Contemporary Pediatric and Adolescent Sports Medicine
Series Editor: Lyle J. Micheli

Lyle Micheli
Cynthia Stein
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Spinal Injuries and Conditions in Young Athletes

Springer

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The mission of the Micheli Center for Sports Injury Prevention is at the heart of the *Contemporary Pediatric and Adolescent Sports Medicine* series.

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The Micheli Center had its official opening in April 2013 and is named after Lyle J. Micheli, one of the world's pioneers in pediatric and adolescent sports medicine. Dr. Micheli is the series editor of *Contemporary Pediatric and Adolescent Sports Medicine*.

Consistent with Dr. Micheli's professional focus over the past 40 years, The Micheli Center conducts world-class medical and scientific research focused on the prevention of sports injuries and the effects of exercise on health and wellness. In addition, the Micheli Center develops innovative methods of promoting exercise in children.

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Dr. Lyle J. Micheli, Series Editor

Dr. Lyle J. Micheli is the series editor of *Contemporary Pediatric and Adolescent Sports Medicine.* Dr. Micheli is regarded as one of the pioneers of pediatric and adolescent sports medicine, a field he has been working in since the early 1970s when he co-founded the USA's first sports medicine clinic for young athletes at Boston Children's Hospital.

Dr. Micheli is now director of the Division of Sports Medicine at Boston Children's Hospital, and Clinical Professor of Orthopaedic Surgery at Harvard Medical School. He is a past president of the American College of Sports Medicine and is currently the Secretary General for the International Federation of Sports Medicine. Dr. Micheli co-chaired the International Olympic Committee consensus on the health and fitness of young people through physical activity and sport.

In addition to many other honors, Dr. Micheli has served as Chairperson of the Massachusetts Governor's Committee on Physical Fitness and Sports, on the Board of Directors of the United States Rugby Football Foundation, as Chairman of the USA Rugby Medical and Risk Management Committee, and on the advisory board of the Bay State Games. He has been the Attending Physician for the Boston Ballet since 1977 and is Medical Consultant to the Boston Ballet School.

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Anatomy and Development of the Young Spine

1

Brian A. Kelly and Brian Snyder

Anatomic changes during the growth and development of the spine put the young athlete at risk for specific injuries of the axial skeleton. As such, a basic understanding of embryology and changes in spine anatomy during growth can inform the clinician regarding mechanisms of injury and specific pathological conditions that affect the structure and function of the spine in the young athlete. Knowledge of the changing anatomy of the spine during growth and development can also provide the clinician with insight as to the range of normal variation as well as an appreciation of the differences between the pediatric and the adult spine and how this can impact interpreting radiographic images of the spine. The goal of this chapter is to review the embryologic development of the spine and pertinent anatomy of the spine in children and adolescents as it changes during normal growth including the identification of common anatomic variants. This anatomic information will serve as the basis for evaluating the structure and function of the young athlete's spine in health and disease.

Embryology

Orientation of the developing embryo begins early in gastrulation. The primitive streak begins to define the longitudinal axis of the embryo on about day 15 of development; during the third week of gestation, cells migrating from this area form the three germinal layers: the endoderm, mesoderm, and ectoderm (Fig. 1.1) [1]. The neural tube also forms at this time, beginning as an infolding of ectodermal tissue that eventually will form the neural elements of the spinal cord. Neural tube defects result from incomplete closure of these in-folding cells. Incomplete closure at the cranial end leads to disorders such as anencephaly, while incomplete closure at the caudal end leads to the spectrum of spina bifida. A group of specialized cells migrate from the cranial portion of the primitive streak and give rise to the notochord, which lies ventral to the developing neural tube. The notochord is the precursor of the vertebral column; it eventually develops into the nucleus pulposus comprising the intervertebral discs and the apical and alar ligaments [2, 3].

The mesodermal cells differentiate into the paraxial, intermediate, and lateral mesoderm (Fig. 1.2). During the fourth and fifth week of gestation, 42–44 pairs of somites form from the paraxial mesoderm on both sides of the notochord. These somites develop in a cranial to caudal fashion to form the skeletal elements and musculature of the face, spine, and thorax. Each somite further differentiates into the sclerotome, which develops into the spinal elements, and the

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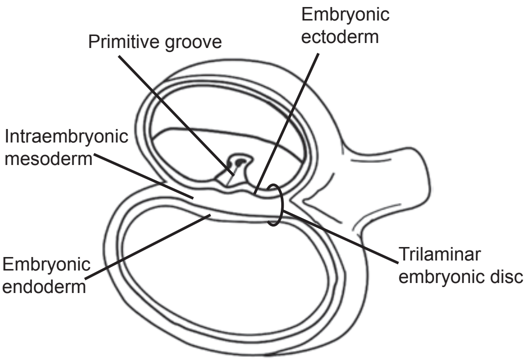


Fig. 1.1 Gastrulation. The primitive streak appears on the bilaminar germ disc on approximately day 15. During the third week, migrating cells from this area become the definitive endoderm and mesoderm

dermatomyotome, which develops into skin and muscle [1].

During the fourth week of gestation, cells from the most cranial sclerotomes begin to migrate and envelop the adjacent notochord. These sclerotomes then divide into a cranial and a caudal half, which will fuse with the adjacent-level sclerotome to form the provertebrae, completing a process known as metameric shift (Fig. 1.3). There are 4 occipital, 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 8–10 coccygeal sclerotomes. These fused segments undergo chondrification during the fifth and sixth weeks of gestation in response to signals from the surrounding tissues to derive the bony elements of the spine [1, 2, 4, 5].

Formation of the spinal elements is a complex, highly regulated process. Any perturbation (i.e., infection, trauma, mutagenic effect of drugs or radiation) during the segmentation and reformation of the sclerotomes can result in abnormal spine anatomy and is frequently associated with abnormalities of other organs such as the heart or kidneys forming simultaneously. The spinal abnormalities consist of either a failure of formation, which produce hemivertebrae, or a failure of segmentation, which produce segmental bony fusions between adjacent vertebrae known as bars [5]. These anomalies can occur in isolation or at multiple levels in various combinations to produce a congenital scoliosis.

Developmental Anatomy

Understanding the pattern of progressive ossification and sequential fusion of synchondroses during the growth and development of the spine is required to properly differentiate apparent discontinuities in vertebrae imaged radiographically from true injuries (Fig. 1.4) [6]. Spinal segments distal to C2 exhibit a similar pattern of ossification and fusion. C1 and C2 are unique in their development and therefore are considered separately.

The C1 vertebra, or atlas, develops from the fourth occipital and first cervical sclerotomes. Three distinct ossification centers develop: the anterior arch and two bilateral posterior neural arches [7]. Twenty percent of children have ossification of the anterior arch at birth, and 50 % undergo ossification of the anterior arch by 1 year of age [4]. The paired posterior neural arches fuse in the midline by 3–4 years of age. The neurocentral synchondroses, between the anterior and posterior neural arches, persist longer and fuse between 6 and 8 years of age [8].

Development of C2, the axis, is considerably more complex. The multiple ossification centers can be confusing when interpreting cervical spine radiographs in children and may be mistaken for fractures [9]. C2 develops from the first and second cervical sclerotomes as five distinct ossification centers. The odontoid process itself begins as two separate ossification centers divided vertically. Fusion of these halves usually occurs by the time of birth, but can persist as a “dens bicornis.” As with the atlas, the neural arches fuse posteriorly by 2–3 years of age [4, 8]. Additionally, the tip of the odontoid process, the os terminale, can appear separately in children aged 3–6 years until it fuses at approximately 12 years of age [10]. As this ossification center is located at the insertion of the apical ligament, it can be mistaken for a type I avulsion fracture of the dens [11, 12].

The dentocentral, or basilar, synchondrosis exists between the body of C2 and the base of the odontoid process. The synchondrosis itself exists inferior to the level of the articular process

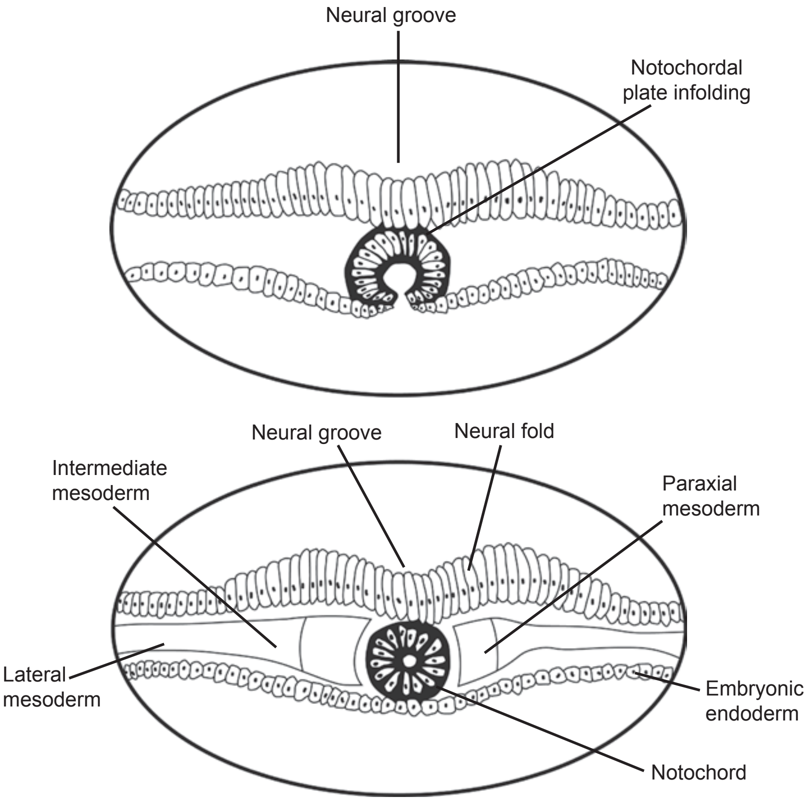


Fig. 1.2 During the third week of gestation, the notochord forms and mesodermal tissue on either side differentiates into paraxial mesoderm. The paraxial mesoderm further differentiates into somites in a cranial to caudal fashion, and 42–44 pairs of somites will form by the end of the fifth week

of the atlas and has a “cork in bottle” appearance on anteroposterior (AP) plain radiographs. Because this synchondrosis fuses later, it can be confused with a dens fracture. The synchondrosis is present in 50 % of children 4–5 years old, and is fused in most children by the age of 6 years [4]. On radiographs, the physeal scar remains visible as a sclerotic line in children up to age 11.

Cervical vertebrae C3 through C7 can be considered together as their growth is similar. Reminiscent of the atlas, these vertebrae begin as three separate ossification centers. The neural arches fuse posteriorly between 2 and 3 years of age. The neurocentral synchondroses fuse between 3 and 6 years of age [8]. The subaxial vertebrae also exhibit secondary ossification centers at either the tips of the transverse processes or the tip of the spinous process that can persist until the third decade of life and can be mistaken for an avulsion on imaging studies [11]. The thoracic and lumbar vertebrae follow much of the same pattern as the subaxial cervical vertebrae.

The sagittal alignment of the spine begins as a single primary kyphotic curve involving the entire length of the spine [3, 13, 14]. As the fetus develops and muscle forces act on the growing spinal column, the secondary lordotic curves of the cervical and lumbar spinal levels begin to develop [15]. This process accelerates when the child begins to load the spine axially during sitting, standing, and walking. These secondary curves continue to progress throughout childhood and adolescence [16, 17].

The spinal canal reaches adult diameters by the age of 6–8 years [18, 19]. Early in gestation, during formation of the spinal cord, the neural elements occupy the entire length of the spinal column. Differential growth between the neural and the vertebral elements causes the terminal aspect of the cord, the conus medullaris, to migrate cranially during fetal development. By 2 months of age, the conus medullaris terminates at approximately the L1–L2 level. After this point in time, growth of the spinal cord and the vertebral

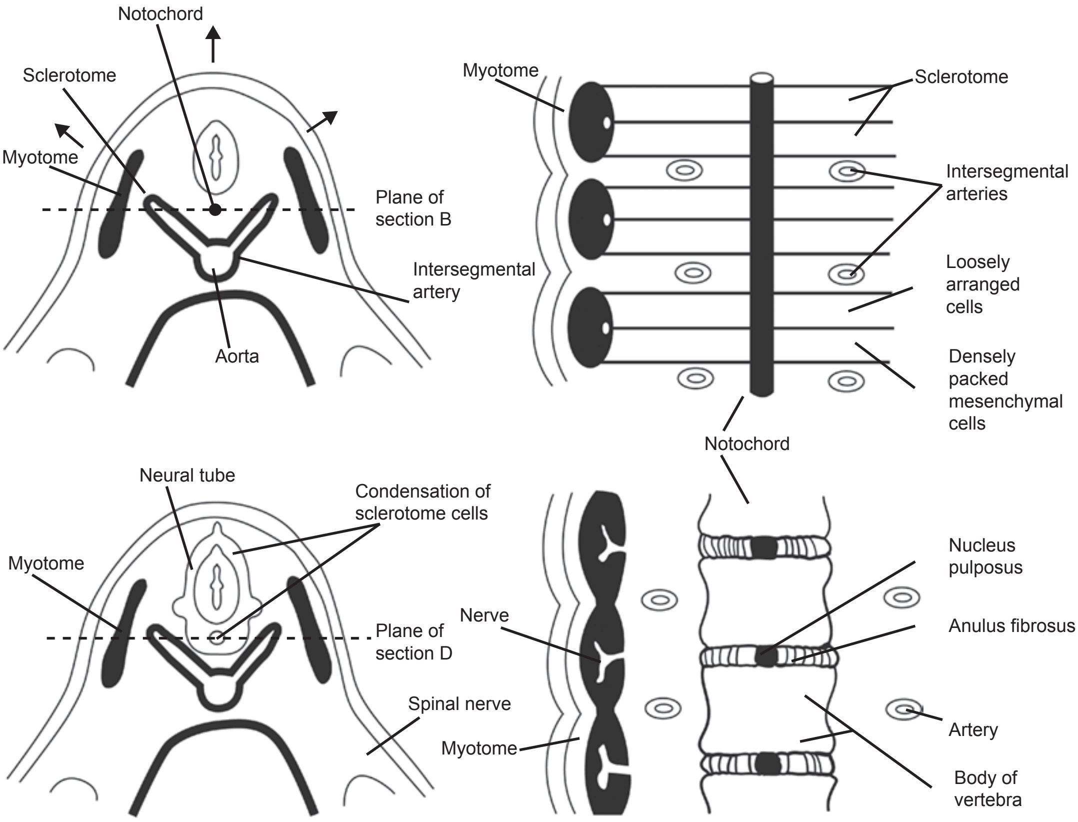


Fig. 1.3 Metameric shift. Starting in the fourth week of gestation, sclerotomes will divide into a cranial and caudal portion and recombine with the adjacent sclerotome. This occurs while segmental nerves grow out to innervate the myotomes

column is relatively symmetric and the conus medullaris remains at the upper end of the lumbar spine [20]. Tethering of the spinal cord during asymmetric growth between the spinal cord and the vertebral column can cause neurologic deficits and scoliosis.

The blood supply to the vertebrae arises segmentally from the intercostal arteries or from nearby arteries in the cervical and lumbar spine. The thoracolumbar spinal cord is supplied by the great anterior radicular artery and paired posterior arteries [18]. In 80 % of individuals, the great anterior radicular artery arises from the left side off an inferior intercostal artery and enters the intervertebral foramina accompanying one of the ventral roots T9–T12 [21]. To limit injury to this artery which supplies the inferior two-thirds of the spinal cord, ligature of vessels during anterior approaches to the spine should be avoided close to the foramen. Innervation of the intervertebral disc arises primarily from the sinuvertebral nerve, a branch off the dorsal root ganglion [22, 23]. A normal vertebra is illustrated in Fig. 1.5.

Cervical Spine

Up to 80 % of pediatric spine injuries involve the cervical spine, underscoring the importance of the anatomy of this region [8]. Nearly 87 % of cervical spine injuries that take place in children under the age of 8 years occur at the C3 level or above (Fig. 1.6) [2]. This is markedly different from the pattern of adult spine injuries, where fewer injuries occur to the cervical spine and the majority of cervical spine injuries that do occur, involve C5 or below. There are several anatomic

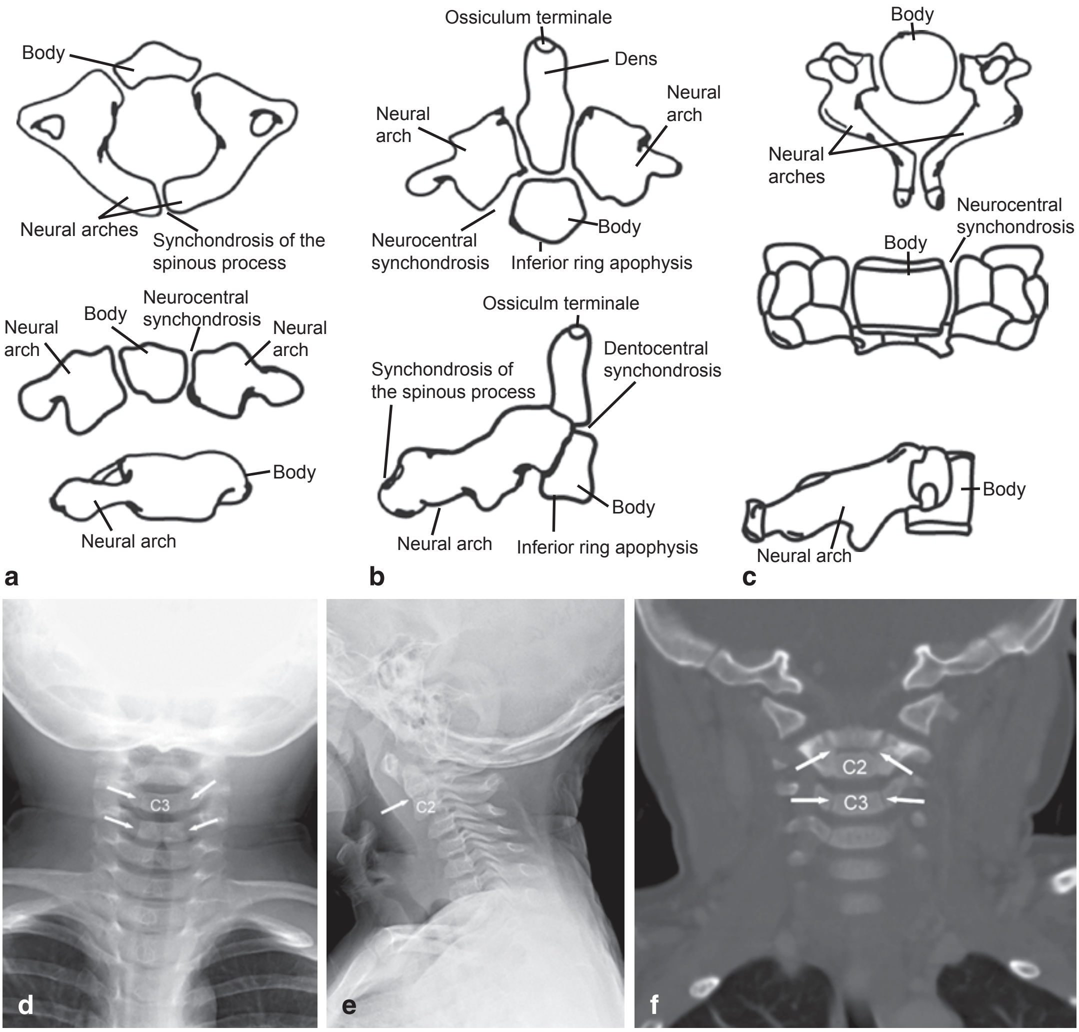


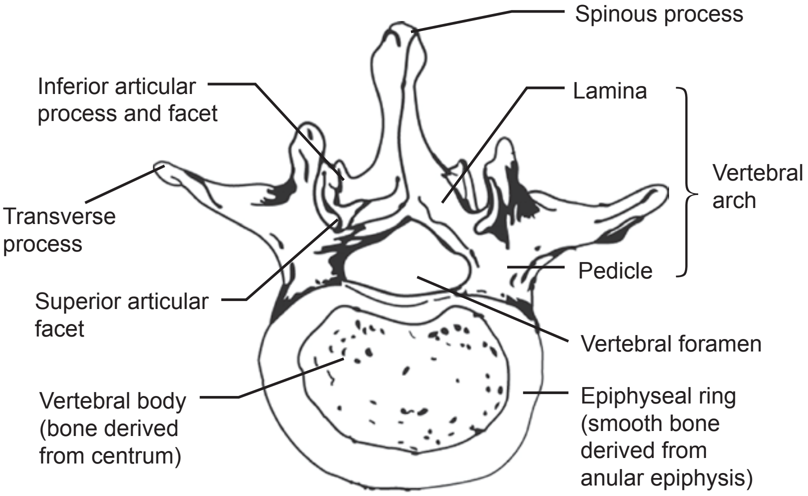
Fig. 1.4 Ossification of cervical vertebrae. Ossification centers and synchondroses of **a** C1, **b** C2, and **c** C3–7. Thoracic and lumbar vertebrae follow a similar pattern as the subaxial vertebrae. Synchondroses of the cervical spine (*arrows*) as seen on **d** AP plain radiograph, **e** lateral plain radiograph, and **f** coronal CT scan

features that account for the differential pattern of spine injuries affecting children and adults [12, 24].

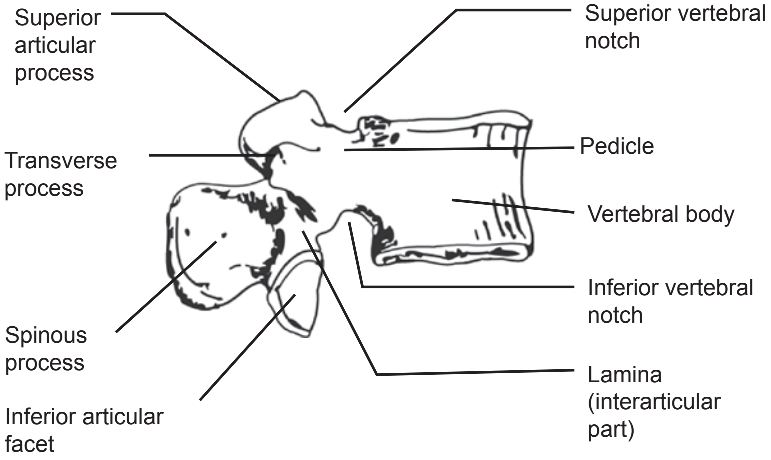
The cervical spine of children differs anatomically from adults in several important ways that contribute to increased motion between spinal segments. Incomplete ossification of both the axis and the dens leads to increased physiologic motion between C1 and C2. At subaxial levels, the facet joints of the cervical spine are shallower and more horizontally oriented at birth, leading to increased translational motion. Early in development, the facets are oriented approximately 30° from the horizontal, but by adolescence, the depth of the facets joint increases and the orientation of the facet increases to 60–70° in the upper cervical spine and 55–70° in the lower cervical spine [25]. Additionally, the uncinate processes, which serve to limit lateral translation and rotation between adjacent cervical vertebrae, are underdeveloped in children. The uncinate processes do not form until approximately age 7 [25].

In addition to specific differences in cervical spine anatomy, children have a proportionally larger head than adults with relatively more weight being supported by the neck. This is

Fig. 1.5 Normal vertebra



Superior view



Lateral view

paired with smaller and less developed musculature which makes head control and stabilizing the neck more difficult for younger children [11]. The increased elasticity of the supporting soft-tissue structures, particularly the interspinous ligaments, posterior capsule, and cartilaginous end plates in the growing child, contributes to the mechanical instability observed in the upper cervical spine and increased propensity for injury to this area [8]. Furthermore, with growth and development there is a change in the kinematic motion of the cervical spine as a consequence of a shift in the instantaneous center of rotation inferiorly. Early in childhood, the instantaneous center of rotation for flexion–extension exists at the C2–C3 level. Changes in the relative size of the head and the structural properties of the vertebrae, surrounding soft tissues, and musculature during growth alter the mechanics of the cervical spine. By the age of 8–10 years, the instantaneous center of rotation shifts inferiorly to the C5–C6 level, where it remains during adulthood [2, 8, 11, 25]. Therefore, the transformation in static and dynamic mechanical properties of the cervical spine that transpire during growth explains the pattern of cervical spine injuries seen in children with a higher incidence of upper cervical spine injuries occurring in children younger than

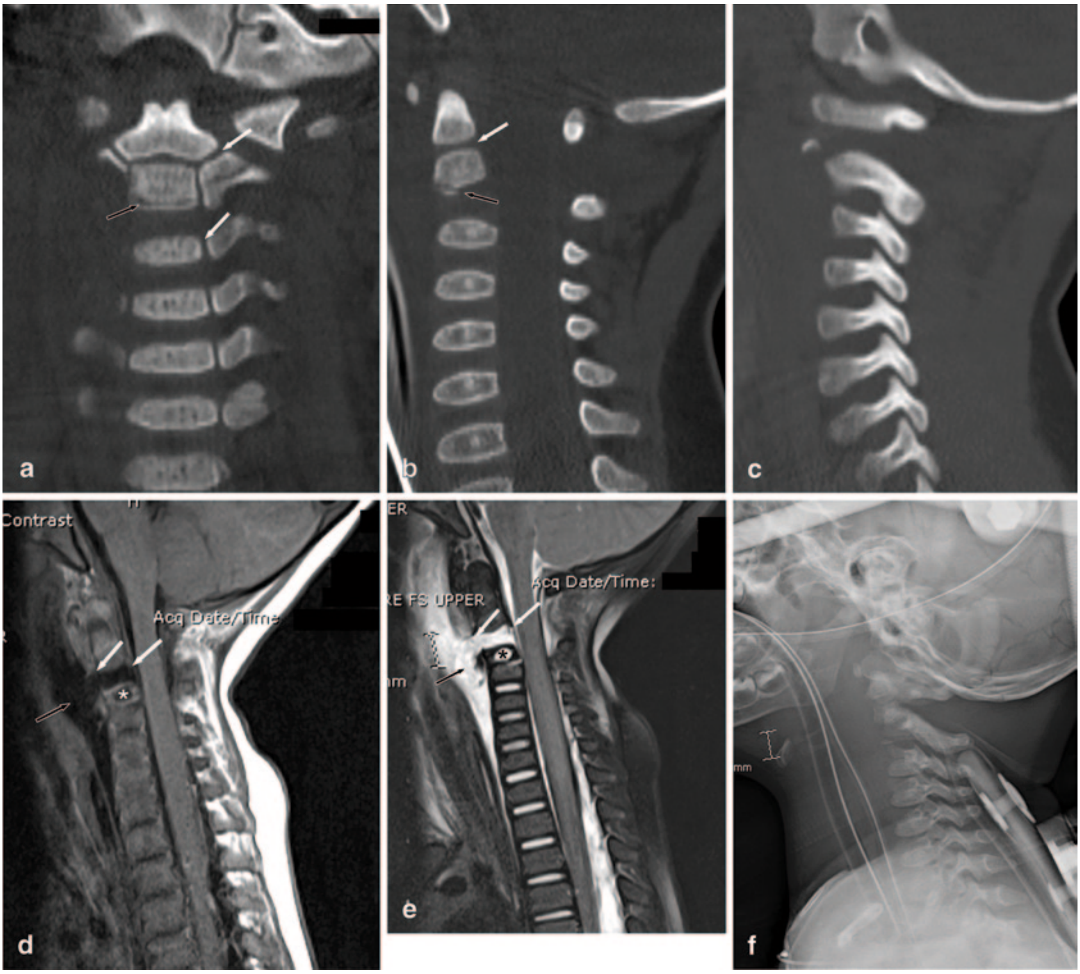


Fig. 1.6 Upper cervical spine injury in a 15-month-old child. The patient suffered a fracture of the inferior end-plate apophysis of C2 in a rollover motor vehicle collision. On coronal CT (**a**) and sagittal CT (**b**), note the differences between normal synchondroses indicated by *white arrows* and fracture of the end-plate apophysis indicated by *black arrows*. Sagittal CT through the facet joints (**c**) illustrates the normal shallow architecture of the joints which contributes to the pattern of upper cervical spine injury in young children. The same injury on T1 (**d**) and T2 (**e**) sagittal MRI, which again demonstrate the fracture, and also the widened disc space (*star*), hematoma (*black arrow*), and injury to ligaments (*white arrows*). Contrast these images with lateral plain radiograph after halo stabilization (**f**) and note the difficulty in interpreting the extent of the injury in a young patient. Many of the concepts discussed later in the chapter can be seen in these images

8 years and lower cervical spine injuries, resembling adults, in children older than 8 years.

Thoracolumbar Spine

Injuries to the thoracic and lumbar spine are less common in children than in adults. Similar to cervical spine injuries, the sagittal contours of the thoracic and lumbar spine segments change during growth affecting the degree of thoracic kyphosis and lumbar lordosis. This shifts the instantaneous center of rotation for these regions of the spine which alters spine kinematics and influences the location of thoracic and lumbar spine injuries in children relative to adults. In children, the most frequent locations for thoracic spine injuries are T6 and T7 and for lumbar spine injuries

L1 and L2, whereas in adults, thoracic fractures occur at T7 and T8, and lumbar fractures occur at the thoracolumbar junction, T12 and L1 [26].

The thoracic spine is unique due to its association with the rib cage. The articulations of the vertebrae with the ribs impart particular rigidity to the thoracic spine. The head of each rib articulates with the vertebral body anterior to the pedicles and the neck articulates with the transverse process. While these joints serve to increase rigidity and stability of this segment of the spine, they also serve to limit motion in the thoracic spine due to the articulation of the ribs with the sternum anteriorly. Motion of the spine is permitted through the costal cartilage as well as through the articulation of the ribs with the sternum [3]. Conversely, motion of the ribs and the chest wall can be affected by the anatomy of the spine. It should, therefore, be emphasized that spine, chest wall, and lung growth are interrelated. Anatomic changes to the ribs or to the spine, whether through injury, congenital abnormality, or iatrogenic causes, can affect chest wall growth and function and therefore respiration [27–29].

The anatomic relationship of the spine to the pelvis has implications to the sagittal balance of the spine as well as to the development of abnormal conditions that can occur in childhood and adolescence. The sacrum has a fixed anatomic relationship to the pelvis, requiring compensation of the spine in the sagittal plane to maintain balance and upright posture [30]. When the sacrum is angled relatively anteriorly relative to the pelvis, the lumbar spine must compensate with increased lordosis to keep the spine balanced and the trunk upright. Increased lumbar lordosis increases the susceptibility of the young athlete to spondylolisthesis, which is a relative translation of one vertebral body relative to another and is most common at the L5–S1 level [31].

Other anatomic variants can predispose the young athlete to lower lumbar conditions. Spondylolysis is a defect or abnormality in the region of the vertebra between the superior and inferior facet joints known as the pars interarticularis. This condition is most commonly seen in the young athlete undergoing repeated hyperextension of the lumbar spine in activities such as gymnastics and rowing [32, 33]. Spina bifida occulta is a common variant in the spectrum of spinal dysraphism in which there is incomplete closure of the posterior bony elements of the spine without herniation of intraspinal contents [34, 35]. This defect occurs in almost 2% of the population and is associated with spondylolysis [36]. Transitional lumbar vertebrae, in which the lower lumbar segments share features of the sacral spine or associate with the sacrum through overgrown transverse processes (e.g., Bertolotti's disease), are a recognized cause of back pain in children and may also be associated with spondylolysis. Transitional vertebrae are thought to be present in 4–8% of the population [37, 38].

Radiographic Variants in the Pediatric Spine

Essential to the proper evaluation of the pediatric spine is an understanding of the radiological anatomy of the growing spine (Table 1.1). When viewing radiographic images of the pediatric spine, it is important to consider the child's age and stage of spinal development to prevent misinterpreting a normal synchondrosis for a fracture. Synchondroses occur in predictable anatomic locations and have smooth, rounded edges with a sclerotic bone border. Fractures present radiographically as irregularly shaped lucencies with non-sclerotic borders in locations atypical for synchondroses [11].

The atlanto-dens interval (ADI) is measured on a lateral radiograph of the cervical spine and represents the distance from the posterior aspect of the anterior arch of C1 to the anterior aspect of the dens of C2 (Fig. 1.7). An increase in this interval might indicate disruption of the ligamentous structures supporting the atlantoaxial joint. In adults, this distance should be less than 2–3 mm, whereas in children up to 8 years of age, an ADI of up to 5 mm can exist with an intact transverse ligament [11, 39, 40]. Up to 20% of children have an ADI of 3–5 mm [41].

Table 1.1 Summary of normal radiographic variants in the pediatric spine

Finding	Children	Adults
ADI	Up to 4–5 mm	<3 mm
Pseudo-Jefferson	Displacement of lateral masses of C1 relative to C2 < 6 mm to age 4–7	No displacement
Wedging	3 mm, most common in C3 body	None
Odontoid epiphysis	Open until as late as 6 years, scar can be seen until age 11	Closed
Pseudosubluxation	Up to 2–3 mm of anterolisthesis, C2 on C3 most common	None
Cervical lordosis	Absent in neutral up to age 16	Present
Overhanging anterior arch C1	Up to two-thirds of arch above dens	None

ADI atlanto-dens interval

Fig. 1.7 Increased atlanto-dens interval (ADI, *arrow*). ADI can be increased in children when compared to adults, with an upper limit of 5 mm up to age 8; 20% of children will have an ADI between 3 and 5 mm

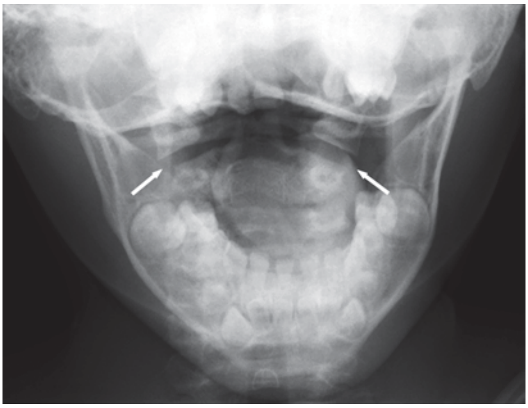


Fig. 1.8 Pseudospread of C1 in a 3-year-old child. On AP odontoid view, the lateral masses of C1 can be seen overhanging the articular surface of C2 (*arrows*). This overhang can be as much as 6 mm in children

When viewing AP odontoid views of C1 and C2, the relationship of the lateral masses of C1 relative to the dens of C2 is different in children compared to adults. In children up to the age of 4–7 years, the displacement of the lateral masses of C1 relative to the articular surface of C2 can be up to 6 mm (Fig. 1.8) [42, 43]. The apparent offset of the lateral masses (pseudospread) can be misinterpreted as a Jefferson fracture of the atlas caused by axial compression that disrupts the ring of C1 [44, 45]. In the pediatric patient, excessive lateral offset does not necessarily represent a fracture or ligamentous injury (pseudo-Jefferson), but is due to incomplete ossification of the dens and lateral masses. Owing to difficulty in obtaining a quality open-mouth view in children, as well as difficulty in interpreting the radiograph, it has been recommended not to obtain this projection in children under the age of 5 [11, 46].

To facilitate interpreting lateral radiographs of the cervical spine for subluxation or listhesis (i.e., anterior or posterior translation of one adjacent vertebral body relative to the other), the spinolaminar line is formed by connecting the anterior portion of consecutive spinous processes to

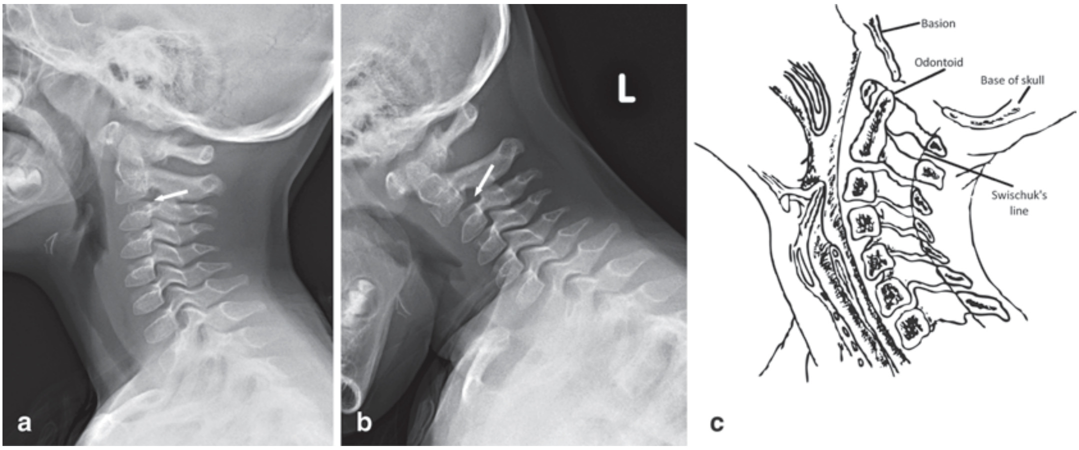


Fig. 1.9 Pseudosubluxation. Appearance of pseudosubluxation (*arrows*) on lateral radiograph in both **a** neutral and **b** flexion. A normal physiologic listhesis can be seen in the c-spine of children, with C2–3 the most common location. This is typically less than 2–3 mm. Further, note the disproportionate increase in distance with flexion between the C1 and C2 spinous processes. **c** The spinolaminar line (Swischuk's line) can be used to differentiate pseudosubluxation from true injury

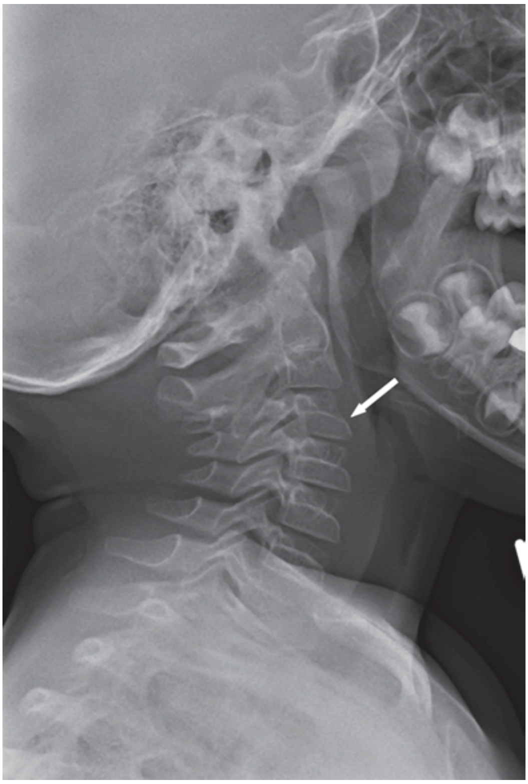


Fig.1.10 Wedging of C3 (*arrow*). A common finding on lateral plain radiographs

create a smooth, unbroken line that passes within 1.5 mm of the spinous process of C2 [47, 48]. A value greater than this is supra-physiologic; it implies listhesis or subluxation. A spinolaminar line distance less than 1.5 mm distinguishes "pseudosubluxation" from true instability patterns in children [11, 39, 49, 50]. Pseudosubluxation is most common at the C2–C3 level followed by the C3–C4 level and can appear as a relative listhesis of up to 2–3 mm between adjacent vertebral bodies (Fig. 1.9) [39]. Pseudosubluxation results from a number of factors, including incomplete ossification of the vertebral bodies, physiologic laxity of ligamentous structures, and facet joint morphology and orientation.

Before the spine becomes completely ossified, the vertebral bodies can appear to be abnormal in shape when imaged using plain radiography. This is most pronounced at C3 where the anterior portion of the body appears to be wedge-shaped on lateral radiographs and is often confused with a wedge compression fracture (Fig. 1.10). Up to a 3 mm difference between the anterior and posterior heights of the vertebral body can be considered physiologic [11]. As ossification of the vertebral body progresses, the vertebrae will take on their

Fig. 1.11 Overriding arch of C1 on lateral radiograph of an 18-month-old child (*arrow*). Up to two-thirds of the arch of C1 can project above the dens in children. Further, note the large head relative to the spine in this younger child

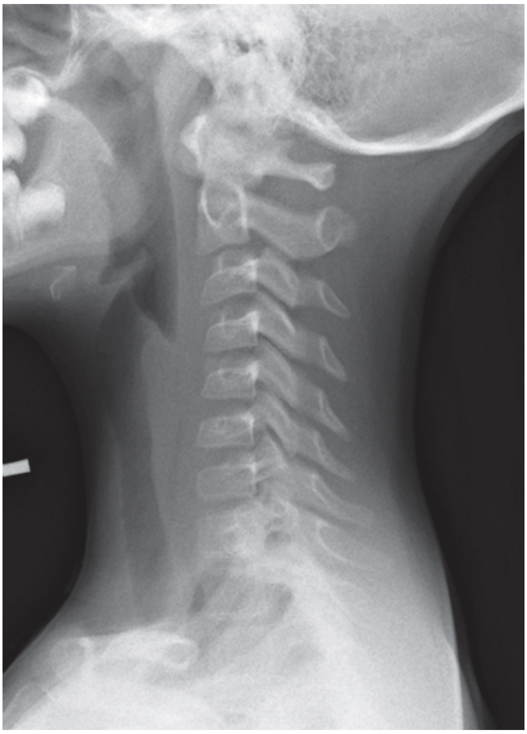


Fig. 1.12 Lack of cervical lordosis in an 8-year-old child

normal rectangular appearance. Complete ossification occurs in a majority of children by 7 years of age, but some mild residual wedging can persist into adolescence [51].

In the adult, the anterior arch of C1 projects anterior to the odontoid process of C2 when imaged in the lateral projection on plain radiographs. As a consequence of incomplete ossification, this relationship can appear abnormal in a child: because the tip of the dens tends to ossify later than the anterior arch of C1, the arch appears to sit superior to and override the dens (Fig. 1.11) [49]. Up to 20% of normal children aged 1–7 years may have up to two-thirds of the anterior arch of C1 project superior to the dens [2, 11].

Cervical spine lordosis normally develops over time. Thus, in children up to age 16, absence of cervical spine lordosis imaged radiographically in the lateral projection with the neck in neutral position may not be indicative of injury (Fig. 1.12) [52]. As a general rule, the distance between consecutive spinous processes should not exceed 1.5 times the interspinous distance of the level above or below. Measurements that exceed this distance might indicate a true flexion-type injury. If flexion and extension lateral radiographs are obtained, it should be noted that in children the posterior occipitocervical ligaments are relatively tighter than the interspinous ligaments, and the distance between C1 and C2 on the flexion view may increase disproportionally [49].

Evaluation of the soft tissues on plain radiographs can be useful in evaluating the cervical spine for injury. Swelling, hemorrhage, or inflammation can increase the projected width of the anterior soft-tissue density observed on lateral radiographs and alert the clinician as to the possibility of an occult injury. In the pediatric patient, the retropharyngeal soft-tissue density should be less than 7 mm, and the retrotracheal space should be less than 14 mm (Fig. 1.13); however, these values can be falsely increased in the screaming or crying child [2, 53].

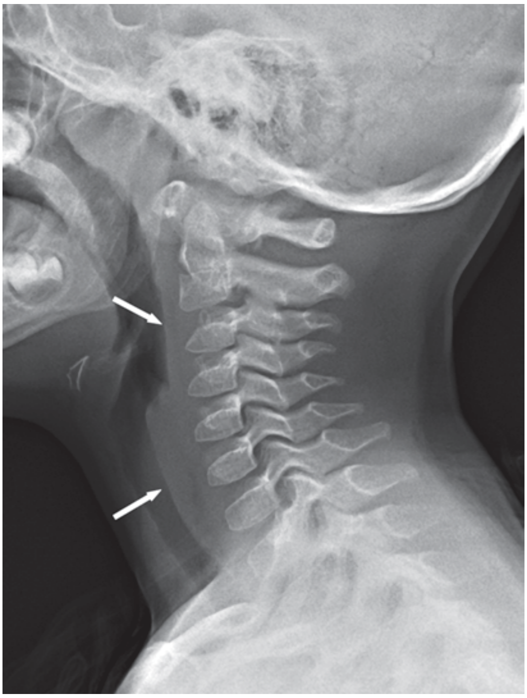


Fig. 1.13 Normal appearance of prevertebral soft tissues on lateral radiograph (*arrows*). Retropharyngeal tissues should not exceed 7 mm while the retrotracheal tissues should not exceed 14 mm

Spinal Cord Injury Without Radiographic Abnormality

A condition unique to the pediatric population is an entity known as "spinal cord injury without radiographic abnormality," or SCIWORA [54]. This is defined as a neurological deficit following trauma in the absence of any identifiable bony or ligamentous injury to the spinal column observed on imaging studies. This phenomenon is a consequence of the differential elasticity of the vertebral column relative to the spinal cord that normally exists in growing children. The ligamentous elements of the spine can stretch up to 5 cm, while the spinal cord can only tolerate approximately 0.5–1 cm of distraction before suffering serious injury or rupture. SCIWORA comprises 18–38 % of cervical spine injuries in children. Magnetic resonance imaging (MRI) is the best imaging modality to define the location and extent of spinal cord trauma in SCIWORA-related injuries [55, 56].

Os Odontoideum

Os odontoideum is a condition that the clinician should be aware of when evaluating the young athlete. It appears as a separate ossicle with smooth cortical margins (Fig. 1.14) [57]. The os is typically seen above the level of the facets, and therefore above the level of the dentocentral synchondrosis. Os odontoideum is often found incidentally on plain radiographs of the cervical spine, frequently without a history of antecedent trauma. It is important to recognize this entity both because it does not represent an acute fracture and because of implications for potential instability during contact sports [58]. It should be distinguished from a nonunion of the os terminale, which is not necessarily associated with spinal instability.

Several theories regarding the etiology of this entity have been proposed, including congenital failure of fusion of the odontoid process or avascular necrosis resulting from trauma. There is now general agreement that os odontoideum is likely secondary to a traumatic process, although a specific incident of cervical spine trauma may be remote or not identified [59].

Summary

Knowledge of the normal development and anatomy of the growing spine is essential for the proper evaluation of the young athlete's spine. Children over the age of 8–10 years tend to experience spine injuries similar to those observed in adults. However, children under 8 years of age are at particular risk for injuries to the upper cervical spine as a result of their relatively larger head size and changes in the structural properties of the vertebrae, surrounding soft tissues, and musculature during growth that alter the static and dynamic mechanical properties of the spine. When viewing radiographic images of the pediatric spine, it is important to consider the child's age and stage of spinal development to prevent misinterpreting a normal synchondrosis or unossified portion of the vertebra as a fracture or injury pattern.

Fig. 1.14 Appearance of os odontoideum in an 18-year-old patient. **a** Lateral extension plain radiograph (*arrow*, anterior arch of C1). **b** Flexion radiograph (*arrow*, anterior arch of C1). **c** Open mouth odontoid view. **d** Sagittal CT scan (*arrow*, os odontoideum)

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