To much of a good thing! Overuse sports injuries in children.

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Learning objectives

• Recognize the importance of overuse injuries related to sports in a pediatric population
• Describe different types of musculoskeletal injuries related to sports in children and adolescents
• Imaging features on MRI, X-ray and US
Background

The practice of recreational and high-level sports in pediatric population is common nowadays. The overload of exercise in an immature skeletal system can be an important cause of morbidity with consequences in adult life, if not diagnosed and early treated.

Overuse injuries are caused by repetitive microtrauma with biomechanics that are sport-specific and occur due to repetitive submaximal loading of the musculoskeletal system when rest is not adequate to allow recovery to take place.

Repetitive forces applied to the immature skeleton cause particular types of injury due to the differences in weakness of the musculoskeletal system between children and adults.

The particularities of the growing skeleton

The most frequent sports injuries are seen at long bones and spine.

Developing long bones have five distinct parts:

1. Epiphysis
2. Physis
3. Metaphysis
4. Diaphysis
5. Apophyses

The epiphysis and metaphysis side the physis (growth plate), a particular aspect of the child skeleton that is closed (not present) in the adult skeleton. The diaphysis comprises the shaft of the bone, merging into the metaphysis in a region termed the metadiaphysis.

The diaphyseal cortex is quite thick and strong, whereas the metaphyseal cortex is comparably weaker, a characteristic that leads to the occurrence of typical metaphyseal-phyeal junction fractures.

On the other hand, the physis is the weakest portion of the long bones and is where the bone lengthening occurs. Therefore, it's easy to comprehend that a fracture located in this site of the bone can lead to growth arrest/longitudinal bone growth disturbance Fig. 1 on page 6.
Fig. 1: Radiograph and CT (sagittal and coronal views) of the ankle showing a bone acquired coalition in the distal fibula with growth impairment and ankle joint instability as a result of a fracture through the physis.

References: Porto/PT

Apophyses are ossification centers protruding from the bone. They are the typical site of implantation of ligaments and tendons and correspond to a fragile element of the growing skeleton. Thus, since apophysial portion of the bone is the weakest element it can break when traction from muscle and tendon is exceedingly applied (apophysial avulsions).

Another weaker portion of the growing skeleton is the growth cartilage (physis). In children repetitive forces applied to long bones are more likely to result in injury of the weaker epiphyseal plate than ligament disruption.

Sports related injuries contributing factors:

Several contributing risk factors have been described. These can be divided into intrinsic factors and extrinsic factors.

Intrinsic factors:

- Increased vulnerability to stress in the growing skeleton (already discussed)
- Previous injury
- Previous level of conditioning
- Menstrual dysfunction
- Psychological and developmental factors-athlete specific
A previous injury is the strongest predictor of future injuries. A fresher injury can occur as a result of inadequate rehabilitation or from a continuing aggression of a previously affected location.

During adolescence growth spur the incidence of injuries have the tendency to increase because growth cartilage present at the physis, apophyses, and articular surfaces are less resistant to tensile, shear, and compressive forces than either mature bone or more immature prepubescent bone.

A decrease in age-adjusted bone mineral density usually occurs during the pre-adolescence phase (before the peak height velocity) and may be also a predisposing factor.

In female young athletes several studies have suggested that a history of menstrual dysfunction with amenorrhea is a significant risk factor for stress fractures due to an inadequate caloric intake with consequent hypoestrogenemia and decreased bone density, which increased the fracture risk.

**Extrinsic factors:**

- Growing pressure from peers, parents and trainers to perform better
- Lack of training and competition programs adapted to the pediatric and adolescent population
- Excessive training workload (rate, intensity, and progression)
- Demanding training and competition schedules
- Inadequate equipment/footwear
- Poor sport technique

The most important extrinsic risk factor is inappropriate training. Training programs are often of great intensity, not adjusted to the growing skeleton and associated with inadequate rest. One study has proved that training more than 16 hours per week was associated with a significantly increased risk of injury requiring medical care. Furthermore, there is a growing pressure to be the best not only from the trainers but also from parents and colleagues.

Sporting equipment should be optimized for the less well-prepared and immature participant. Improper sizing and poor maintenance of equipment, as well as failure to use equipment that is proper for the sport may play a role in overuse injuries.
Fig. 1: Radiograph and CT (sagittal and coronal views) of the ankle showing a bone acquired coalition in the distal fibula with growth impairment and ankle joint instability as a result of a fracture through the physis.

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Findings and procedure details

Sports related injuries can be acute or due to overuse. Unlike acute injuries that are more easily recognized as they are associated with a sudden traumatic event that causes acute symptoms, overuse injuries should be suspected when a minor trauma cause disproportionate symptoms. MRI is the mainstay in imaging overuse injuries (high potential for early depiction of bone marrow, cartilaginous and soft-tissue structures).

Acute sport injuries

Acute osseous sport injuries are typically fractures and dislocations.

Compared with the adult skeleton, pediatric bone is more pliable and may bend without fracturing completely.

Bowing fractures reflect a bend in the long bones (more frequently seen in radius and ulna) without a cortical break. They usually don't require any type of intervention and heal with remodeling. A greenstick fracture is an incomplete fracture with a cortical break along the convex side of the cortex but not on the concave side. They are typically seen before the age of ten and they are more frequent at mid-diaphyseal portion of the bone and affect most commonly the forearm and the lower leg.

The physis is the part of the bone more commonly affected and pediatric fractures are therefore classified taking into account its involvement.

Salter-Harris classification system (Fig. 2 on page 29) is the most used and has five different types:

- Type I - separation of the physis (growth plate)
- Type II - fracture plane through the physis and metaphysis
- Type III - fracture involves the physis and epiphysis
- Type IV - fracture involves the metaphysis, physis, and epiphysis
- Type V - crush injury to the physis
Fig. 2: Salter-Harris Classification

References: Case courtesy of Dr Matt Skalski, Radiopaedia.org, rID: 27144

Fig. 3: Tibial fracture, Salter-Harris type III on plain radiograph and MRI T1-w (hypo intense fracture line involving the epiphysis and physis) and T2-w, fat sat imaging (surrounding edema)

References: - Porto/PT
Fig. 4: Tibial fracture, Salter-Harris type III on multiplanar CT with 3D reconstruction

References: - Porto/PT

All of these acute injuries may result in growth abnormalities from physeal damage.

However, Salter-Harris type I and V can be the result of overuse injuries to the growth plate.
Fig. 5: Sequel of Salter-Harris type I. (T1-w and DP fat sat) Focal alteration in the epyphysis and metaphysis (arrows), without epiphysiodesis (bone bridging).

References: - Porto/PT
**Fig. 6:** Salter-Harris Type I. Growth plate enlargement and minor epiphysis posterior displacement (epiphysiolisis).

*References:* - Porto/PT

Type I usually has a good prognosis while type V has the greatest likelihood for growth anomalies.
Overuse sport injuries

Overuse sport injuries can be divided by type of injury or by characteristic location.

Approaching these kind of injuries by type, we can classify them as:

**Fig. 7:** MRI - coronal and sagittal views of the left knee - Epiphysiodesis of the medial aspect of the tibia (bone bridge between epyphisis and metaphysis).

*References:* Porto/PT
1) Stress fractures

Pediatric stress fractures are similar to those seen in adults. They result from repetitive forces on the musculoskeletal system that has no time to recover, usually due to demanding schedules and pressure from trainers and peers. The clinical evaluation is often difficult as children have difficulty to provide a clinical history.

A high grade of suspicion should be raised in athletes with pain at the classic sites of stress injuries.

These sites comprise the lower lumbar spine, anterior hip, groin or thigh, anterior knee, anterior leg, medial ankle, dorsal/medial midfoot, lateral foot, and plantar aspect of the great toe.

The recognition of the characteristic features of these types of fractures on both radiographs and MRI is therefore crucial for diagnosis.

However, stress fractures are not always visible on plain radiographs for several weeks following stress event and some may never become apparent. This is what makes the magnetic resonance imaging (MRI) the study of choice for early stress fracture diagnosis.

**MRI typical features comprise:**

- Bone marrow edema
  - Low signal intensity on T1-weighted imaging
  - High signal intensity on STIR and T2-weighted imaging
- Linear, well defined, low-intensity fracture line on T1 and T2-weighted sequences
  - Subperiosteal fluid may be present
  - Enhancement after contrast secondary to edema that reveals a more conspicuous fracture line.

Typical sites of stress fractures are:

- Tibia
- Femur
- Metatarsal and tarsal bones
- Pelvis

**Tibial Stress Fractures**
Tibial stress fractures are one of the most common sites of stress fractures in the adolescent athlete. This type of injury typically occurs with activities requiring sudden stops or changes in direction such as football and tennis. Stress also can result in shin splints, which are probably a precursor injury of stress fracture. On MRI, shin splints are seen as linear areas of high signal intensity limited to the medial aspect of the tibia. Radiographs can demonstrate cortical irregularity and periosteal reaction, typically along the posteromedial proximal third of the tibial shaft.

![Image: Coronal T1 and DP fat sat - Right knee. Stress fracture in the middle aspect of the tibia (metaphysis) with surrounding edema.](image)

**Fig. 8:** Coronal T1 and DP fat sat - Right knee. Stress fracture in the middle aspect of the tibia (metaphysis) with surrounding edema.

**References:** Porto/PT

**Femoral Stress Fractures**

Stress fractures of the femur are relatively rare and tend to affect the inferior surface of the neck (most frequent), the shaft, and the distal metaphysis. This injury is most common in endurance runners, soccer players, jumpers and dancers.

If apparent, it will be demonstrated by a linear sclerosis, periosteal elevation, and cortical thickening on radiographs.
Fig. 9: Sagital (T1) and coronal DP fat sat. Stress fracture on lateral distal metaphysis of the femur (incomplete fracture line with surrounding edema).

References: - Porto/PT

Metatarsal and tarsal Stress Fractures

Metatarsal stress fractures mainly occur at the second metatarsal with the third and the fourth being also frequent. The sports mostly implicated are endurance sports such as running. As the foot bone marrow signal intensity is heterogeneous in children, it’s more difficult to identify stress injuries, although they tend to be asymmetrical and extend to the involving soft tissues.

Tarsal bones can also be affected, being the navicular the most commonly injured.
Fig. 10: 17 years old football player - MRI axial T1-w and T2 fat sat, Navicular stress fracture (hypointense line perpendicular to the navicular great axis representing the fracture line and surrounding edema of the tarsal bones)

References: - Porto/PT

**Spine Stress Fractures**

Spondylolysis is a stress injury of the pars interarticularis that is caused by repetitive forces of extension and torsion of the trunk. It usually occurs at the lower segments of the lumbar spine (fourth and fifth lumbar vertebrae) and is mostly seen in gymnasts. Computed tomography (CT) is the best imaging modality to assess this type of injury as it may show explicit defects in the vertebral elements. It is also a good follow-up method as it can show confirmation of healing. However, in pediatric population, MR imaging is important due to its lack of radiation. This imaging method can demonstrate bone marrow edema, signal change in adjacent muscles and disc degeneration making possible a differentiation between active and inactive spondylolysis.
**Fig. 11**: Gymnast athlete -17 years old male. Lumbar spine oblique views with bilateral defect in the fifth lumbar vertebra (arrows).

**References**: - Porto/PT

**Fig. 12**: CT lumbar spine (axial on the left and sagittal on the right). Axial bilateral pars defect of L5 and sagittal plane of the left side.

**References**: - Porto/PT
Sacral Stress Fractures

Female runner athletes are more prone to sacral stress fractures as they have caloric imbalance, hormonal deregulation and impaired bone health, more frequently. Radiographs are often normal, while MRI demonstrates linear low signal intensity fracture lines on T1-w images with the corresponding edema on T2.

Most of the described fractures can heal if treated appropriately with rest (physical activity related to injury should be stopped) and rehabilitation. If not treated properly, these injuries may undergo nonunion and result in chronic pain and degenerative joint disease.

2) Apophyseal and physeal injuries

Overuse injuries unique to young athletes include apophyseal and physeal stress injuries.

Osgood-Schlatter disease

Osgood-Schlatter disease (or *tibial tubercle stress apophysitis*) is an osteochondrosis of the tibial tubercle characterized by pain of this anatomic region. It is frequently bilateral and is commonly seen in teenagers (more in males than females). This entity results from chronic repetitive microtrauma and subsequent injury of the tibial attachment of the infrapatellar tendon that leads to a fragmented appearance of the tibial tubercle, with ossification in the distal infrapatellar tendon. This disease is often the result of sports that entail jumping.

Radiographs support the diagnosis as they demonstrate swelling of the soft tissues and fragmentation and irregularity of the tibial tubercle. MRI may demonstrate bone marrow edema in the tibial tubercle, as well as edema in the attachment of the infrapatellar tendon.
Fig. 13: Football junior player. MRI T1, T2* sagittal - Osgood Schlatter disease. Knee pain with a lump in the anterior aspect of the tibia at the patellar tendon insertion. Edema at insertion of the tendon with thickening and bone edema.

References: - Porto/PT
**Fig. 14**: Hockey junior player with anterior knee pain. MRI sagittal T1, T2 fat sat. Anterior tibial tuberosity with scleroses and surrounding edema at the patellar tendon insertion.

*References*: - Porto/PT

**Sinding-Larsen-Johansson disease (SLJ)**

Sinding-Larsen-Johansson disease is an osteochondritis of the intrapatellar tendon attachment to the inferior patellar pole. It is similar to Osgood-Schlatter disease but along the inferior aspect of the patella. Some authors classify SLJ as a pediatric version of the "jumpers knee".

**Fig. 15**: Young football player. Lateral x-ray view - Focal sclerotic lesion of the inferior pole of the patella with MRI (sagittal T1 and DP fat sat) showing edema at patellar tendon insertion

*References*: - Porto/PT
Fig. 16: Football junior player - Sinding-Larsen-disease. Lateral X-ray view of the knee - overgrowth of the inferior pole of the patella. MRI - sagittal plane - DP fat sat with bone overgrowth of the inferior pole of the patella but no edema surrounding meaning chronicity of the lesion.

References: - Porto/PT

Sever's disease

Sever's disease is one of the most common causes of heel pain in children. Sever's disease is an inflammatory condition of the growth plate of the calcaneus. Running and jumping are the most frequent implicated activities. On plain radiographs this entity can be unapparent and on MRI it is usually identified as an edematous change within the calcaneal apophysis.
Fig. 17: Female volleyball player with heel pain (lateral radiograph) - sclerosis of the calcaneus apophysis; MRI T1 and STIR sagittal - Inflammation of the calcaneus growth plate with the correspondent edema

References: - Porto/PT

Acromial Apophysiolysis

Chronic repetitive traction forces from the deltoid muscle leads to the failure of fusion of the acromion. The resultant *os acromiale* can lead to impingement symptoms in the shoulder (chronic shoulder pain of insidious onset). In younger patients, differentiating between an *os acromiale* and normal apophyseal development can be challenging.
However, irregular cortical margins and abnormal marrow signal with adjacent bony edema favors the diagnosis of acromial apophysiolysis.

**Little Leaguer’s Shoulder**

Little leaguer’s shoulder is a term used to describe injury to the proximal humeral physis typically caused by repetitive overhead throwing. It is often diagnosed in male baseball pitchers in whom the excessive rotational forces of overhead throwing lead to physeal injury. Patients tend to present with focal pain over the anterolateral shoulder that worsens with overhead throwing. Radiographs typically demonstrate physeal widening and irregularity. On MRI the findings include similar widening of the physis, with additional demonstration of bone marrow edema on T2-weighted imaging.

**Little Leaguer’s Elbow**

Little Leaguer’s elbow is an injury of the medial epicondylar apophysis. Patients are also young pitchers as in the previously described injury. They present medial elbow pain and the plain radiographs typically demonstrate widening or fragmentation of the apophysis.

**Gymnast’s Wrist**

Gymnasts are commonly exposed to mechanical forces of dorsiflexion and compression at the distal radius. These forces can lead to physis injury that can be seen on plain radiographs as widening and irregularity of the physis. On MRI it’s also evident edema through the metaphysis. Severe cases can lead to premature fusion of the physis with growing impairment.
**Fig. 18**: 13 years old Karate athlete - X-ray AP view: physis impaction. Similar changes as in gymnast wrist with physis injury at the MRI (type V Salter-Harris classification) and edema through the metaphysis.

**References**: - Porto/PT

**Pelvic Apophyseal Injury**

Traction apophysitis in the pelvis is a commonly documented overuse injury in pediatric population. The mechanism involved in this type of injury is twisting as occur in dancing, running, football and lacrosse, resulting in traction on the apophyses.

The most common sites of injury include the anterior superior iliac spine (origin of the sartorius and tensor fasciae lata), the anterior inferior iliac spine (origin of the rectus femoris), and the ischial tuberosity (origin of the hamstrings). Radiographs can demonstrate a variety of findings from cortical irregularity to frank avulsion of bone. On MRI it's possible to identify bone marrow edema at the site of the apophyseal avulsion and variable signal intensity in the corresponding tendons, depending on the extent of their injury.
**Fig. 19:** Avulsion fractures

**References:** Stevens M, El-Khoury et al. Radiographics, 1999

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**Fig. 20:** 12 years old junior football player with anterior proximal right thigh pain. MRI T1 coronal (A), T2 coronal (B), T1 sagittal (C) and T2 fat sat axial (D) - avulsion of the rectus femoris insertion at the anterior inferior iliac spine with edema in the liquid sensitive sequences.

**References:** - Porto/PT
Fig. 21: 17 years old running athlete A) Ultrasound of the back thigh - sagittal: Heterogeneity of ischial insertion of hamstring common tendon. B) CT scan coronal: apophyseal ischial avulsion. C) MRI T2 fat sat coronal: bone marrow oedema reaction to apophyseal traction.

References: - Porto/PT

3) Osteochondroses

Osteochondroses are defined as noninflammatory and noninfectious derangements of the growing bone that occur at bone growth centers through periods of intense activity.
Osteochondritis dissecans

Teenagers are the group most often affected and occurs after a traumatic (impaction) event. The disorder is most common in the lateral aspect of the medial femoral condyle followed by the medial talar dome (less common).

On radiographs it's possible to see a linear lucency in the subchondral bone and the correspondent free fragment can lead to mechanical symptoms. MRI plays a crucial role in the assessment of the location of the osteochondral fragment.

Fig. 22: 11 years old ballet dancer. MRI of the knee (coronal T1 and DP fat sat) - Focal semilunar signal alteration with sclerosis and edema on the medial femoral condyle.

References: - Porto/PT
Fig. 23: 12 years old male, Hockey player - Grade II osteochondritis dissecans of the lateral talar dome (sclerosis of bone) and surrounding edema

References: - Porto/PT
**Fig. 2:** Salter-Harris Classification

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Conclusion

Overuse injuries are common in children and adolescents practicing high-level sports.

The immature musculoskeletal system of young athletes is at risk for physeal and apophyseal injuries both in the acute and chronic setting. Early diagnosis and appropriate management are essential to prevent morbidity and to achieve quick return to sport.

MRI is very sensitive and specific for identifying, classifying and monitoring sports-related injuries in the developing skeleton.
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