the four primary ossification centers:
  - 1 for the odontoid process (●)
  - 1 for the body (●)

- Osilade terminale (arrow) appears between 3-6 years (Fig 3a) and fuses totally by age 12 years (Fig 3b).

- The two longitudinal secondary ossification centers that fuse in vitam, can be seen (double arrow) (Fig 3b).
Fig. 5: anatomy of C3 to C7
Verify:

- **Cervical lines**, should be aligned and paralleled:
  - Anterior cervical line (drawn between the anterior faces of vertebral bodies),
  - Posterior cervical line (drawn between the posterior faces of vertebral bodies),
  - Spinolaminar line (drawn between the anterior aspect of spinous processes).

**[IT IS THE MOST IMPORTANT LINE]**

- **SWISCHUK line** between the anterior aspect of spinous process from C1 to C3.

- **Atlantodens Interval**: This distance should ≤ 5 mm until 1 year of age, ≤ 4 mm until 8 years and ≤ 3 mm beyond 8 years.

- **prevertebral soft-tissues**: A prevertebral space of ≤ 7 mm at the level of C4 is considered normal in children. Under C4, prevertebral space should be ≤ 14 mm.

In children, widening of the prevertebral soft tissues can be a normal finding that is related to expiration. When lateral radiography in an infant with possible spinal injury shows wide prevertebral soft tissues, repeat lateral radiography in mild extension and in inspiration should be performed to determine if the apparent soft-tissue abnormality is real.

- **Harris ring** (dotted line) is a ring-like structure resulting of projection of the lateral masses of C2 on its body.

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**Fig. 6:** Analysis of the lateral view
Fig. 7: analysis of the anteroposterior view
Verify:

- alignment of the lateral processes of C1 and C2.
- distance between the processus odontoides and the lateral masses of C1 should be equal on each side.
- symmetric position of lateral masses of C1 and C2:
  - Pseudoposses of the atlas on the axis can be seen.
  - Up to 6 mm of displacement of the lateral masses relative to the dens is common in patients up to 6 years.
  - Above 6 mm, a C1 fracture with transverse ligament rupture should be suspected, and confirmed by CT.
  - Any asymmetry is suggestive of a fracture, but it may also be caused by tilting of the head and secondary to torticollis.
- the line drawn (blue line) from the odontoid process should be line up with the spinous process of C2.
- no bone fragment between odontoid process and one of the lateral masses of C1 (no bone avulsion of the transverse ligament).

**Fig. 8:** analysis on open-mouth view
**Fig. 9:** analysis on dynamic view

- They are usually most helpful in detecting ligamentous injury
- Radiographs are in general technically imperfect because of the painful contracture
- Typically, this view is ordered at 7 to 10 days post injury when the cervical spine is less painful
- Should be realized in case of absence of osseous lesions in the static views (AP, Lateral, open-mouth)

- Patient flexes and extends their own neck under the supervision of the requesting physician.
- No manual flexion/extension should be applied.
- Contraindications:
  - Altered state of consciousness;
  - Documented neurologic deficit;
  - Inability of patient to flex and extend the neck without assistance.

*Dynamic view is particularly useful before 4 years of age to study C2-C3, to avoid overor under-estimated a pseudosubluxation. Reduction of subluxation with neck extension help to differentiate this from more serious disorders.*
- SWISCHUK line: line drawn between the anterior edges of the spinous processes from C1 to C3.
- The anterior edges of the spinous processes of C1, C2, and C3 should line up within 1 mm of each other on both flexion and extension radiographs.

! anterior aspect of posterior arch of C2 should be within 1-2 mm of this line:
- > 2mm → false location C2 on C3
- < 2mm → bilateral intervertebral fracture

Even in this 10 years-old child, with a fusion of the vertebral bodies and posterior articular masses of C2 and C3 (●), C4 and C5 (●), within a malformation syndrome shows that the SWISCHUK line is always tangent to the anterior aspect of spinous processes of C1 to C3.

We note that the SWISCHUK line does not change with age or with the dynamic views (on both flexion and extension radiographs).

Fig. 10: Swischuk line
Fig. 11: atlantodens (predental) space

This interval is the space between the odontoid process and the anterior portion of the ring of C1:
- < 5 mm until 1 year of age.
- < 4 mm until 8 years of age.
- > 3 mm beyond 8 years of age.

An increase in this space may be visible in case of:
- Ligamentous disruption.
- Atlantoaxial subluxation.
- Jefferson fracture Type C1.

The tangent to the cartilage growth (subtle synchondrosis) of the dens must pass through the superior articular facet of C2. (Fig. 11)
**Fig. 12:** Spinal columns and lines

- These landmarks are applicable when pediatric cervical spine reaches adult proportions (> 8 years)

- Normally there will be no abrupt step offs or breaks in continuity in these lines.

**Anterior spinal line**
Along the anterior vertebral body cortex.

**Posterior spinal line**
Along the posterior vertebral body cortex.

**Spinolaminar line**
Formed by the anterior edge of the spinous processes.

- anterior and posterior lines should be traced to the superior aspect of the dens.

Red: middle column
Blue: posterior column
Yellow: anterior column
Green: spinolaminar line

Prevertebral soft-tissue:
- the law of 7: ≤ 7 mm (above C4)
- ≤ 14 mm (below C4)
In children, this physiologic misalignment can be seen below 8 years of age at C2-C3 level and less commonly at C3-C4 level.

In normal circumstances, this anterior displacement occurs in neutral lateral view and flexion view, and should disappear in extension.

It occurs because of increased ligamentous laxity, more horizontal nature of facet joints.

Reduction of subluxation with neck extension help to differentiate this from more serious disorders.

**Fig. 13:** Pseudo-subluxation C2 on C3 (1)
Fig. 14: Pseudo-subluxation C2 on C3 (2)
**Fig. 15:** failure of fusion of synchondroses and absence of primary ossification center
**Fig. 16: Neurocentral synchondrosis**

Neurocentral synchondrosis:

- Fixed location: 3-6 years of age
- They appear as a smooth and regular radiopaque line with a slightly concave profile
- Three possible locations in a sequential progression
  - Must be symmetrical to maintain normal spine alignment
- Sometimes, closure is asymmetric and may be confused with fracture, especially at 3-7 years of age
- The differential diagnosis will be by distinguishing a synchondrosis (arrow) from a bordering synchondrosis

Arteriograms of a pediatric cervical spine at 35 months of age illustrate the typical osteochondral bordering them (arrows).

Arteriograms of the cervical spine of a 4-year-old child show the non-symmetric closure of neurocentral synchondrosis (a) They are seen at right (double arrow). Osteochondroses allow to distinguish them from real fracture, especially in a post-trauma.
Fig. 17: Pseudo-Jefferson fracture

- It is a pseudospread of the atlas on the axis. Ossification of lateral masses may precede that of the body of C2, causing an apparent lateral displacement of the masses in relation to C2.
- True Jefferson fracture is rare before the age of 10.
- It is present in 90% of children of 2 years of age and usually normalizes by 4-6 years.
- Up to 6 mm of displacement of the lateral masses relative to C2 is common in patients up to 4-6 years old.
- Above 6 mm, a C1 fracture with transverse ligament rupture should be suspected, and confirmed by CT.
- Beyond 6 years of age, the lateral masses of C1 and C2 should be perfectly symmetrical.

The interest of the open-mouth radiograph remains disputable because:
- Jefferson fractures are rare and secondary to severe trauma where radiography is replaced by a CT-Scan.
- This pseudo-fracture is present in 90% of children of 2 years of age and usually normalizes by 4-6 years.
**Fig. 18:** Persistence of subdental synchondrosis

It usually fuses between 3-6 years of age. This fusion line (subdental synchondrosis), or the remnant of the cartilaginous synchondrosis, can be seen until 11 years of age. The synchondrosis is always surrounded by a thin and regular sclerotic margins (arrows).

Knowledge of this variant is important to avoid mistaking it for fracture following trauma.
**Fig. 19:** interdental space and laryngo-tracheal airways
Fig. 20: Pseudo-widening of prevertebral soft tissue

- abnormal + thickening of prevertebral soft-tissue (+) is seen on the lateral radiograph in a child of 10 months of age (Fig 1) with a radiographic suspicion of subluxation C2 on C3.
- Under real-time radioscopic (fluoroscopic) control in expiration (Fig 2) and in inspiration (Fig 3), this important widening observed in expiration (arrows) disappears in mild extension and in inspiration (arrows head).

In pediatric patients, widening of the prevertebral soft tissues can be a normal finding that is related to expiration. We have to repeat lateral radiography in mild extension and in inspiration to determine if the apparent soft-tissue abnormality is real.

A prevertebral space of less than 7 mm at the level of C3 is considered normal in children.
Fig. 21: TAKE HOME MESSAGE
Conclusion

Cervical spine injuries in children are usually seen in the upper cervical region owing to its unique biomechanics and anatomy.

Knowledge of the normal development and radiographic features of the pediatric cervical spine can aid in the correct interpretation of plain radiograph in the setting of trauma.

Emergency radiologic analysis of the pediatric cervical spine can be challenging because of wide range of normal anatomic variants and changes that occur with the maturation or ossification process.

Interpretation of a post-traumatic plain radiograph of cervical spine must be based on age of children, localisation and mechanism of the trauma.

Personal information

References


