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The cervical spine in paediatric radiology

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Abstract

Accurate radiological assessment of the cervical spine is vital in the management of the child presenting with trauma. Compared to an adult's spine, the significant differences in the developmental anatomy (variants or synchondrosis), biomechanics and fracture patterns in the paediatric cervical spine makes assessment difficult, even for experienced radiologists. This review discusses the unique biomechanical factors, developmental anatomy, patterns of injury and imaging strategy in the paediatric population.

Key words: Cervical spine; Paediatric; Radiology

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Introduction

Cervical spine injury is rare in children, accounting for only 1–2% of traumatic injuries (Booth, 2012; Jones et al, 2019). In children younger than 5 years of age, the incidence of cervical spine injuries is even lower (approximately 0.4–0.7%), whereas the incidence of traumatic cervical spine injury in adults is about 4% (McAllister et al, 2019). However, it is important to note that when cervical spine injury does occur in children, it is associated with significant neurological sequelae and mortality. Approximately 60% of patients experience permanent neurological deficit, with mortality rates as high as 40% (Booth, 2012), and there is an inverse relationship between the risk of death and the child's age (Shin et al, 2016).

Falls and motor vehicle collisions account for the majority of cases in children under the age of 8 years. In older children, sporting injuries are a more common cause of cervical spine injuries. In addition, non-accidental injury should be considered, particularly if there are signs of a whiplash mechanism of injury or if the clinical history is inconsistent with the pattern of injury (Booth, 2012).

Accurate radiological assessment of the cervical spine is vital in the management of the child presenting with trauma. Compared to the adult's spine, the significant differences in the developmental anatomy (variants or synchondrosis), biomechanics and fracture patterns in the paediatric cervical spine make assessment difficult for even experienced radiologists.

This article discusses the unique biomechanical factors, developmental anatomy, patterns of injury and imaging strategy for cervical spine injuries in the paediatric population.

Biomechanical factors

The cervical spine reaches adult proportions by the age of 8–10 years and the pattern and sequelae of injury beyond the age of 10–12 years is similar to adults. However, in younger children the cervical spine has unique biomechanical features that cause a distinctive location and pattern of injuries (Lustrin et al, 2003).

In children under the age of 8 years the head is disproportionately larger than the body, which sets the centre of gravity more cranially and the fulcrum of movement at the level of C2–3. This means that young children are more likely to have high cervical spine injury, usually between the cranio-cervical junction and the level of C2–3. As the child grows, the position of the fulcrum (and thus the location of injury) moves caudally and reaches the C5–6 level (adult position) by 8–10 years of age (Lustrin et al, 2003).

There are a number of anatomical factors that contribute to hypermobility of the developing cervical spine:

1. The vertebral bodies are wedge shaped anteriorly
2. The intervertebral disc spaces are wider

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Figure 1. Sagittal reconstruction of a computed tomography scan of the cervical spine in a 6-month-old child demonstrating horizontally oriented facet joints.

3. The facets are more horizontally orientated (Figure 1)
4. The supporting muscles and ligaments of the cervical spine are more lax.

These factors result in increased shear and torque forces acting on the C1–2 region, with an increased risk of anterior translation and spinal cord injury without radiographic abnormality. Last, unfused synchondroses are also vulnerable to injury, which may only be picked up by a magnetic resonance imaging (MRI) scan (Lustrin et al, 2003; Booth, 2012).

It is also important to consider ligamentous laxity caused by comorbidities such as rheumatoid arthritis and trisomy 21, which may also increase the risk of cervical spine injury.

Normal developmental anatomy of the paediatric cervical spine

The most challenging aspect in the radiological assessment of the immature cervical spine is the differing appearances relating to age including:

- Unossified synchondrosis
- Apophysis
- Distinctive vertebral architecture.

In addition, the numerous physes (growth plates) compound the difficulty in interpretation as they can be mistaken for fractures.

A knowledge of this normal developmental anatomy is essential to avoid inappropriate misdiagnosis of fracture (Figure 2). Generally, physeal plates are seen in predictable areas and have smooth and sclerotic margins, while fractures are irregular and may not have sclerotic margins (Lustrin et al, 2003).

The vertebral bodies from C3 to L5 have similar developmental anatomy consisting of three ossification centres; one centrum and two neural arches. The two neural arches fuse first, posteriorly, between the ages of 2 and 3 years, followed by the anterior synchondrosis,

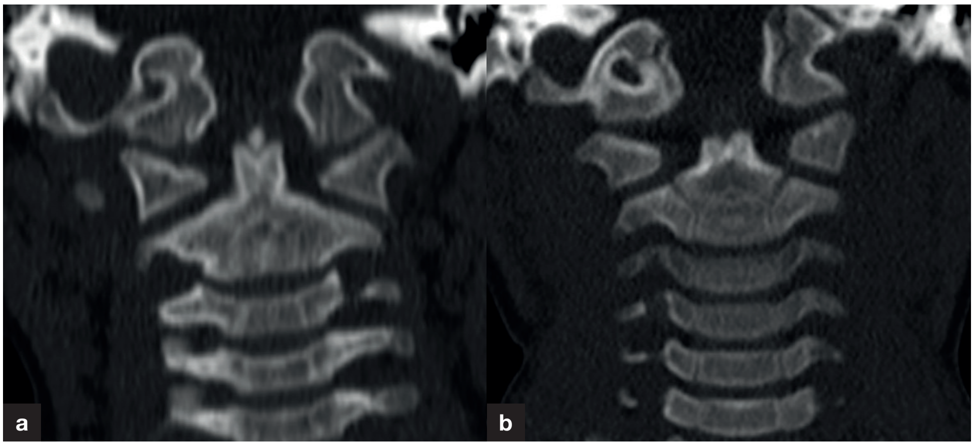

Figure 2. a. Computed tomography scan of the cervical spine reformatted in the coronal plane demonstrating the apicodental ossification centre and synchrodrosis in a 6-year-old. b. Computed tomography scan of the cervical spine reformatted in the coronal plane in a 2-year-old demonstrating that the apicodental ossification centre is not yet developed.

between the centrum and the two neural arches, between the ages of 3 and 6 years (Thavarajah and McKenna, 2012; Offiah and Day, 2017).

It is important to recognise the secondary ossification centres, which are usually seen at the tip of the transverse and spinous processes, and can be seen up to the third decade of life. The first two cervical vertebrae also have unique developmental anatomy which often causes diagnostic difficulty (Lustrin et al, 2003; Kalamchi and Valle, 2021). Figures 3 and 4 illustrate the anatomy of C1 and C2 respectively. Figure 2 shows images from a computed tomography (CT) scan of the cervical spine reformatted in the coronal plane, demonstrating the apicodental ossification centre. This appears between the ages of 3 and 6 years. The apicodental synchondrosis fuses by the age of 10–12 years (Jumah et al, 2017; Offiah and Day, 2017).

Ligamentous anatomy

The two atlantooccipital membranes (anterior and posterior) run from the atlas to the anterior and posterior aspects of the foramen magnum respectively (Figure 5). The apical and tectorial ligaments lie between the two atlantooccipital ligaments. The apical ligament runs from the apex of the dens to the basion. It is a weak ligament and does not contribute much to stability. Posterior to the apical ligament lies the tectorial ligament, which is the continuation of the posterior longitudinal ligament and runs cranially to attach to the anterolateral aspect of the foramen magnum.

The primary stabilisers of the atlantoaxial joint are the cruciform and alar ligaments. The alar ligaments run from the lateral margins of the dens to the medial aspect of the occipital condyles, which allows them to limit contralateral rotation. As a result, injury to the alar ligaments can cause rotational instability.

Imaging strategy for the assessment of paediatric cervical spine trauma

X-rays are the first-line imaging modality in patients who present with a high-risk mechanism of injury, but have typical neurological examination findings.

The Royal College of Radiologists (2014) paediatric trauma protocols and the National Institute of Health and Care Excellence (2016) guidelines (Table 1) recommend the acquisition of three standard views: lateral, anteroposterior and peg view. The peg view should be attempted in any child, of any age, who can cooperate with the view, but can be omitted in any patient that cannot tolerate it.

The lateral view is the most important view as it has a sensitivity of 85% in identifying pathology following trauma. The optimal lateral radiograph should include the craniocervical junction and the T1 vertebral body. Dynamic flexion and extension views should be avoided in the acute setting because of the risk of cord injury, although muscle spasm often precludes

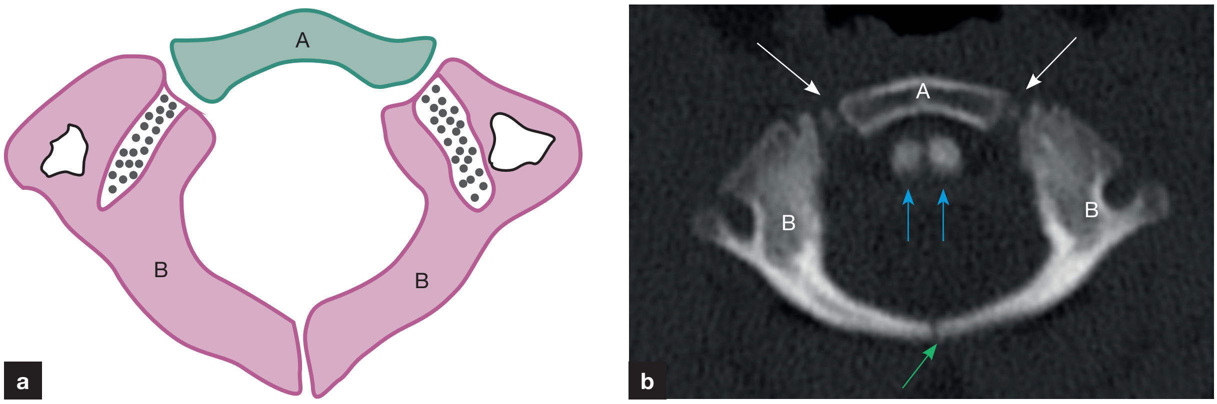

Figure 3. a. Anatomy of the atlas and (b) computed tomography scan of the atlas in the axial plane in a 2-year-old child demonstrates the three ossification centres: A = the anterior arch (ossifies by 1 year of age), B = the two neural arches (ossified at birth). The two anterior synchondrosis (white arrows) and one posterior synchondrosis (green arrow) are demonstrated. The segmented odontoid tip is also seen (blue arrows). The posterior synchondrosis fuses by the age of 3 years and the two anterior synchondrosis fuse by the age of 7 years.

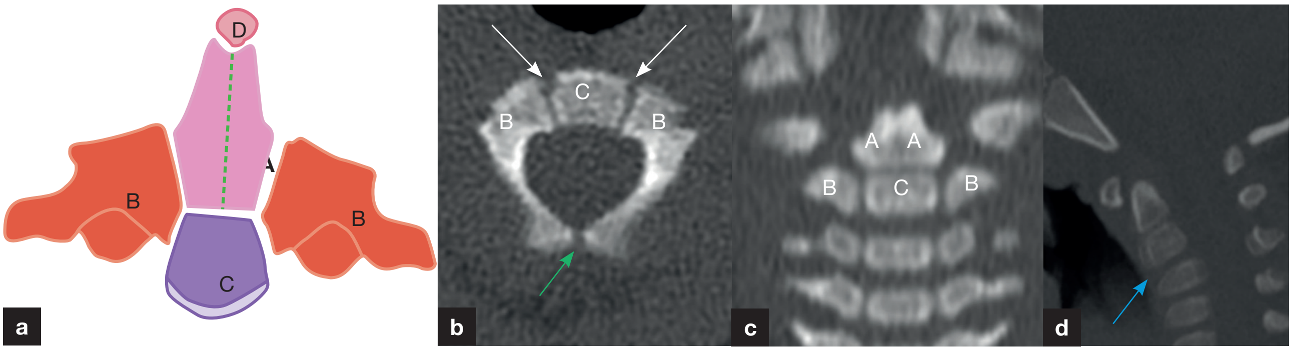

Figure 4. a. Schematic representation of all ossification centres of the axis (C2). Computed tomography images of C2 ossification centres in a 2-year-old child in the (b) axial, (c) coronal and (d) sagittal planes. A = dens ossification centre; B = neural arches; C = centrum; D = odontoid tip. The odontoid synchondrosis (dashed line separating A) fuses in utero at 7 months of fetal life. The green arrow demonstrates the posterior neural synchondrosis, which fuses between the ages of 2–3 years. White arrows represent neurocentral synchondrosis, which fuses between the ages of 3–6 years. On the sagittal image, the blue arrow points to the subdental synchondrosis, which fuses between the ages of 3–6 years. It is important to note that a fusion line may persist here until the age of 11 years and could be mistaken for a fracture. The apicodental synchondrosis is between A and D.

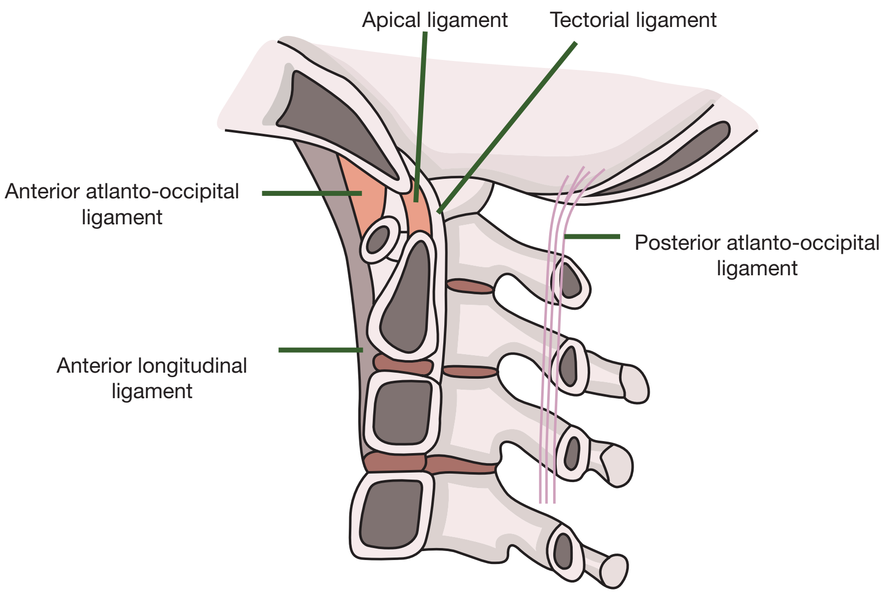

Figure 5. Schematic diagram of the upper cervical spine that shows the atlanto-occipital articulation and ligamentous anatomy, including the tectorial ligament, apical ligament, anterior longitudinal ligament, and anterior/posterior atlanto-occipital ligament.

Table 1. Guidelines for imaging the cervical spine in children presenting with trauma

Use cervical spine computed tomography if	Glasgow Coma Score at presentation <13
	Patient is intubated
	Focal peripheral neurological deficit
	Upper arm paraesthesia
	Other body parts being imaged where there is a high likelihood of associated cervical spine injury
Use cervical spine radiography if computed tomography criteria not met but:	Neck pain and tenderness
	Dangerous mechanism of injury such as fall from >1 metre, fall down five stairs, axial loading (such as diving accident), high speed road traffic collision)

Adapted from National Institute of Health and Care Excellence (2020)

movement. Instead, these views are acquired in patients with MRI-proven ligamentous injuries to assess stability 7–28 days post injury, under the supervision of a spinal surgeon (Copley et al, 2019; National Institute of Health and Care Excellence, 2020).

Further assessment with CT should be carried out if:

- The X-rays are inadequate
- There is still a high clinical suspicion for cervical spine injury
- The X-rays demonstrate a significant injury.

Magnetic resonance imaging

The indications for MRI in the setting of paediatric trauma include patients with neurological deficit and suspicion of ligamentous injury on X-rays or CT (Cassar-Pullicino and Leone, 2017; National Institute of Health and Care Excellence, 2020). The National Institute of Health and Care Excellence guidelines recommend using MRI as the first-line imaging modality in patients with a high risk of spinal cord injury or spinal column injury based on clinical signs and symptoms. A negative MRI examination performed within 2 days of injury is reliable in ruling out substantial ligamentous injury (Cassar-Pullicino and Leone, 2017).

In patients with vertebral misalignment, fractures involving the transverse foramina or a posterior circulation stroke, MRI or CT angiography should be included in the imaging protocol in order to assess the vertebral arteries (National Institute of Health and Care Excellence, 2020).

The advantage of MRI is that it provides excellent soft tissue resolution without any ionising radiation. Unfortunately, young children may not tolerate MRI and sedation or general anaesthesia may be required. The duration of the examination can be shortened by using sequences with short acquisition times.

Assessment of the cervical spine

There are many ways of assessing the cervical spine X-ray but it is essential that the review is systematic and thorough. Figure 6 and Table 2 outline considerations for lateral projection, and Figure 7 and Table 3 outline considerations for the antero-posterior projection.

Pitfalls in the assessment of the cervical spine

Soft tissue thickness

On a lateral spinal X-ray, the prevertebral space in children should measure less than 7 mm at the level of C3 and less than 14 mm below C4. In adults, the normal prevertebral soft tissue thickness is less than 7 mm and 21 mm at levels C3 and C7 respectively. It should be noted that prevertebral soft tissue can appear wider as a result of expiration (such as in a crying child), and, in these cases, if there is persistent clinical concern a repeat X-ray should be obtained in inspiration and mild extension (Adib et al, 2016; Copley et al, 2019).

Developmental wedging of the vertebral body

Cervical vertebrae in children demonstrate typical, developmental anterior wedging, particularly at C3 and C4, where the difference between the posterior and anterior heights of the vertebral bodies can be up to 3 mm. This may be misinterpreted as a compression fracture by an inexperienced radiologist or clinician. As the cervical spine develops, the degree of anterior wedging reduces and the vertebral bodies start acquiring the rectangular morphology of adulthood (Adib et al, 2016; Copley et al, 2019; McAllister et al, 2019) (Figure 8a).

Pseudosubluxation

Pseudosubluxation is typically seen at C2–3 and less frequently at C3–4, where there is slight anterior positioning of one vertebral body over the vertebral body below. On radiographs of the cervical spine, the posterior spinal line will intersect the vertebral body below.

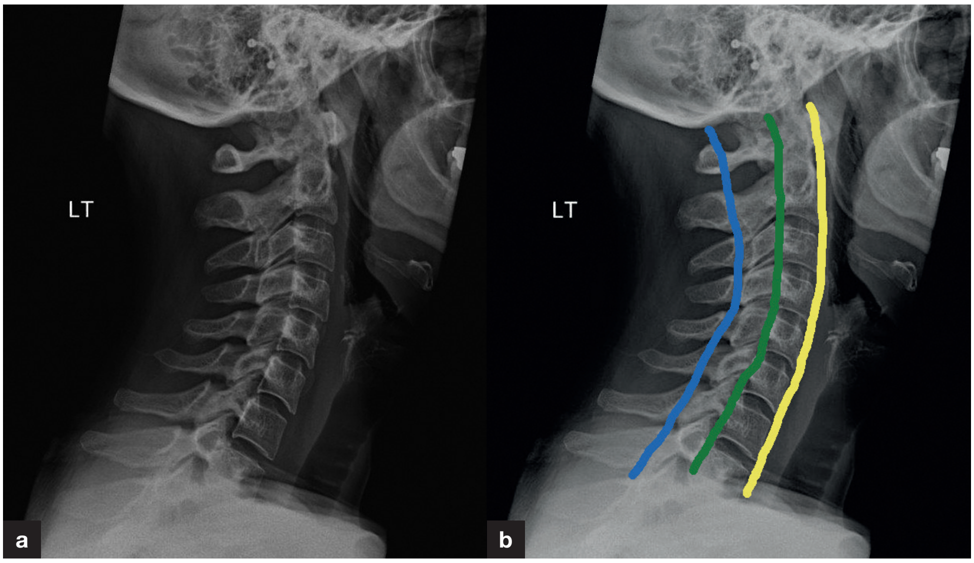

Figure 6. a. Lateral projection. b. Yellow line = anterior line along the course of the anterior longitudinal ligament; green line = posterior line along the course of the posterior longitudinal ligament; blue line = spinolaminar line along the anterior margin of the spinous processes.

Table 2. Assessment of lateral projection

Quality of X-ray	All vertebral bodies from the skull base to T1 vertebral bodies should be visible
Prevertebral soft tissues	The width of the prevertebral soft tissues above the level of the hyoid bone should be no more than half the width of the corresponding vertebral body. Below the hyoid bone it should be no more than the width of the corresponding vertebral body.
Alignment	Anterior line (Figure 6 yellow line): along the course of the anterior longitudinal ligament Posterior line (Figure 6 green line): along the course of the posterior longitudinal ligament Spinolaminar line (Figure 6 blue line): line drawn along the anterior margin of the spinous processes The spinal cord lies between the posterior and spinolaminar line
Interspinous distance	Widening is suggestive of ligamentous injury
Facet joints	The inferior facet of a vertebra articulates with the superior facet of the vertebra below. Look specifically for perched or dislocated facet joints
Bones	Trace the margins of all bones to look for cortical disruption that may indicate a subtle fracture
Intervertebral disc spaces	Disc spaces should be approximately equal in height
Others	Interrogate the remaining structures such as the mandible, teeth, paranasal sinuses, hyoid bone and pituitary fossa Assess the soft tissues for any surgical emphysema

Pseudosubluxation is normal in children under the age of 7 years and occurs as a result of ligamentous laxity and the horizontal orientation of the facet joints. It resolves with age and is very rarely seen beyond the age of 7–10 years.

It is important to differentiate pseudosubluxation from true subluxation:

1. Assess for any soft tissue swelling – this should not be seen in pseudosubluxation
2. Assess the line of Swischuk. This is a vertical spinolaminar line drawn from the anterior margin of the posterior arch of C1 to the anterior margin of the posterior arch of C3. The anterior margin of the posterior arch of C2 should normally lie within 2 mm of this line. A distance >2 mm is concerning as it may indicate true subluxation as seen in a hangman's fracture (C2 bilateral pars interarticularis fracture) (Lustrin et al, 2003; Adib et al, 2016; Copley et al, 2019; McAllister et al, 2019) (Figure 8b).

Differentiating synchondrosis from fractures

It is important not to misdiagnose a normal synchondrosis (physis) as a fracture. Synchondroses are sited in predictable locations between unfused ossification centres, as described earlier. They are well corticated, with smooth, regular borders and subchondral sclerotic lines. Acute fractures, on the other hand, are irregular, and without a defined cortical margin.

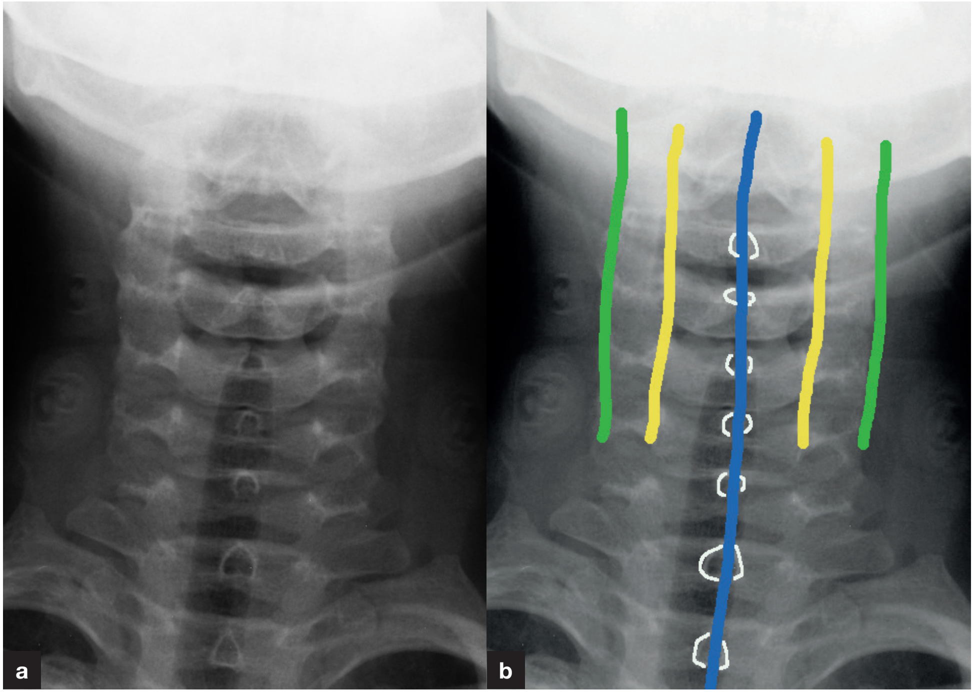

Figure 7. a. Anteroposterior projection. b. Transverse process lines (green), uncinate lines (yellow) and spinous line (blue). The lines should be parallel and equidistant. The spinous processes are highlighted in green.

Table 3. Assessment of the antero-posterior view	
Quality of X-ray	The entire cervical spine and the upper thoracic spine should be included
Alignment	Follow an imaginary line along the lateral edges of the cervical spine to ensure typical vertebral alignment
Spinous processes	Spinous process should align in a straight line and should be evenly spaced. The interspinous distance of two adjacent vertebral bodies must not differ by more than 2 mm
Bones	The height of the vertebral bodies should be approximately equal The margins of the bones should be carefully traced but fractures are typically less conspicuous on the antero-posterior view than the lateral view
Others	Assess the peripheries of the film for fractures of the clavicles and ribs and the lung apices for pneumothoraxes. The soft tissues should be assessed for any surgical emphysema

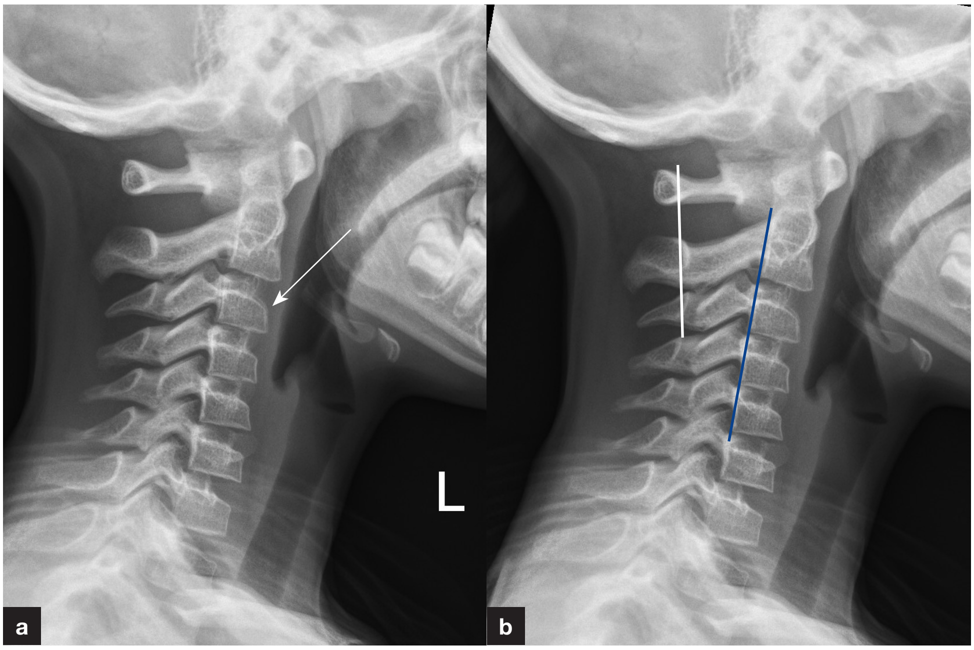

Figure 8. Lateral X-ray of the cervical spine in a 6-year-old demonstrating (a) physiological wedging of the anterior aspect of the superior endplate of C3 (arrow). Notice similar physiological anterior wedging of the vertebral bodies of C3–C7. b. Pseudosubluxation of C2 over C3. The blue line running along the posterior border of the vertebral bodies does not meet the posterior border of C2. However, notice that Swischuk's line (white line) is maintained and the posterior arch of C2 is within 2 mm of this line. Note there is no prevertebral soft tissue swelling.

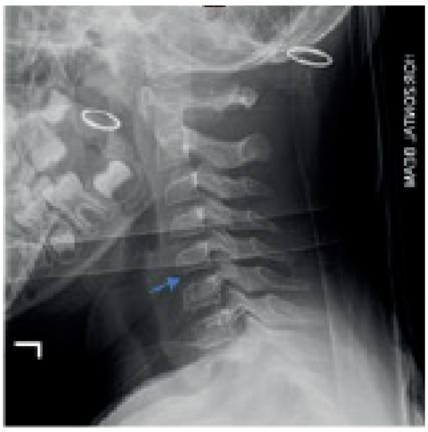

Figure 9. Lateral cervical spine X-ray in a 12-year-old child demonstrates ring apophysis lying above and below the end plates of the cervical vertebrae.

Fractures involving the synchondrosis cause misalignment and abnormal widening of the synchondrosis and adjacent soft tissues. Small osseous fragments adjacent to the synchondrosis may also be indicators of injury. These should be further assessed with MRI (McAllister et al, 2019).

Ring apophysis

The ring apophyses are secondary ossification centres that encircle the superior and inferior end plates of the vertebral bodies (Figure 9). These develop during late childhood and early puberty and are rarely seen under the age of 6 years. By the age of 14 years all the apophyses are present. The superior apophysis fuses by the age of 18 years but the inferior apophysis can be seen in the third decade. The ring apophyses should lie within 1 mm of the vertebral end plates in the craniocaudal axis and within 2.5 mm in the anteroposterior axis (Jaremko et al, 2015; Woo et al, 2018).

Key points

- Accurate radiological assessment of the cervical spine is vital in the management of the child presenting with trauma.
- Understanding the imaging findings in a typical paediatric cervical spine will give greater confidence in interpreting cervical spine imaging of children following trauma.

Conclusions

Although uncommon in children, cervical spine injuries can often be associated with very poor prognosis, both in terms of mortality and long-term neurological sequelae. This article describes the unique developmental features, biomechanical factors, mechanisms of injury and normal morphology in order to assist in the interpretation of imaging of the cervical spine in the context of trauma.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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