Anatomy of the pediatric spine and spine injuries in young athletes

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Abstract: Injuries to the spine in a young athlete can be devastating. They can also be very challenging to diagnose due to the anatomical and radiologic differences between the adult and the pediatric spine. A thorough history and full physical examination is of the utmost importance for evaluating any spine injury. This allows an understanding of possible injuries prior to any advanced imaging. Most injuries will require at least a standard set of radiographs, but many injury patterns will require further imaging. MRI is the preferred imaging modality in the pediatric population over CT scan due to the lack of ionizing radiation. Injuries range in severity from a muscle strain to fractures to spinal cord neurapraxias. The primary goal for treatment of these injuries is to prevent any long-term complications in this young population. The secondary goal of treatment is to return the pediatric athlete to the sport of their choice. With prompt and proper treatment both goals are attained most of the time.

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Introduction

Injuries to the spine in the young athlete can range from minor muscle strains to life changing devastating injuries of the spinal cord. It is important to understand the unique anatomy of the pediatric spine before trying to understand the injury patterns. In addition to this, once must recognize developmental and congenital abnormalities that can occur in the pediatric spine. Proper diagnosis and treatment of pediatric spine injuries is essential for good long-term outcomes.

Anatomy of the child spine

Developmental anatomy

C1

The C1 vertebra, atlas, has three ossification centers. The anterior arch and two posterior neural arches. The anterior arch undergoes ossification by age 1 approximately 50% of the time and the posterior neural arches fuses in the midline by 3–4 years of age (1). The anterior and posterior neural arches fuse at 6–8 years of age.

C2

The C2 vertebra, axis, has multiple ossification centers. This is very important to understand when interpreting radiographs in the pediatric spine. There are five separate ossification centers of the axis. The odontoid process begins as two separate ossification centers that fuse by the time of birth. The neural arches fuse at around 2–3 years of age. The tip of the odontoid process fuses generally at 12 years of age, this can appear radiographically like a type 1 dens fracture (avulsion fracture). The basilar synchondrosis between the body of C2 and the odontoid process fuses by the age of 6 years old and a physeal scar can remain visible until 11 years of age (1).

Sub axial cervical vertebrae and thoracolumbar vertebrae

The remaining cervical vertebrae, sub axial vertebrae, and the thoracolumbar spine share very similar development patterns. Each of these vertebrae begin as three distinct ossification centers. The neural arches fuse posteriorly between 2 to 3 years of age. The anterior and posterior neural arches fuse between 3 and 6 years of age (1). These vertebrae also have separate ossification centers at the transverse processes and the tips of the spinous processes that can appear to be avulsion fractures on radiographs (1). These can persist until the third decade of life.

The spinal cord occupies the entire length of the spinal column during gestation. Differential growth of the vertebra and the neural elements leads to cephalad migrations of the conus medullaris during development. The conus medullaris ends at around the L1–2 level at 2 months of age, which is where it remains during the remainder of childhood into adulthood.

Radiographic evaluation of pediatric spine

Understanding the developmental stages of the pediatric spine is essential to the radiographic evaluation of these athletes. The developmental age of the child must be considered when interpreting between the pathologic conditions versus normal findings in the pediatric spine, such as fractures and synchondrosis (1,2). A fracture will present as an irregular shaped lucency in an atypical location for a synchondrosis, while a synchondrosis will present with in a predictable anatomic location with smooth rounded sclerotic edges (1). Other radiographic parameters that should be evaluated on lateral radiographs are the retropharyngeal space, which should be less than 7 mm, and the retro tracheal space, which should be less than 14 mm (1-3).

Radiographic variants of the pediatric cervical spine

Children also have other normal radiographic variants that would be abnormal if present on an adult spine radiograph. The atlanto-dens interval is the distance between the anterior arch of C1 to the anterior aspect of the dens. In adults, this distance should be around 2–3 mm, while in children this measurement can be up to 5 mm without an indication of disruption of the transverse ligament (4). Pediatric patients can have displacement of the lateral masses of C1 relative to C2 of <6 mm prior to the age of 7, adults do not have displacement of the lateral masses (4). This is due to incomplete ossification of the dens and the lateral masses. An open mouth odontoid view thus has limited clinical utility in children of this age range. The cervical vertebrae in the pediatric spine can also appear to have an abnormal shape on lateral radiographs, as they tend to have a wedged shaped appearance which can be confused with a wedge compression fracture. Complete ossification of the cervical vertebrae is complete by 7 years of age (4). There is commonly a lack of cervical lordosis until the age of 16 years old.

Spinal mechanics of the young athlete

Besides the anatomical and radiologic differences of the pediatric spine there is also a difference in the biomechanics between the adult and pediatric spine. These biomechanical differences are the results of increased flexibility, relative muscle weakness, and incomplete ossification of the osseous components of the spinal column. Pediatric athletes who participate in sports place undue stress on the developing spine leading to overuse type injuries, such as spondylolysis which will be discussed later.

Acute cervical spine injuries

Introduction/general evaluation

The majority of pediatric spinal injuries involve the cervical spine. Thankfully, most of these injuries are mild in nature and rarely does severe spinal cord damage occur during a sport event. Of injuries involving the cervical spine in children around 87% of them affect the C3 level and above (5,6). There is a bimodal age distribution of injury with a peak between 13–15 years of age in boys and another peak around 5 years of age without gender predisposition (5,6). This differs greatly from adults where the majority of cervical injuries affect the C5 level and below (6). This difference can be explained anatomically and biomechanically.

Firstly, there is increased motion between each of the individual spinal segments in the pediatric cervical spine. Incomplete ossification of the axis and the dens allows for increased the motion at the C1–2 joint. In the sub axial cervical spine, facet joints are shallower and horizontally oriented at birth leading to increased translational motion (1). Second, the uncinate processes are underdeveloped in children, which limits the ability of these structures to prevent excessive lateral translation and rotation between adjacent cervical vertebrae (1,7). Third, children have a proportionally larger head than adults and less developed musculature which makes stabilization of the neck much harder for young children.

The biomechanical reason for an increase in upper cervical spine injury in children is due to a shifted center of rotation (COR) compared to the adult cervical spine (1). The COR of the cervical spine shifts to the adult level (C5–6) at the age of 8–10 years old. Prior to this time the COR of the cervical spine is located at the C2–3 level.

Presentation/imaging

After an injury to the cervical spine there should be a prompt evaluation of the child athlete. These injuries can range from mild unilateral neck pain to spinal cord injury. In the case of mild neck pain frequently no imaging will be needed, and the athlete can return to play once he is symptom free. In cases where a more severe injury is suspected the initial imaging study of choice is an AP and lateral cervical spine radiograph (7). If the child is older than 8 years of age an open mouth odontoid view can be obtained as well. Interpretation of cervical spine radiographs in the pediatric population can be difficult. When evaluating for C2–3 instability/subluxation assessment of the spinolaminar line is the most reliable way to detect true injury versus pseudo subluxation (8). The ADI can be used to measure for C1–2 instability, but in young children an ADI up to 5 mm can be normal (1,9,10).

CT scans of the cervical spine are frequently used in the pediatric population when there is clinical concern for a cervical spine fracture or instability (11,12). While there is risk regarding the dosage of radiation in this young population, the risk of missing a cervical spine injury is too great to forgo this imaging modality (13). The sensitivity of CT scan for cervical spine fracture up to 100%, while plain radiographs had a sensitivity for 62% in one study (11,12). Additional studies have determined that CT scan is more likely to be clinically useful in older children who have similar injury patterns to adults where as young children tend to have more purely ligamentous injuries. An MRI of the cervical spine will frequently be necessary in the pediatric population due to the concern for injury to soft tissues that could indicate cervical instability in the absence of a fracture (13).

Muscle strain

Muscle strains are the most common cervical spine injury to young athletes. These injuries will present as unilateral neck pain from a direct injury or from a stretch on the muscle. These injuries will carry no neurological findings or any red flag signs on physical examination. There is no need for imaging for these injuries, if the patient is cleared after a thorough examination by a physician. The treatment for these injuries is rest, anti-inflammatories, and ice/heat. The patient can return to play after they are symptom free.

Neuropraxias

Neuropraxias are the most common injury pattern in the pediatric cervical spine after simple muscle strains. These injuries range from temporary stingers to cervical cord neuropraxias and the treatment between the varying injuries greatly differs.

Stingers

Stingers are the most common neurologic injury in the pediatric athlete (14,15). These injuries occur most often during football or rugby, but can occur in other sports as well. The mechanism of injury is either a forced stretching of the head away from the affected limb which results in traction of the C5 and C6 nerve roots or a forced compression of the head towards the affected limb causing neuroforaminal narrowing resulting in a compression of the nerve root (16,17). The symptoms of a stinger are burning and weakness in the affected limb, which returns to baseline function within 10 minutes. A diagnosis of a stinger can only be made if the symptoms are felt in one limb. Unless multiple stingers have occurred or there has been an incomplete resolution of symptoms there is little reason to obtain imaging for this self-limited condition. A return to play can occur as soon as the patient is asymptomatic and has full painless range of motion in the neck (18). If the symptoms are felt in multiple limbs a spinal cord related event is likely to have occurred, which would automatically rule out the athlete from returning to play until further imaging studies are performed (16).

Cervical cord neurapraxia

A cervical cord neuropraxia should be differentiated from a stinger, due to the presence of symptoms in greater than one limb. These injuries present with a transient quadriplegia with loss of sensation in the extremities. Typically, motor function recovers very quickly, with a slower recovery of sensory function. These injuries are typically the result of congenital cervical stenosis in the adult population, but this has not been shown in the pediatric population (16). As multiple studies have shown that children with cervical cord neurapraxias had Torg ratios >0.8 (16).

Due to the mobility of the cervical spine in the child athlete from more compliant ligaments, underdeveloped paraspinal musculature, increased water content of intervertebral discs, and immature facet joints there is more likely to be a stretch related injury to the cervical spine. A cervical cord neurapraxia in the child athlete after a traumatic event is thought to be a mild form of the injury pattern called Spinal Cord Injury without Radiographic Abnormality (SCIWRA) (19). This injury pattern is unique to the pediatric population and is defined as a neurologic deficit without any obvious bony or ligamentous injuries to the spinal column. This is due to the differential elasticity of the spinal cord, which can stretch around 0.5 cm, and the vertebral column, which can stretch up to 5 cm (19). Due to the lack of an obvious injury pattern on standard radiographs a high index of suspicion is needed for diagnosis of this pathology. For any child with a neurological deficit following a trauma to the cervical spine an MRI should be obtained to the define the location of the spinal cord trauma. Often, both plain radiographs and MRI are normal. Fortunately, most children will make a complete recovery from cervical cord neurapraxia.

Return to play guidelines are not clear for this injury but the pediatric population has not shown to be at increased risk for a repeat cervical cord neurapraxia like the adult population has. Many children have returned to athletics after this injury without evidence of recurrence (16,18). However, there are guidelines for contraindications to return to play in the adult population that translate to the pediatric population in cervical cord neurapraxia, which are ligamentous instability, a single neurapraxic event with evidence of cord damage, multiple events, and/or events with symptoms lasting longer than 36 hours (16).

Fractures

Cervical spine fractures in pediatric athletes are quite rare, when these injuries happen they frequently occur from the occiput to C3 (2). Sub-axial cervical spine fractures are very uncommon in the pediatric athlete, but can occur as the child approaches his/her teenage years and young adulthood. The cervical spine fractures seen in young athletes are C1 ring fractures, odontoid fractures, and as stated before sub-axial cervical spine fractures (14,20). Even in the teenage and young adult population sub-axial spine injuries only account for around 25% of fractures.

C1 ring fractures

C1 ring fractures are very uncommon injuries. The mechanism of injury is axial compression with neck extension (14). The force required for this injury is usually only seen in car accidents or high velocity trauma, but can occur with more high impact sports such as hockey and football. Treatment of this fracture is usually non-operative with a Minerva cast which is used instead of a traditional halo vest in the pediatric population. This injury is very rare and return to play guidelines do not exist for this fracture in the pediatric population. In the adult population this fracture is a relative contraindication to return to contact sports (18).

Odontoid fractures

Odontoid fractures are one of the more common pediatric cervical spine fractures. They usually occur after a forced hyperflexion. They can be seen in football and other high impact sports. In the pediatric population these fractures occur at the synchondrosis of C2, located at the base of the odontoid (14). These fractures tend to displace anteriorly with posterior angulation of the odontoid. These fractures can be visualized on lateral radiographs of the cervical spine. There fractures can be reduced with extension and posterior translation. Definitive treatment is generally a Minerva cast. The risk of non-union is very low and these fractures tend to heal between 6–10 weeks' time. There is no consensus for return to play in the pediatric population, but this injury is a relative contraindication to contact sports in adults (18).

Sub-axial cervical spine fractures

These injuries occur more frequently in older adolescents and teenagers. The most common injury patterns include compression fractures, burst fractures, and facet fracture/dislocations. These fractures patterns are treated as they would be in the adult population and will not be the focus of this review article.

Instabilities

Children are more likely to develop instability from a ligamentous injury of the cervical spine rather than have a fracture. These can be challenging injuries to diagnose because some degree of laxity in the pediatric cervical spine is normal. These injuries range can include atlanto-occipital dislocation and atlantoaxial instability.

Atlantooccipital dislocation

This is a very rare injury that results from a hyperextension and distraction force (21). These injuries are usually seen in car accidents because of the magnitude of force required and it is very rare in sports. However, they can be seen in patients with pre-existing conditions such as Down's syndrome and rheumatoid arthritis. In the event this injury occurred it is imperative to keep the spine in a neutral position as standard adult sized backboard have the tendency to cause cervical flexion in the pediatric population due to the relatively large head size of a child (22,23). Treatment would involve an Occiput to C2 fusion and any return to play would be contra-indicated (21). This injury is fatal around 50% of the time.

Atlantoaxial instability

Isolated ruptures of the transverse ligament may occur in the pediatric population. This injury is also very rare. The mechanism of injury is a forced displacement of the neck (13,24). These injuries can be seen in tackling sports such as football and rugby. Standard lateral radiographs can make the diagnosis as the ADI will increase to >5 mm (1,13). In the acute setting and in the absence of neurological findings these injuries can be treated with non-operative management in a Minerva cast. If there is persistent instability after a trial of non-operative treatment a posterior C1–2 fusion can be performed. Return to play is contraindicated in this patient population.

On field management of suspected cervical spine management

If a cervical spine injury or spinal cord injury is suspected there should be a prompt response by medical staff, which should consist of several members with one leader. Neutral cervical stabilization should be initiated and if a helmet is present it should remain in place, unless it's presence is impairing the ability to care for the patient. A cervical collar should be placed and the athlete's head should be moved into a neutral position unless moving the athlete's head/neck causes increased pain, muscle spasm, loss of neurological function or restriction in range of motion (22,23).

A player found in the prone position should be rolled to the supine position. This can be done either with the "prone log role technique". The patient should be transferred to a backboard via the "lift and slide technique". Youth athletes have larger head-to-body ratios, resulting in cervical flexion if placed on a standard backboard. A special backboard with a cut out for the occiput establishes a neutral cervical alignment in this scenario.

Acute thoracic/lumbar spine injuries

Introduction/general evaluation

While the majority of acute pediatric spinal injuries affect the cervical spine, acute traumatic injuries to the thoracolumbar spine can also occur. Most injuries to the thoracolumbar spine are not serious in the pediatric population, but it is important to understand the different injury patterns to be able to identity serious injuries. The initial evaluation of a patient with an acute lumbar or thoracic spine injury starts with a thorough exam and an understanding of the mechanism of injury. Initially, the physical exam should include documentation of pain with range of motion, specifically if the pain is with flexion or extension. A neurologic exam encompassing motor strength and sensation, as well as reflexes should be performed. Physical exam maneuvers should also be performed on the hips and abdomen to ensure there is no additional pathology that is mimicking low back pain. An AP and lateral radiograph of the lumbar and thoracic spine should be performed in any child athlete with traumatic back pain. These preliminary radiographs will identify approximately 90% of all fractures (25,26). A CT scan is generally not performed unless there is a high index of suspicion for an occult fracture, as these studies require a high dose of ionizing radiation. An MRI should be performed for any patient that has an abnormal neurologic exam or if there is suspicion for a disc herniation.

Muscle strain

When dealing with the lumbar spine the majority of injuries represent muscular injury, either a muscular strain or contusion (26). The mechanism of injury is a direct blow causing muscular contusion or stretch causing a muscular strain. The pain with this type of injury is generally not severe and is self-limited, improving greatly within 48 hours after the injury. To make this diagnosis after an acute traumatic injury, there must be no neurologic deficit or any radicular complaints present in the athlete. Radiographs will be normal in this condition and there is no need for advanced imaging. There will be tenderness to palpation over the area of the muscle strain as well as pain with range of motion in all directions. This injury generally responds very well to NSAIDs, rest, ice, and heat treatment modalities. Athletes can return to play after they have obtained full painless range of motion and can maintain a neutral spine position during sport specific exercises. This generally occurs within 2 weeks to 2 months.

Fractures

Acute fractures of the thoracolumbar spine are rare injuries and usually occur in the setting of high energy trauma. These types of fractures are most common in high-impact sports, such as football, hockey, gymnastics, and rugby. Initial on field management of these injuries requires trained medical personal to stabilize the patient. Specific to the spine, these patients should be placed on a backboard using a logroll technique to prevent further injury secondary to an unstable spine fracture. The patient's neurologic status should be documented. The patient should also be evaluated for addition injuries as commonly there are associated chest and intra-abdominal injuries with thoracolumbar trauma. Once the patient is stabilized and transported to the hospital plain standard radiographs should be taken. A CT scan should be undertaken for further understanding of the fracture pattern, but limited to the area of the fracture to eliminate the need for excessive radiation in the pediatric population. An MRI should also be obtained to evaluate for ligamentous injury and to evaluate the neural elements for compression. Treatment for this condition is entirely dependent on the type of fracture present and the associated neurologic sequelae after recovery (27,28).

Compression fracture

A compression fracture is caused by axial loading of the spine and is characterized by loss of vertebral body height and anterior wedging (27,28). By definition, a compression fracture only involves the anterior column of the spine (28). It is thought to be a stable injury. The injuries are not associated with a neurologic deficit and it is unlikely to have any additional intra-abdominal injuries. These fractures should be evaluated with standard radiographs. There is no need for a CT scan in the absence of red flag type symptoms if standard radiographs have a characteristic appearance of anterior wedging of the vertebral body without involvement of the middle column. The fractures can be treated in a TLSO brace for 6 weeks followed by rehabilitation for 6 weeks (28). Once the athlete has achieved an abatement of pain with sport related activities and is able to maintain a neutral spine position during sport specific exercises they can return to play. This generally happens at about 3 months (18).

Burst fracture

Unlike a compression fracture a burst fracture is considered an unstable injury. This fracture pattern typically involves a high energy trauma. These injuries can occur during high impact sports such as hockey and football. This fracture involves both the anterior and middle column of the spine (29). There is bony retropulsion into the spinal canal, which can cause injury to the spinal cord and/or nerve roots. These fractures will need assessment with standard radiographs, CT scan, and MRI (29). The treatment is based on a combination factors including fracture alignment and neurologic exam. A well-aligned fracture with no neurologic compromise and without evidence of injury to the posterior ligamentous complex can be treated conservatively with a TLSO brace. If there is any neurologic compromise the treatment for a burst fracture is laminectomy/decompression of the stenotic region and an instrumented fusion (29,30). Return to play guidelines are very limited for burst fractures. In cases of conservative treatment, the guidelines would be very similar to a compression fracture in terms of timeline for return (18). In cases where a burst fracture was treated with an instrumented fusion that crosses the transition zone of the thoracolumbar spine there is an absolute contraindication to return to contact sport (18). If the instrumented fusion does not cross the transition zone return to play recommendations should be evaluated on an individual basis.

Transverse process/spinous process fractures

Transverse process fractures and spinous process fractures are both very painful injuries. The mechanism of injury is generally a direct blow, such as during a tackle in football. These fractures are stable. A high index of suspicion is needed to detect splenic and renal injuries which are associated with transverse process fractures (30).

Any pediatric athlete with confirmed diagnosis of a TP fracture should be evaluated by a physician for these associated injuries. These fractures are identifiable on plain radiographs. If there is no associated neurologic exam or any other red flag symptoms, these injury patterns do not require any additional imaging. The treatment for these injuries is purely symptomatic. No bracing is required, but can be used for discomfort. Anti-inflammatory medications and icing are first line treatment modalities for the pain associated with these fractures. Once the pain subsides to manageable levels physical therapy can commended. Return to play should take place within 6–8 weeks (18). The patient needs full range of motion and show they can participate in sport specific exercise before returning to play.

Apophyseal ring fractures

Apophyseal ring fractures are uncommon, but typically occur in the adolescent to young adult population (18–25 years of age) (30,31). They are most commonly seen in young male athletes participating in contact sports and are most frequently seen in the L4–5 and L5–S1 vertebrae. However, there is controversy regarding the mechanism of injury as some think this injury is the result of repetitive stress on the apophyseal ring rather than traumatic. This fractured is characterized by a separation of an osseous fragment at the posterior aspect of the cephalad or caudal edge of the adjacent vertebral body, which is the region where the apophysis fuses with the adjacent vertebral body. This fusion generally occurs between 18–25 years of age, which coincides with the age of presentation for this injury pattern (30). These injuries are also associated with lumbar disc herniations. The presentation of this fracture is variable with symptoms ranging from only back pain to radicular complaints as well. These symptoms are very similar to lumbar disc herniation. However, the symptoms of apophyseal ring fractures tend to be more severe than a simple disc herniation (30,31). These fractures are not commonly detected on plain radiographs and are only visualized 16–69% of the time using this modality. CT scan is very useful at detecting the location and morphology of the fracture. MRI can helped identify compression of the neural elements, but is very poor at defining and identifying the fracture. Since this injury is relatively rare there is very little consensus for treatment. Conservative treatment can be undertaken in the absence of neurologic compromise and a relatively small fracture fragment (31). Patients with large fragments have a high likelihood of developing chronic back pain if they undergo conservative treatment (31). In the setting of unrelenting back pain or radicular pain a decompression with resection of the apophyseal fragment is necessary (31). It is controversial if you need to excise the apophyseal fragment and literature is lacking, but most surgeons recommend excision of this piece to prevent residual bony spinal stenosis in the future. Fusion is generally not necessary. There is no literature supporting or against return to play after an apophyseal ring fracture. This decision must be made on an individual basis between the surgeon and the patient (18).

Disc herniation

A lumbar disc herniation is characterized by an annular defect and herniation of the nucleus pulposus. The mechanism of injury is an axial load to the intervertebral disc, which causing increased intra-discal pressure leading to extrusion to the nucleus pulposus through the annular defect (30,32,33). Commonly this injury occurs during football, baseball, hockey, rugby, and basketball. A disc herniation can cause a direct mass effect on the exiting or traversing nerve roots leading to a lumbar radiculopathy (30,32). In addition to a direct mass effect a disc herniation can also cause chemical irritation of the nerve root. Back pain can be a significant symptom with a disc herniation as well due to irritation of the sinuvertebral nerve that innervates the annulus fibrosis (30). Neurological deficits are less common in the pediatric population compared to the adult population. A complete lower extremity neurologic exam should be performed. Physical exam findings that may be present are pain that is worse with lumbar flexion, a positive straight leg raise, and a contralateral straight leg raise (30). Plain radiographs are likely to be normal in the pediatric population because degenerative changes are much less likely to be the root of symptoms (32). An MRI should be performed in patients with a neurologic deficit or radicular symptoms that fail to improve with conservative treatment after 6 weeks (32). The initial treatment for disc herniations should be conservative unless there is evidence of cauda equina symptoms or if there is a neurologic deficit. Conservative treatment consists of anti-inflammatory medication, rest, and physical therapy. These modalities usually obviate the need for any surgical intervention and have good outcomes in around 90% of patients. The next line in treatment is an oral steroid pack. If this fails to improve symptoms an epidural steroid injection can be considered directly around the affected nerve root.

If these modalities fail to improve symptoms a lumbar microdiscectomy can be performed. Most pediatric athletes will be able to return to play after a microdiscectomy at their prior level of sport (33). Generally, patients can return to sport after completing a trunk stabilization program and can perform sport specific exercises. The average time for a pediatric athlete returns to sport is at around 6 months, and 85% of patients have returned to play by 12 months (33).

Overuse injuries

Spondylolysis and spondylolisthesis

The most common cause of back pain in the child athlete is spondylolysis (34). This injury is the results of repetitive stresses on the pars interarticularis with the back in hyperextension. This injury is common in sports such as ballet, cheerleading, football, and gymnastics. These patients present with activity related pain which is worse in hyperextension (34,35). It is usual to have a normal neurologic exam with this condition. Spondylolysis can be seen on plain radiographs, especially an oblique view which visualizes the pars interarticularis very well. However, plain radiographs are not very sensitive for identifying this condition. A SPECT bone scan is the most sensitive imaging modality for diagnosis of a spondylolysis (36). An MRI is also quite sensitive for identification of an acute spondylolysis (37). A CT scan is usually not indicated due to the radiation exposure, but this imaging modality can be used to assess for bony union in cases of continued back pain despite treatment (37). The majority of athletes treated for this condition do well with non-operative treatment. The initial treatment is to provide a period of rest and hold all athletic activity (36,38). Bracing with a thoracolumbar orthosis is often utilized as well, but this is controversial. The purpose of bracing is to prevent hyperextension of the lumbar spine, which is thought to contribute to the initial injury process. Over the period of 3–4 months, activity is increased with guided physical therapy focusing on spinal stabilization and strengthening of paraspinal musculature. If the athlete is pain free at the end of physical therapy, they may return to play without restriction (38). If pain continues the use of a bone stimulator may enhance healing (39). When symptoms continue despite conservative treatment a direct pars repair or a one level fusion may be attempted. If this condition is untreated it can progress to become spondylolisthesis which is an anterior slippage of on to cephalad vertebrae on the caudal vertebrae (35). This only occurs around 5–15% of the time in the pediatric population with a spondylolysis. Once a spondylolysis has progressed to a spondylolisthesis neurologic symptom can develop. The degree of slippage and the angle of the slip determine how likely a spondylolisthesis is to progress. The treatment for a spondylolisthesis is a decompression and posterior spinal fusion (35). A surgical reduction of the spondylolisthesis is very controversial and there are no accepted guidelines.

Spinous process apophysitis

Spinous process apophysitis is a less well described overuse injury of the lumbar spine in pediatric athletes. The mechanism of injury is a repetitive impact of the spinous processes on each other with hyperextension and axial loading (40). This injury is most common in gymnastics and ballet dancers. This injury presents very similarly to a spondylolysis, with the caveat that direct palpation of the spinous processes worsens the patients' symptoms (40). Plain radiographs and CT scan will not show any abnormalities. A SPECT scan will show diffuse uptake in the affected spinous processes without abnormalities in the pars interarticularis. The treatment for this condition is 6 weeks of rest and activity modifications (40). Once the patient is symptom free they may return to sport.

Conclusions

There are a variety of both acute and chronic injuries to the pediatric spine that are related to sports. The diagnosis of these injuries can be challenging in the pediatric population due to the lack of traditional radiographic findings. However, prompt diagnosis and treatment are essential to preventing future disability in this pediatric population. An understanding of the anatomy and the development of the pediatric spine is essential to treating these injuries. With proper treatment most patients with spine injuries will be able to return to the sport of their choice without sequelae.

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