The Spine: Sports-Related Pathology

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Participation in sports by the pediatric population has increased over the years. Youth sports participation carries an inherent risk of injury, including overuse injuries. Acute injuries to the spine in children are uncommon, accounting for only 2–3 % of spinal injuries [1] and for 1 % of pediatric fracture, but contribute to significant morbidity in children. Acute injuries are the same as those that occur in nonsporting accidents, whereas overuse or repetitive trauma injuries are unique to sports medicine and represent approximately between 30 and 50 % of all pediatric sports-related injuries. There are substantial differences between children and adults in the clinical presentation as well as anatomy, diagnosis, treatment, complications, and functional outcome for spine injuries, especially for very young children.

6.1 Acute Injuries

6.1.1 Epidemiology

The incidence of spinal injuries among pediatric patients is variable, depending on age and level of activity. Injury rate and severity increase with age: before puberty, boys and girls are equally likely to sustain sports-related injuries; after puberty, the incidence of injury is greater in boys than in girls and boys tend to sustain more severe injuries, possibly because they play highest-risk games, but for certain sports, such as horse riding, injuries are four times more common in females. The most commonly encountered lesions are soft tissue trauma and include ligament sprains, muscle strains, and soft tissue contusions; fractures and dislocations are uncommon. Between 60 and 80 % of all pediatric vertebral injuries are in the cervical region and about 40 % of these are associated with neurological involvement. This is in contrast to adults in whom cervical injuries constitute only 30–40 % of all vertebral injuries. Most spinal injuries below the age of 12 years involve the atlantoaxial or atlantooccipital joints, although all levels are encountered. Thoracolumbar trauma is rare in children younger than 12 years of age, representing fewer than 8 % [2]. Multilevel contiguous fractures are common, and between 6 and 12 % of patients

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sustaining a spine injury had noncontiguous second fractures [3, 4].

Injury rates vary considerably among sports. The high-risk sports-related or recreation-related activities for acute spinal injuries are contact sports (American football, hockey, rugby , and wrestling), diving, winter sports (skiing, snowboarding, sledding, and tobogganing), horse riding, and gymnastic. A limited number of case reports of spinal trauma have been described in children or adolescents playing basketball or baseball, or following bicycle accidents.

American football is one of the most popular sports played by young athletes in USA. Spinal and axial skeleton injuries occur frequently in football and can result in significant time missed from practices and games. Cervical spine injuries are estimated to occur in 10–15 % of all football players, most commonly in linemen and defensive players. Injuries usually are secondary to high-velocity collisions between players and have a wide spectrum of severity. The burners and stingers syndrome is one of the most common injuries in American football. The cervical cord neurapraxia is a less common and more dangerous injury due to hyperextension, hyperflexion, or axial loading. Serious injuries (e.g., fractures, subluxations, dislocations) remain infrequent. Catastrophic cervical spine injuries with neurological sequelae in football are rare but tragic events. The mean incidence of neurological injury over the past 30 years has been approximately 0.5 per 100,000 participants at high school level and 1.5 per 100,000 at the collegiate level [5].

Cervical injuries in ice hockey are not rare. About half of major spinal injuries occur to players 16–20 years of age [6]. Impact of the head with the boards after being checked or pushed from behind is the most common mechanism of spinal injury. In rugby, cervical spine injuries are uncommon but have received growing attention owing to their often catastrophic nature. The majority of injuries occur after hyperflexion of the neck or after an axial compression mechanism and related “buckling” of the cervical spine [7].

Diving is the most common mechanism of spinal injury from recreational sport. Lesions occur almost exclusively in the cervical spine [8]. Diving accidents often strike young people, particularly children, who are more prone to take risks and fail to understand the consequences. The typical patient profile is of a teenager, athletic male, who suffered an injury to the cervical spine after diving into shallow water, usually during the summer months [9]. Injuries have a high tetraplegia rate, and the most commonly fractured vertebra is C5 [10].

Horseback riding has moderate to high risk of spinal injuries, and it is 20 times as dangerous as motor cycling [11]. In some countries, 70 % of all spine fractures caused by sports activities are sustained by equestrian activities. Other studies evidence that 7–10 % of all riders requiring hospital admission have a spinal injury [12]. As many as one-third of all horse riders are children. Female riders are more likely to be admitted with serious injury, but there are more women riding, and the number of accidents to female riders is probably in proportion to the total number of women riders [12]. Injuries are due to falls, and jumping is the most dangerous horse-riding activity. Lumbar and thoracic fractures are much more common than cervical fractures, the likelihood being that this is due to fall on the buttocks or being thrown against obstructions [13]. Most of the spine fractures occur at the thoracolumbar junction, and this is simply a reflection of the most common location of compression-type fractures.

Spinal injuries in snow sports are relatively rare but are on the increase with the development of acrobatic and high-speed activities on the mountains. Recreational alpine skiing and snowboarding may result in high-energy falls or collisions with other skiers, mountain equipment, or trees, resulting in significant trauma. Skiers usually suffer acute serious spinal injuries from falls or collisions at high speeds, whereas snowboarders are frequently injured from failing attempted jumps. Globally, the majority of severe spinal injuries are related to skiing, but rate of spinal injuries among snowboarders is fourfold that among skiers [14]. There is approximately one significant spinal injury every 100,000 skier-days. Snowboarders tend to fall backward, whereas skiers fall forward [15], so skiers tend to suffer from more cervical spine injuries related to falling forward, whereas those injured snowboarding had higher frequencies of injury to the lumbar spine. Concomitant injuries and multilevel fractures are common. The skiing injuries occurred to novices and top-class skiers alike, with one-third of those sustaining a fracture having associated spinal cord injury (SCI). Cervical spine trauma was associated with the highest likelihood of SCI. Nearly one-third of patients had fractures at more than one vertebral level: these injuries were often contiguous fractures of the vertebral body or transverse process fractures. The majority of thoracolumbar fractures are compression injuries with anterior column failures of less than 25 % vertebral body height [16].

6.2 Relevant Developmental Anatomy

There are certain anatomic and biomechanical differences between the immature spine of pediatric patients and adults. Children have hyperlaxity of ligamentous and capsular structures with hypermobility, poor development of musculature, incomplete ossification with the presence of epiphysis and synchondroses, unique features of the vertebral bony elements (e.g., flatter slope of the cervical facet joint and an immature uncinate process, wedge-shaped vertebral bodies). Younger children have disproportionately larger head than adults.

The subaxial cervical spine, as well as the thoracolumbar vertebrae, all follows a similar pattern of development with three ossification centers (Fig. 6.1): two in the neural arches and one in the centrum. At the puberty, secondary ossification centers appear in the tip of the spinous processes and transverse processes.

The formation of the atlas (C1) and the axis (C2) differs from the typical vertebral pattern. The atlas has three ossification centers

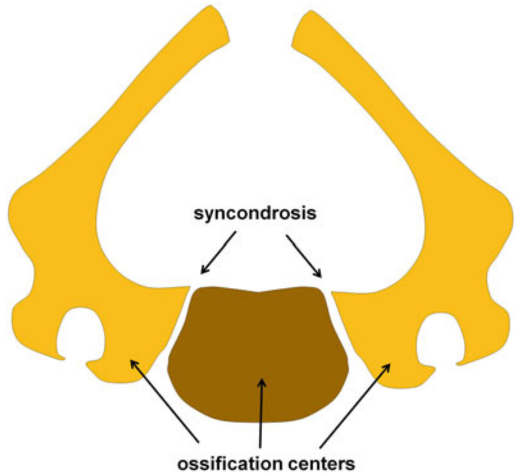

Fig. 6.1 Ossification of a subaxial cervical vertebra at 1 year of age

(Fig. 6.2), consisting of the body and two neural arches; synchondroses occur posteriorly and anteriorly on either side of central ossification center. The axis is formed from five primary ossification centers (Fig. 6.3): the centrum, the two neural arches, and two laterally situated centers that form the odontoid. The ossicle at the tip of the dens (os terminale) typically fuses by 12 years.

Growth of the vertebral bodies continues thoughtout childhood and adolescence and is completed between the ages of 18 and 25. In the immature spine, the intervertebral disk space is occupied by the nucleus pulposus, the annulus fibrosis, and the vertebral end plate. The child's disk has a high water content, is a better shock absorber than the adult, and is more resistant to injury than the vertebral bone. The end plate consists of a layer of hyaline cartilage that covers the surface of the disk and the physeal cartilage adjacent to the bony vertebral body. The physeal cartilage further consists in a physeal plate and a ring apophysis. In the immature spine, the cartilaginous end plate is attached to the ring apophysis and the annulus fibrosis. The ring apophysis develops between the ages of 6 and 8 years in girls and between the ages of 7 and 9 years in boys. At first, many foci of ossification coalesce to form a single rim, surrounding the upper and lower margins of the

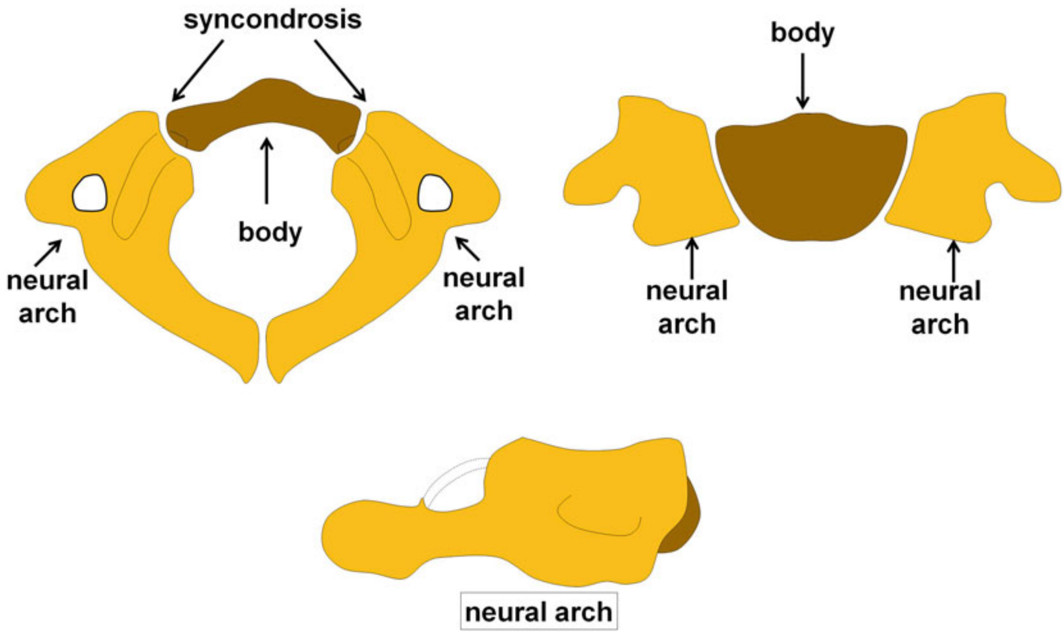

Fig. 6.2 Development of C1 at 1 year of age

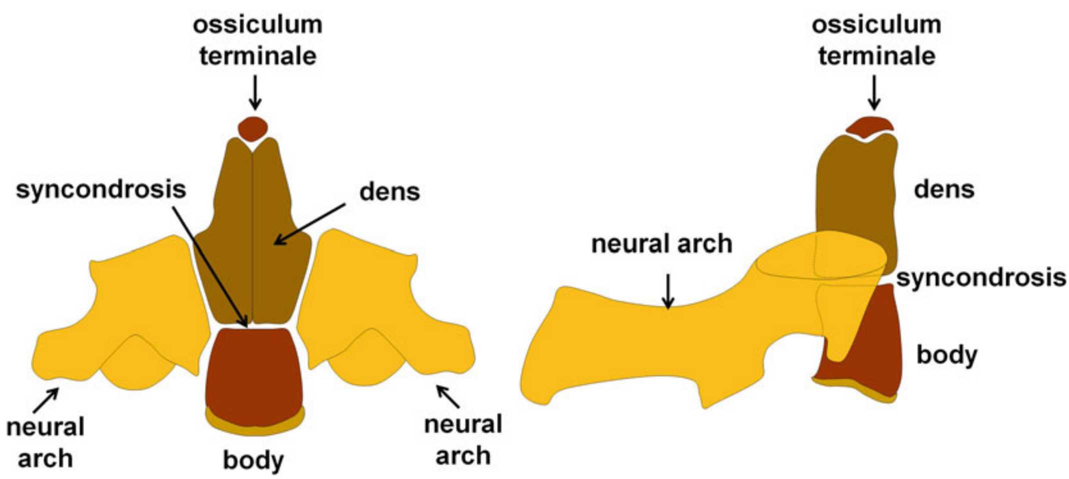

Fig. 6.3 Development of C2 at 1 year of age

vertebral body at the edges of the cartilaginous plate. By 12–15 years, the apophysis starts to ossify, forming the radiological ring. It usually fuses with vertebral body between the ages of 14 and 18 years. The ring apophysis does not specifically contribute to growth of vertebral body, but its fusion signals the cessation of longitudinal growth.

6.3 Cervical Trauma

Injury of the cervical spine in childhood and adolescence is relatively uncommon. There is a predominance of upper cervical lesions over lower cervical (the opposite of that seen in adults), due to increased head size. In children, sporting injury is the most common mechanism of cervical injury after motor vehicle-related accidents.

The most common mechanisms of injuries include athletic (American football, rugby, hockey, wrestling), recreational (skiing, snowboarding, horseback riding, mounting biking), and diving accidents. The most common sports-related injury of the neck is a ligament sprain or muscle strain. They are the result of a fall, impact, or contact with another person, object, or surface. In adolescent athletes, it is described as an equivalent of the clay-shoveler's fracture [17].

Anterior subluxation (hyperflexion sprain) [18] is a purely ligamentous injury associated with three column disruption, and it is the most unstable cervical spinal injury. Subluxation can be missed in plain radiograph because the initial radiological signs are subtle (in supine position), and even when recognized, the injury may not be considered significant. Additional studies, such as flexion–extension radiography and magnetic resonance imaging (MRI), are often used in the acute setting to assess injury status. Radiographically, anterior subluxation is characterized by a localized kyphotic angulation at the level of injury and anterior rotation or displacement of the subluxated vertebra; anterior narrowing and posterior widening of the disk space; widening of the space between the subluxated vertebral body and the subjacent articular masses; displacement of the inferior articulating facets of the subluxated vertebra with respect to their contiguous subjacent facets; and widening of the interspinous space. The treatment for such a kyphotic deformity may consist of surgical fixation of the lesion.

Disk herniations are often degenerative in nature, and such conditions should be considered chronic athletic injuries [19]. Disk herniation is sometimes associated with axial loading and hyperflexion (wrestling, diving, rugby, American football). Immature athletes tend to develop disk herniation at higher level than adults (C3–C4 or C4–C5).

Atlas fractures are extremely uncommon in children. Normal synchondroses should not be misinterpreted as a Jefferson fracture, but before age 7, fractures may occur through the neurocentral synchondroses. The computerized tomogram (CT) scan is the most sensitive tool for the diagnosis of these fractures. Normally, an immobilization with halo vest or halo cast is requested.

Odontoid fractures in young children always occur as an epiphyseal separation of the growth plate at the base of the dens. After the closure of the growth plate, fractures are extremely rare and they follow the patterns seen in adults. Neurological deficit is rare. The treatment for odontoid fractures traditionally has been halo stabilization for 8–12 weeks.

Subaxial cervical spine tends to be seen in the older child, and the injury patterns are similar to those seen in adults. Cervical end plate injury represents the only peculiar lesion. Injury to the physeal end plate is rare, frequently associated with neurological damage, and often unrecognized radiographically. In the subaxial spine, there is a wide variety of fracture types, ranging from simple linear fractures affecting the vertebral bodies or posterior portion of the spine, to complex fractures involving several elements of the spine or many vertebral levels. A fracture may or may not make the spinal column unstable, depending on its type and severity.

The decision to obtain radiographs can be made on the basis of the history and physical examination. Plain radiograph is typically the initial image test for the detection of cervical spinal injuries in traumatized children. In child who is alert, has no cervical tenderness, no painful distracting injuries, no neurological deficits, and is not intoxicated, X-rays are not necessary to exclude an injury.

The standard X-ray series consist in anteroposterior, lateral, and the open-mouth view. The latter is very difficult to obtain under age 8, and it is not useful for diagnosis. The most diagnostic view is the lateral film. Adequate lateral cervical radiograph visualizes the top of T1. Plain radiographs have a high sensitivity for cervical spine injury [21], but interpreting the cervical X-rays in skeletally immature patients is not always easy. Ossification centers may cause confusion as they appear and fuse at various ages.

Disturbance on alignment of the body may arouse concern about underlying occult injury. Special consideration includes the following (Fig. 6.4):

1. Pseudospread of C1 on C2: in open-mouth view, the ossification of the lateral mass of atlas may exceed that of the ossification of C2, simulating an atlas fracture.
2. Odontoid discontinuity (Fig. 6.4b): the synchondrosis in the waist of the dens can be mistaken for a fracture.
3. The atlantodental interval (ADI) in infants and young children can be wider than in adults, with up to 3–5 mm being considered normal (Fig. 6.4a).
4. Retropharyngeal swelling: prevertebral soft tissues are difficult to evaluate in infants and young children and can be up to 8 mm in width, especially when the child is crying (Fig. 6.4e).
5. Pseudosubluxation of the body of C2 on C3 and, less commonly, of C3 on C4: pseudosubluxation is the apparent anterior subluxation, commonly seen in normal pediatric population (Fig. 6.4c). A true ligamentous instability at the C2–C3 is extremely rare. The gliding of C2 on C3 depends on the relative horizontal plane of the articular process in the upper cervical spine but also on the hypermobility with ligamentous laxity. Finally, under age of 8 years, the C2–C3 articulation is the normal fulcrum of the cervical movement, in contrast to the normal fulcrum in adults which occurs at the C5–C6 level.
6. Anterior wedging of C3 (Fig. 6.4d) and C4 is often a normal finding and can be mistaken for compression fracture. Physiologic wedging gradually disappears as the child gets older.
7. Absence of cervical lordosis is a common normal finding seen in child (Fig. 6.4f).

If an upper cervical spine injury is suspected on standard X-rays, a CT scan should be obtained. If initial radiographs are normal and symptoms are continuing, flexion and extension lateral radiographs are needed after paraspinal muscle spasm has subsided. Radicular pain or neurological involvement prompts further evaluation with MRI. In the obtunded and high-risk pediatric trauma patient, high-resolution CT with sagittal and coronal reconstructions should be the basis for cervical spinal clearance, in combination with the interpretation of films by an expert radiologist [21]. Treatment for the cervical injuries depends on severity of diagnosed injury and can range from an individualized cervical spine rehabilitation program for cervical sprains to cervical spine decompression and fusion for more serious bony or ligamentous injury.

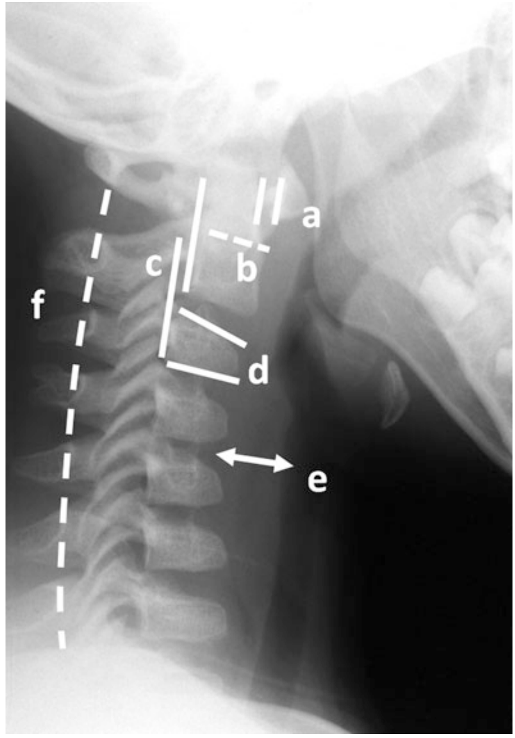

Fig. 6.4 Common normal variations seen in children: **a** widening of the atlantodental interval, **b** odontoid discontinuity, **c** pseudosubluxation of the body of C2 on C3, **d** anterior wedging of C3, **e** retropharyngeal swelling, **f** absence of cervical lordosis

In pediatric cervical injuries, nonoperative treatment is more frequently employed than in adults and the overall prognosis is best in childhood. The current trend is represented by closed reduction and halo immobilization for instable injuries of the C1 and C2. For most patients treated in this manner, adequate bony healing occurs within 12 weeks of halo immobilization. Halo application is different in children: the size of the halo is smaller, the number of pins is higher, the location of pins is different, and less torque is used. Primary operative therapy is recommended for isolated ligamentous injuries of the cervical spine with associated deformity. The surgical procedures performed on children need to take not only their smaller size but also their unique biomechanics into consideration. Surgical dissection should be limited only to the involved levels. Spinal instrumentation is performed according to the type of lesion. The use of allograft bone should be avoided because it often results in poor fusion. Anterior or posterior fusion alone may be not appropriated in young children for the risk of rapidly progressive deformity.

Return-to-play decisions after a cervical injury are controversial [22]. Patients with minor injuries (i.e., spinous process fracture) or non-displaced subaxial fractures have no contraindication to return to sports after healing [19]. Absolute contraindications to return to play are atlantooccipital fusions, three or more levels of fusion, permanent instability of the spine, persistent neurological deficits, residual canal stenosis for fragments or trauma-induced sagittal malalignment. Return-to-play criteria for others conditions include the following: no pain, full range of motion, normal strength, normal neurological evaluation, ability to run and sustain contact without pain, no intake of pain medication, player education about preventive measures and future risks.

6.4 Burners and Stingers

Burners and stingers represent an upper cervical root injury (neurapraxia of a cervical nerve root or brachial plexus), due a traction, compression, or direct blow. Burners are most common in American football players but are also seen in those who participate in hockey, wrestling, and diving. The injury is named for the stinging or burning pain that spreads from the shoulder to the hand. Symptoms are usually transient and resolve quickly. The main treatment is rest until the symptoms disappear and muscle strength is regained. Return-to-play criteria after burners syndrome are resolution of pain and paresthesias, recovery of full range of motion and normal strength, negative brachial plexus stretch, and negative maneuver of axial compression.

6.5 Cervical Cord Neurapraxia

Neurapraxia is defined as transient post-traumatic paralysis of the motor and/or sensory tracts in the spinal cord. It has often been referred to as a “spinal cord concussion,” or “transient quadriplegia.” Although usually seen in athletes in traditional contact sports such as American football, wrestling, and ice hockey, neurapraxia may also be seen in other sport activities in which collisions occur, such as basketball, soccer, gymnastics, and baseball. Penning [23] postulated that an extreme movement can occur in high-velocity injuries, resulting in rapid compression of the spinal cord by the posterior–inferior cervical vertebral body and the subjacent spinal lamina (“pincers effect”). Return-to-play decisions after an episode of neurapraxia are controversial. Athletes with neurapraxia and documented ligamentous instability, MRI evidence of cord defects or swelling, neurological symptoms or signs for greater than 36 h, or more than one recurrence have an absolute contraindication [24]. It is also generally recommended that athletes with neurapraxia secondary to a herniated cervical disk, focal stenosis, or compressive osteophyte are not allowed to participate further in contact sports.

6.6 Thoracolumbar Trauma

The majority of pediatric thoracolumbar spine fractures occur in older children and adolescents [25]. The most common sport-related mechanism of injury is winter sports and horse riding.

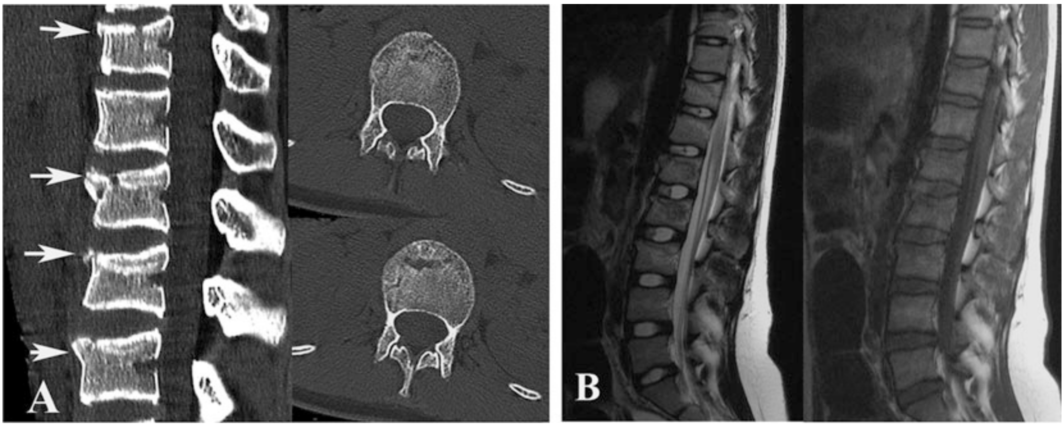

Fig. 6.5 Multiple thoracolumbar fractures in horse-riding child. Reprinted with permission [26]

The principal site of fracture is the thoracic spine, probably because the thorax is much more elastic in children than in adults, and the second most frequently affected site is the thoracolumbar junction. The most frequent fractures include compression fracture (wedge fracture) and fractures of posterior elements (transverse process, spinous process). Multiple contiguous fractures are more common in the child's spine than in the adult (Fig. 6.5). The incidence of neurological injuries in children is less than in adults, occurring between 14 and 35 % of spine fractures, and the prognosis is better. Children with permanent neurological lesions are at great risk of scoliosis formation. Deformities can also occur without neurological lesions when the growth zone of an end plate is affected, but significantly growth disturbance is rare.

There is no classification validated in children, and thoracolumbar fractures are typically described using adult classifications. The more commonly used classification in Europe is the AO/Magerl classification [27], based on the pathomorphological characteristics of the injury. Three mechanisms of injury, of which the effect is shown in the radiographs and CT scans, give name to the three main types: A = compression, B = distraction, and C = rotation fractures. A simple grid, the 3–3–3 scheme of the AO fracture classification, is used in grouping the injuries. Every type has three groups, each of which contains three subgroups with specifications. Type A fractures represent the majority of thoracolumbar fractures in children. Over half of the Type A injuries are wedge fracture (A1) with the intact posterior wall of the vertebral body. These fractures are stable. Burst fractures (A3) are rare in young children [28], but in adolescents have almost the same incidence as in adults. The risk of neurological injury in burst fractures may be more closely related to the level of injury (thoracic) than the degree of spinal canal compromise, as in children the diameter of the canal is relatively larger and incidence of SCI is low despite significant retropulsion of bone fragments.

The diagnosis of thoracolumbar fracture in children may be difficult. The mechanism of the trauma, in combination with the complaints of the patient, generally gives rise to the suspicion of a spinal fracture. The patient's spine must be palpated using log roll to look for tenderness, swelling, bruising, or step off. The clinical examination had a good sensitivity and average specificity; however, missed injuries are common in pediatric patients [29], and clinical examination as a stand-alone screening tool for evaluation of the thoracolumbar spine is often inadequate. Most of spinal fractures in children are demonstrable in plain radiographs. Initial examination should include supine anteroposterior and lateral views of the thoracolumbar spine. Special attention should be given to look for additional levels of injury when a single-level spinal column injury has already been detected. In these patients, radiography showing at least 4 levels above and below the fracture should be performed [4]. Wedge vertebrae in Scheuermann's disease should not be misinterpreted as compression fracture. CT scan is sometimes necessary in suspected unstable fracture or in burst fracture to determine the degrees of canal compromise. MRI is useful in evaluating those patients with neurological injury, especially in cases that cannot be accounted for by osseous disruption on plain radiographs or CT scan. MRI can reveal the injury to the spinal cord, ligaments, annulus fibrosis, disk herniations, and epidural hematomas. Most spine injuries do not need operative treatment [25]. Compression fractures (wedge) in children usually require little treatment, with a good long-term outcome, particularly in those younger than 10 years of age (or Risser sign of 0 or 1). Fractures with less than 10 degrees of wedging require no treatment: after a few days of bed rest and analgesics, early mobilization can begin without a brace [30]. For fractures with a wedge angle greater than 10°, a brace should be prescribed. Most burst fractures and potentially unstable fractures can also be treated with bed rest, casting, and bracing for 8–12 weeks. Long-term studies lack to demonstrate improvement in kyphosis or clinical outcomes with surgical treatment in comparison with those treated conservatively. After rehabilitation, return to play is allowed if there is evidence of radiographic union, resolution of pain, and no neurological deficit. The main indication for surgical intervention is the presence of progressive neurological deterioration in documented spinal cord compression. Stabilization of the affected segment is required in case of unstable fractures. Early decompression and stabilization are indicated in children or adolescents with a partial deficit. Stabilization is also indicated in patients with complete neurological injury to prevent progression of deformity and facilitate nursing care. Prognosis for recovery of neurological injury is related to the severity of the initial damage. Under no circumstances should a laminectomy on its own be performed in patients with a neurological lesion as the risk of a severe post-traumatic kyphosis developing at a later date is great. Although the decision on when to return to play should be made on a case-by-case basis, patients who require a major surgical intervention with a spinal fusion and instrumental fixation may not able to return to participate in that specific sport.

6.7 Fracture of the Posterior Rim

Avulsion or fracture of posterior ring apophysis of lumbar vertebra is not a common clinical entity, and missed injuries are frequent. These fractures are typically seen in adolescents and young adults, because fusion in this area is not complete until the age of 18–25 years. Trauma resulting from strenuous sports activity has been reported as an important mechanism for this injury. Most of these lesions occur in lower lumbar spine. The cervical spine has also been reported as locations of these lesions.

Clinical signs usually imitate those of lumbar disk herniation: the most common symptoms are low-back pain and radicular pain due to nerve root irritation. Other symptoms and signs include paralumbar muscle spasm and tenderness, restricted back motion, tight hamstrings, limping (or a waddling gait with flexed knees), and neurological deficits caused by compressed nerve roots. Clinical signs may also be absent.

Based on the three-dimensional information that was obtained from computer tomography, Takata and colleagues [31] classified the fractures in three types: Type I is a simple separation of the entire arcuate posterior margin of the vertebra, and in this type there is no osseous defect in the posterior part of the vertebral body; Type II is an avulsion fracture of the posterior rim of the vertebral body, including a rim of bone; and Type III is a more localized fracture. Epstein and colleagues [32] added Type IV, a fracture of both cephalad and caudal end plates, which spans the full length of the posterior margin of vertebral body.

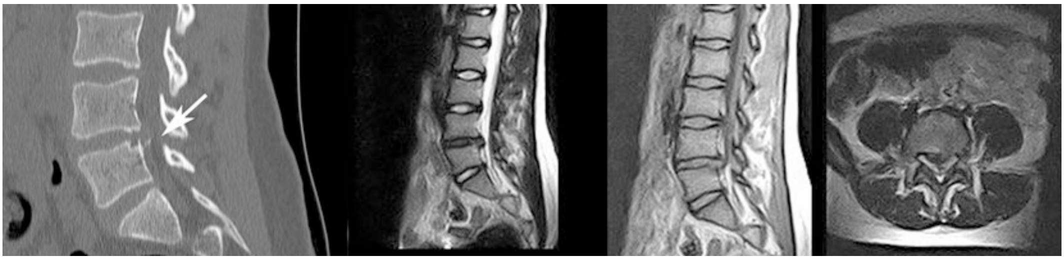

Fig. 6.6 CT scan and MR images of a 12-year-old boy with an avulsion fracture of the posterior rim of L5. The fragment is recognized only in computed tomography (*white arrow*)

For early detection of epiphyseal fracture, computerized tomography is recommended to show bony component of herniated material; posterior lumbar vertebral apophyseal ring fractures may be difficult to visualize on MRI imaging and MRI findings are less specific than CT signs. MRI can show prolapsed intervertebral disks (Fig. 6.6) and any associated nerve root compression useful for guiding surgical decision and intervention. Plain film radiographs of the lumbar spine show no abnormalities in many cases (but radiological signs of Scheuermann's disease are present in 50 % of the cases).

Treatment for this condition is not standardized. Conservative treatment such as rest, analgesics, modification of activity, and physical therapy should be used initially. The indication for surgical decompression is failure of conservative treatment, with persistent back pain adversely affecting the patient's ability to function, with or without neurological deficits. Usually, Type I fracture occurs in children less than 14 years and respond to conservative treatment well. Type II fracture occurs in somewhat older children between 14 and 18 years, and they also respond to conservative regimen with some potentiality for operative treatment. The most used surgical options are laminectomy with posterior discectomy and simultaneous excision of apophyseal fragments without spine fusion. Surgical outcomes are usually favorable, but recurrence requiring further surgery is seldom reported.

6.8 Spinal Cord Injuries

Spinal cord injuries constitute uncommon but nonetheless devastating occurrences to those participating in athletic events. The exact incidence of pediatric SCI is unknown, but reports vary from 1 to 10 % of all spinal cord injuries. These injuries happen primarily to athletes involved in the contact sports of American football, wrestling, and ice hockey, with football injuries constituting the largest number of cases. Spinal cord injuries can produce complete neurological loss or any of wide variety of incomplete patterns. Injury to the spinal cord in the cervical region, with associated loss of muscle strength in all 4 extremities, is termed tetraplegia (that replaces the term quadriplegia). Paraplegia is an injury in the spinal cord in the thoracic, lumbar, or sacral segments, including the cauda equina and conus medullaris.

SCI can be sustained through different mechanisms, with the following 3 common abnormalities leading to tissue damage: destruction from direct trauma; compression by retropulsed bone fragments into the canal, hematoma, or disk material; ischemia from damage or impingement on the spinal arteries.

The American Spinal Injury Association (ASIA) and the International Spinal Cord Society (ISCoS) published a system of tests used to define and describe the extent and severity of a patient's SCI, called the *International Standards* *for Neurological and Functional Classification of Spinal Cord Injury* (ISNCSCI), widely used to document sensory and motor impairments, following SCI. The standard classification can be used in subjects older than 6 years [33]. It is based on neurological responses, touch and pinprick sensations tested in each dermatome, and strength of ten key muscles on each side of the body. Traumatic SCI is classified into five categories on the ASIA Impairment Scale: A indicates a "complete" SCI where no motor or sensory function is preserved in the sacral segments S4–S5. Complete SCI usually does not recover. B indicates an "incomplete" SCI where sensory but not motor function is preserved below the neurological level and includes the sacral segments S4–S5. C indicates an "incomplete" SCI where motor function is preserved below the neurological level and more than half of key muscles below the neurological level have a muscle grade of less than 3, which indicates active movement with full range of motion against gravity. D indicates an "incomplete" SCI where motor function is preserved below the neurological level and at least half of the key muscles below the neurological level have a muscle grade of 3 or more. E indicates "normal" where motor and sensory scores are normal. The incomplete clinical syndromes are the *central cord syndrome* (incomplete loss of motor function with a disproportionate weakness of the upper extremities as compared with the lower extremities), the *anterior spinal cord syndrome* (complete loss of all motor function below the level of injury, in addition to loss of sensation of pain and temperature), the *Brown-Sequard syndrome* has been classically described as hemisection of the spinal cord with loss of ipsilateral motor function and contralateral spinothalamic (pain and temperature) modalities, the *posterior cord syndrome* (loss of proprioception and epicritic sensation below the level of injury with motor function, sense of pain, and sensitivity to light touch intact), the *conus midollaris syndrome* injury to the sacral cord and lumbar nerve roots leading to areflexic bladder, bowel, the *cauda equina syndrome* injury to the lumbosacral nerve roots in the spinal canal, leading to areflexic bladder, bowel, with varying neurological involvement of the lower limbs. In children, incomplete SCI have high rate of neurological improvement.

The initial assessment of an injured player, who is suspected of having a vertebral column or SCI, begins by consideration of basic life support. The athlete should not be moved unless it is absolutely essential to maintain the airway, breathing, or circulation. The patients must be immediately immobilized and transported carefully to avoid neurological injury. When it becomes necessary to move the athlete, the head and trunk must be moved as one unit. Due to the difficulty in attaining a definitive exclusion regarding the possibility of spinal injury in an on-field setting, it is recommended that any athlete with significant neck or spine pain, diminished level of consciousness, or significant neurological deficits be transported, in an appropriate manner, to an emergency department, where a more formal neurological examination can be conducted and serial assessments can be completed with definitive diagnosis. In American football, neither the helmet nor the shoulder pads should be removed. Only the face mask, if present, should be removed, before transportation. At the hospital, the helmet is manually and carefully removed without moving the neck. Cervical spine injuries in children tend to displace on a standard spine board because of the relatively larger size of a child's head. There are special pediatric spine boards with head "cut out," or alternatively, the cervical spine flexion can be corrected by placing a folded towel or a bump under the patient's shoulders.

The principles involved in treatment for pediatric SCI are similar to those established in adults. Patients with severe spinal cord injuries diagnosed within 8 h of injury are usually administered a 24-h course of methylprednisolone based on the recommendation of the National Acute Spinal Cord Injury Study III , but the use of steroids in traumatic SCI in children is controversial [34]. Patients who have a demonstrable spinal cord compression and are having progressively worsening neurological deficits secondary to a fracture fragment impinging on the spinal cord, epidural hematoma, or extruded disk causing compression are candidates for early surgery. The main principles of treatment are correction of any spinal column deformity, decompression of the spinal cord if present, and recognition and management of unstable segments of the spine. The question of whether to allow an athlete to return to contact sports after a documented or suspected spinal injury has always been an issue. Any athlete who suffers a neurological injury to the spinal cord ordinarily should not be allowed to return.

6.9 SCIWORA

Spinal injury may also occur in the absence of a bony abnormality. This entity has been defined as SCIWORA, an acronyms that stands for spinal cord injury without radiological abnormalities. The estimated incidence of SCIWORA varies widely from 8 to 50 %, depending on the definition. The SCIWORA is usually defined as an SCI with no abnormality depicted on conventional radiography or CT scans. Younger patients account for 2/3 of all SCIWORA injuries and have a higher proportion of complete neurological injuries. Adolescents show a far less frequent incidence of complete SCI due to SCIWORA. This kind of SCI may occur in any location, but it is most common in the cervical spine.

SCI may be sustained as a result of lesser elasticity of the neural elements compared with that of the immature cervical spine structure in response to deforming stresses. The other suggested cause of SCIWORA is ischemia that results from direct vessel injury or hypoperfusion of the spinal cord parenchyma. Alternately, the pathology may be a radiographically inapparent fracture through vertebral cartilaginous end plate.

Profound or progressive paralysis occurs immediately or after a short latency period (usually within 48 h); transient symptoms can also occur, such as numbness, paresthesias, or paresis. This delay in diagnosis may be secondary to the development of spinal cord ischemia or spinal instability. The prognosis of SCIWORA depends on the degree of SCI. Once a SCIWORA injury is diagnosed, the child is at increased risk of recurrence of this episode. Recurrent injuries are typically more severe than initial injuries and may have permanent sequelae. Immobilization seems unnecessary in children with SCIWORA, but the data are conflicting and many centers maintain patients in external braces such as a stiff cervical collar for several months in order to prevent further injury.

6.10 Overuse Injuries

Spondylolysis and spondylolisthesis are the most common overuse injuries of the lower back in sport, especially in growing adolescents. The term of spondylolisthesis indicates a pathologic condition due to a forward slippage of one vertebra over the one below and can be considered one of the costs paid to the upright position. Spondylolisthesis can be secondary to a variety of causes, as well as differ sharply in terms of clinical characteristics and radiographic appearance. These considerations, together with factors such as severity, etiology, age, gender, and evolution, indicate the need for a case-by-case differentiation. Use of blanket term spondylolisthesis contributes little to the fulfillment of practical needs. Each case must be examined on its own merits, to ensure unerringly accurate diagnosis and to serve as the basis for correct treatment.

To achieve the most exact classification of spondylolisthesis is not only a scientific but, perhaps even more, a practical necessity. Classifications must be clear, simple, and comprehensive and based on totally unequivocal criteria. In 1997, Marchetti and Bartolozzi [35] proposed a new classification that has been internationally accepted and widely utilized. It distinguishes two main groups of spondylolisthesis: the developmental and the acquired with their subgroups (Table 6.1). Spondylolysis and spondylolisthesis in young athletes due to sport activities have to be classified as “acquired

Table 6.1 Marchetti and Bartolozzi classification system of spondylolisthesis [36]

Developmental
High dysplastic
• With lysis
• With elongation
Low dysplastic
• With lysis
• With elongation
Acquired
Traumatic
• Acute fracture
• Stress fracture
Post-surgery
• Direct surgery
• Indirect surgery
Pathological
• Local pathology
• Systemic pathology
Degenerative
• Primary
• Secondary

traumatic" even if it is not always possible to demonstrate that the lesion was not preexistent the beginning of the athletic training.

We distinguish two subgroups in the traumatic form: the ones due to an acute fracture and the others due to a stress fracture. In both cases, the fracture is the result of an efficient trauma in an essentially normal bone. When the trauma would be insufficient under normal conditions but results in fracture associated with congenital dysplasia, the spondylolisthesis is classified as developmental. The bony lesions characteristics of true acute traumatic spondylolisthesis occur not so much in the pars as in the articular masses. The injury is associated with fractures of the transverse processes and, frequently, with injuries to abdominal organs. These are generally cases of high-energy trauma. Traumatic spondylolysis caused by a true acute fracture of the pars rarely is observed with a mild slip; traumatic spondylolisthesis usually follows severe injury with various degrees of listhesis. Mild cases usually heal with a simple immobilization, whereas severe cases generally require surgical stabilization.

Stress fractures of the bony hook are an interesting form of spondylolisthesis and are common among those involved in competitive sports, such as gymnastics and weight lifting. The site of the lesion is usually the neural arch. Many authors have shown that athletes can have intact L4 and L5 vertebrae at the outset of their competitive careers but present a high incidence of isthmic spondylolysis or spondylolisthesis after some years. The pars is the weakest site on the bony hook and is the most subject to stress. The pars interarticularis of the posterior lumbar vertebral arch is a narrow bridge of cortical bone joining the lamina and inferior articular facet to the pedicle and superior facet. Repeated stress injury of the pars may lead to fatigue failure producing a fracture. Persistent motion through the fracture may result in the establishment of a pseudarthrosis. The aim of this chapter is the detection and treatment for this lesion.

The forces acting on the pars during flexion and extension of the spine are very strong. In flexion, resistance is applied to the spinous process; the lower part of the pars is subjected to forces of compression, and the upper portion is subjected to forces of traction. On the contrary, in extension of the spine, resistance is applied to the lower articular process. The forces acting on the lower portion of the pars are those of traction, whereas those acting on the upper part are those of compression. The frequency of lysis is not only of the isthmus, but also at the level of the pedicles and of the lamina so that more properly we define "isthmic" lysis, pedicle lysis or lamina lysis, often associated, is increased by the widespread of the CT scan (Fig. 6.7).

When the lysis occurs, the antisliding function of the arch is compromised. If the intervertebral disk, in association with the ligaments that are the structures absorbing the sliding forces, is whole, the lysis is not followed by the listhesis. Only after a progressive degeneration or an acute lesion of the disk, the listhesis could occur.

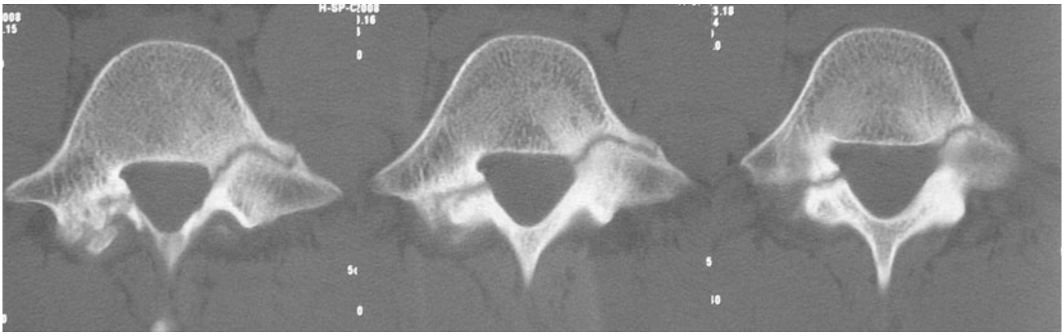

Fig. 6.7 A 17-year-old athlete presented with low-back pain: CT images reveled spondylolysis in the right pars interarticularis and lysis of the left pedicle of L5

People with these injuries typically present because of activity-related lumbar pain. Because spinal pain in the adolescent and young adult is a worrisome symptom, a careful evaluation is warranted when symptoms do not disappear. In the athletically active person particularly, the possibility of a pars interarticularis stress reaction or stress fracture should be considered. An acute injury resulting in a pars interarticularis fracture is unusual. Symptoms are gradual in onset, activity-related, and largely relieved with rest. Only when spondylolisthesis has occurred, neurological symptoms and associated hamstring muscle tightness are present and it is an exceptional situation. Although plain radiography, especially oblique views, may be revealing, they may not show a recent injury. In this respect, a pars interarticularis fracture is similar to a fatigue fracture of the metatarsus. If suspicion warrants a single-photon emission computed tomography (SPECT) scan is most useful in confirming the presence of a stress lesion. This kind of instrumental examination is not as specific as sensitive. For this reason, if positive, it should be followed by a CT scan of the suspect area. Whereas the SPECT scan may be indicative of metabolic activity, the CT scan will reveal whether actual fracture of the pars has occurred. Regardless of the treatment elected, the CT scan will be the most helpful study in determining the progress or lack thereof in healing of the pars.

Even if bracing of an established spondylolysis (or even spondylolisthesis) with clinical symptoms has been discussed, this lesion may have potential consequences: contralateral pedicle fracture, contralateral lamina fracture, spondylolisthesis, or subjacent disk degeneration. Thus, at least in the symptomatic person, treatment would appear to be indicated. Non-operative treatment should provide satisfactory resolution of symptoms in the person with pain, a stress reaction but no established fracture. In this situation, the SPECT scan will reveal metabolic activity and the CT scan will show thickening of the pars. Avoidance of aggravating activity or the use of a brace has been effective treatments.

If a fracture has occurred and SPECT scan is positive, a trial of brace immobilization is warranted.

A period of 3 months is to be considered enough to understand whether or not this mode of treatment will be successful. Again, the CT is most helpful in reexamining the pars for evidence of healing. However, if a pseudarthrosis of the pars is clearly established, as evidenced by rounding of the fracture edges or inactivity on SPECT scan, then conservative treatment with a brace will have little prospect of obtaining union of the fracture. If the pain is resolved, the usual question is the follow: “May I take up the usual sport activity again?” The permission has to be carefully evaluated and only if the pain does not reappear. In these circumstances or if the pain compromises the daily activities, the surgical solution has to be considered.

In a symptomatic young patient with an established lesion of the neural arch, the surgical options are as follows: the direct repair or the stabilization of the motion segment. The direct repair has to follow the principles of treatment for a pseudarthrosis: debridement of the lesion and grafting with autologous bone, plus stabilization with different possibilities (Scot method with wire fixation or pedicle screw and sublaminar hooks). We must consider that this kind of surgery is not a minor one, that the risk of failure in the repair is high, and that a direct repair in case of listhesis ignores a certain degree of degeneration of the disk. The stabilization of the motion segment is a more aggressive procedure and modifies the normal anatomy, especially in young patients. The posterior fixation with screws and bars has to be completed with intersomatic cages (PLIF, TLIF, etc.) to avoid the risk of breakage of the instruments. The arthrodesis is posterolateral utilizing the laminar morselized bone. The surgical procedure is more delicate and demanding. After a surgical treatment, the young patient would have to be allowed to return to the previous sport activity.

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