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Reviews

AVULSION FRACTURES OF THE LOWER LIMB

IN THE PEDIATRIC AND ADOLESCENT PATIENT

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Abstract: This review intends to address the importance of avulsion fractures in the pediatric patient , given that they are relatively frequent and an underdiagnosed pathology. We have searched the most recent bibliography available in concern with this topic to reveal the most important aspects of this pathology such as the pathophysiology, and the diagnostics techniques and treatments available. Muscular traction is seen to be the main cause of this particular growth plate fractures. For the diagnosis a proper interview and physical examination is needed, to explain the mechanism of production and physiopathology, we will also need the use of simple radiography and CT to characterize these lesions. As far as the treatment is concerned, it will be conservative with a slowly progressive rehabilitation program in most of the cases, nevertheless some complications may appear, and surgical rescue may be indicated. Surgical techniques are variable, multiple, and surgeon-dependent, also the location of the lesion and characteristics of the patient should count to decide the best treatment. Due to possible complications, an early diagnosis is needed.

Keywords: fractures, avulsion; pediatrics; therapeutics

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Abstract: The objective of this review is to give the importance it deserves to avulsion fractures in pediatric patients, since they are relatively frequent, and also tend to go unnoticed . An exhaustive search of the current bibliography has been carried out to try to give an answer to the pathophysiology, diagnostic techniques and available treatments. Muscle traction is the main cause of these particular epiphysiolysis. Diagnosis requires a good history and physical examination to explain the mechanism and pathophysiology. In addition, we will rely on simple radiography and CT to better characterize these lesions. Regarding the treatment, it will be conservative in most cases with a progressive rehabilitation treatment , but it must be taken into account that there may be medium-term sequelae that indicate a surgical treatment. The techniques are varied, and it depends on the preference of the surgeon, the location of the lesion and the characteristics of the patient. Due to the possibility of complications, an early diagnosis will be necessary.

Keywords: avulsion fracture; pediatrics; treatment

1. Introduction and generalities

An **avulsion fracture** is defined as one in which the bone fragment is separated from its main part through the soft tissues that are fixed to it [1,2]. These can be:

- Ligaments
- Tendons
- Peritendinous sheaths or sheaths
- Joint capsules
- Specific soft parts: labrum, retinaculum, meniscus or syndesmosis.

Regarding **etiology,** there are 4 large groups: 1. Acute.

Almost all of which are sports injuries, in the population young.

2. Chronic due to repetitive force and continuous microtrauma. Many times this type of lesions associates pathological characteristics of the bone. It usually presents symptoms of pain or apophysitis some time before the lesion occurs.

3. Iatrogenic. For example, by obtaining donor bone from the iliac crest, we weaken the bone of the ASIS.

4. Pathological or
   - Genetic Defects or
   - Infections or
   - Neoplasms

It must be taken into account that the size of the lesion does not have to be correlated with the symptoms (clinical-radiological dissociation) [3] and in many cases it is associated with some other concomitant soft tissue or osteochondral lesion, because an instability is produced that can trigger the failure of other structures [4].

1.1. Special characteristics of the pediatric population

There are an infinite number of avulsions, since each insertion of soft tissues can produce an avulsion in the bone on which it rests. For this reason, we will focus on those that are more frequent or are typical of the pediatric population and adolescence, with special interest in those that are produced by mechanisms related to sport.

These are lesions that generally occur in secondary epiphyseal nuclei that do not contribute to the longitudinal growth of the body. In adolescents, it could be said that they are something similar to a transition fracture, which is one that occurs on the physis when it is partially closed [5].

It is not known exactly what the prevalence of this pathology is, especially due to the great variability of lesions that we can find, many of which do not seek treatment as they are asymptomatic, in other cases they go unnoticed or are part of lesions. nes in polytraumatized patients. They are estimated to account for 16% of all pediatric sports injuries [6]. What has been observed is that it is increasing due to an earlier and more frequent start in high performance sports activities, and also that we have improvements in diagnostic tools. It has also been shown that, in this population subgroup, males have a 3-5:1 ratio with respect to females [7].

2.

Physiopathology The production mechanisms can be direct, indirect, dislocations, traction / rotational 93 tion, or their combination, but in almost all there is an axial load on the affected limb [6]. Therefore, the following **movements are described:** 95

- Throws (fast contraction of antagonistic muscles). • Muscular 96
  eccentric phase (in which the elastic capacity 97 of the bone can be exceeded by pulling the bone fibers with the active stretching-contraction that 98 occurs in this phase). • Rapid 99
  acceleration-deceleration movements (kicks, start of the race, 100 jumping, direction changes...). 101
- Passive stretching (when doing *splits* in dancers, opening the legs). 102

In all these movements, muscle traction is produced in the opposite direction to that of the 103 myotendinous contraction that aims to move the joint. 104

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And why do these injuries occur? The Sharpey fibers (type I collagen) that 106 join the muscle to the epiphysis are stronger than the osteochondral junction of the physis, and tend to 107 produce tearing on the area of hypertrophy of the latter *(see Figure* 1). It has also been seen in 108 rats that, during adolescence, the epiphyseal cartilage is even weaker 109 [8]. For all these reasons, it is usually more frequent to see these lesions also in patients 110 with active growth, while adults present injuries to the myotendinous / muscular 111 junction , and the elderly fracture more frequently. In 112 TTA avulsion , the physis is composed of fibrocartilage until a few months before physeal closure 113 which transforms into weaker hyaline cartilage making it susceptible to avulsion 114 [4].

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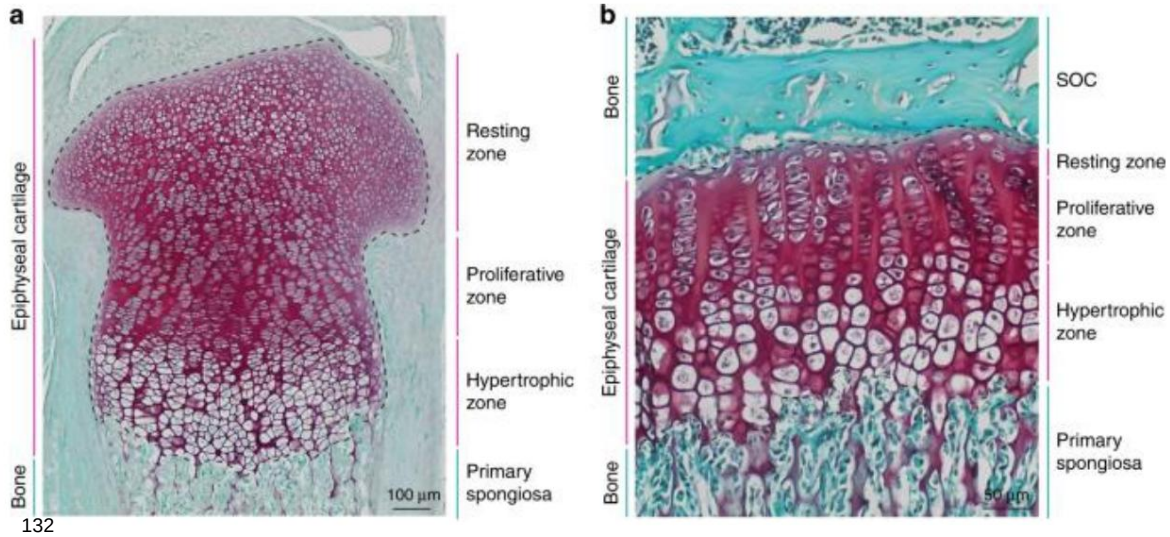

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Figure 1. Image of the growth plate of a mouse, similar to that of the human. Obtained from the work of Chagin, AS, Newton, PT Postnatal skeletal growth is driven by the epiphyseal stem cell niche: potential implications to pediatrics. Pediatric Res 87, 986–990 (2020). https://doi.org/10.1038/s41390-019-0722-z

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3. Diagnosis

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When suspecting this pathology, we must discern what is the **producing mechanism** 138 (high vs. low energy; acute vs. chronic), ask about the activity that the patient 139 performs , or if he has presented dislocations. On many occasions, being pediatric patients , 140 the anamnesis can be confusing with different lines of argument on the part of 141 parents and patients. They usually report a history of a sudden crunch, followed by pain, which will improve with rest. 143

Regarding the **examination ,** special attention must be paid to gait, as well as all the parameters that must be taken into account when assessing fractures (mobility , pain on palpation, wounds, neurovascular involvement...). Adjacent joints should always be assessed , as well as the contralateral one for comparison [9]. In some cases it will be necessary to wait a few days (10-14 days) to carry out an exploration, because the swelling and pain prevent a proper assessment of the lesion [10]. It is important to note that epiphysiolysis is more common than muscle tears and sprains in children.

In order to make a good diagnosis, it is crucial to have a good understanding of the anatomy of the injured regions, as well as the chronology of skeletal maturity to avoid going unnoticed possible extensive lesions of cartilaginous origin not visible on **simple radiology** (such as it happens with patella luxations), which is our greatest complementary tool (load-bearing, stress...) and with which it is also interesting to obtain an image of the contralateral joint [11]. We can find varied findings:

- Acute lesions: small bone fragments with irregular borders, non-sclerotic, close to where a structure is known to attach to the bone. In addition, we can also observe the swelling and edema of the surrounding soft tissues.
- Chronic lesions: we will find fragmentation of both the avulsed bone and the bone origin, formation of enthesophytes and calcifications (it is important to make a differential diagnosis with osteosarcoma) [12].

The role of CT is to determine comminution, possible displacement, or for pre-surgical planning. In the case of MRI, which is not routinely used, it can be useful to assess chondral lesions in patients who are still skeletally immature. The ultrasound is inferior to the rest of the tests in terms of sensitivity for diagnosis. Summarizing , we will use these tests when we find a clinical-radio- logical dissociation (clinical suspicion without observable lesion on X-rays or vice versa).

Based on these tests, McKinney et al. performed a classification of avulsions bone, in order to simplify treatment, into 4 types [13] *(see Table* 1).

Table 1. Classification of avulsions according to McKinney [13].

Guy	Description
Yo	no displacement
II	Offset ÿ2mm
II	Offset ÿ2mm
IV.	Symptomatic nonunion or painful heterotopic calcifications

In case of dislocations, it will be important to perform clinical examination and comprehensive tests . supplementary before and after reduction.

3.1. Specific Examples

- Segond's fracture: tearing of the anterolateral tibial ligament (pathognomonic of ACL injury) [14].
- Olecranon avulsion: suspect if bilateral, and after low-energy trauma, in osteogenesis imperfecta [15].
- Fleck-sign: avulsion of a fragment of the lateral edge of the base of the 1st MTT (Lisfranc plantar interosseous ligament) [3].
- Dashboard injury: tearing of the posterior tibial plateau in anteposterior knee injuries (pathognomonic of PCL injury) [16].

4. Treatment

In all patients, the first thing to do, whether we diagnose a fracture-avulsion or not, is to reduce the possible displacement and apply the **RICE** (Rest, Immobilization, Compression, Elevation) **protocol .**

In most of the patients we will carry out a conservative treatment, which will require a close clinical-radiographic follow-up. Subsequently followed by a strict rehabilitation program (the stricter the greater the patient's functional demands) that can last up to 2 months [13,17]: 1. Week 1. Discharge + RICE + cold local + NSAIDs 2.

Weeks 2-4. Increased recruitment of injured fibers through voluntary contractions and passive movement, until gaining more and more mobility.

3. Weeks 5-8. After gaining 75% of range, you must begin to gain strength muscular.

4. Weeks 9 onwards. After obtaining 50% of the muscular strength, we integrated the use of the injured muscles with the axial load. Most of the injuries during treatment occur during this phase due to a lack of muscle strengthening and stretching . This last phase would be the previous one until achieving the previous sports performance .

Regarding **surgery** [7,18], the following absolute indications have been described:

- cancerous articular fragments
- Compartment syndrome
- Areas that will rarely heal without invasive treatment
- frank instability
- Skin compromise.

Other indications would be size, displacement, associated lesions, functional demand , neurovascular alteration, dominance, age of the patient, physeal involvement...

The techniques that can be used are varied, and it depends on the place where the lesion has occurred. In addition, intraoperative stress tests should be considered before and after fixation to assess the stability that has been achieved.

- ORIF (open reduction internal fixation) to reconstruct the joints and give more stability. It has been seen that this system, in some series, achieves an earlier initiation of sports activities and maximizes functional results .
- Reconstruction of soft parts. Sometimes it is necessary to reconstruct other ligaments, since, in most cases, the structure that has avulsed the fragment remains intact.
- Excision / excision of bone fragments.
- Arthrodesis if it is not possible to achieve stability that allows adequate function sister

5. Prognosis [19]

In some cases, treated conservatively, there is a fibrous non-union, which can become symptomatic over time, and even those that do consolidate, can present chronic pain and even osteoarthritis. In these cases, rescue surgery would be indicated . When we operate, we can present stiffness in 60% of patients, and the rate of complications will be higher the longer it takes to diagnose and treat the lesion.

• Acute: heterotopic ossification, hematoma, neurovascular injury/irritation, loss of proprioception (Golgi organs), compartment syndrome (TTA avulsion) • Bone loss, resorption and erosion • Accelerated osteoarthritis

• Chronic pain

• Pseudoarthrosis • Malunion • Mismetries or angle misalignments

• Contractures • Loss of function or delay in return to sport • Avascular necrosis

• Recurrent injury and instability

What best ensures a good prognosis is early diagnosis and adequate treatment , without “running” in rehabilitation because that is when most injuries occur. Age and osteoporosis are also associated with a worse prognosis.

5. Avulsions of the lower limb in the pediatric population

In the population subgroup of athletes, lesions occur above all at ages between 4-17 years, which is when the secondary ossification centers of the MMII appear, where most of them are located, since they bear the entire load bodily . It is important to know when the nuclei appear and disappear, in order to know the most probable location of the lesion, and to take into account that, with the exception of ISAE, the rest are usually fused over 17 years of age, and that in women they appear and merge a 1-2 years earlier [1].

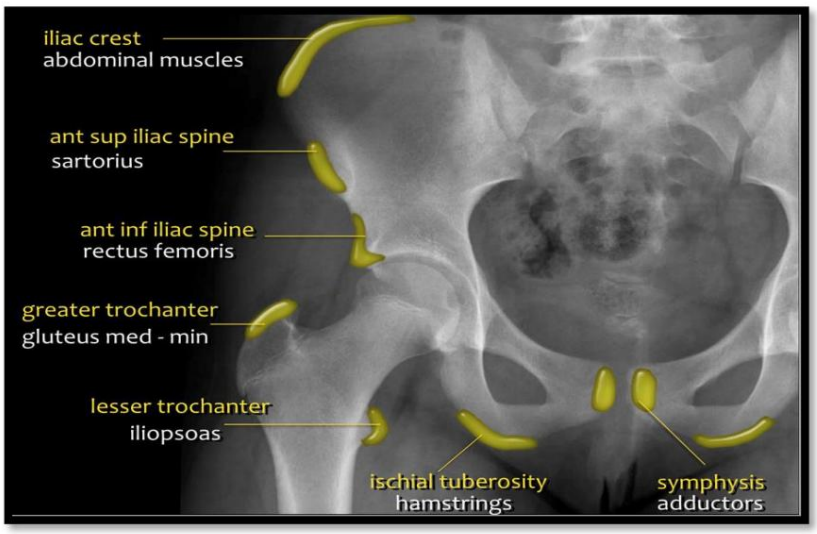

Figure 2. Muscle attachments that can cause avulsion fractures in the pelvis. Image obtained from the work of Joosje Bomer and Herma Holscher. Juliana Children's hospital, the Hague, the Netherlands: https://radiologyassistant.nl/pediatrics/hip/hip-pathology-in-children

At the same time, the most frequent locations are the AIIS, the ischial tuberosity and the ASIS (in that order, although it depends on the series). The iliac crest, pubic symphysis, TTA, and greater trochanter can also be affected [20]. Now we will see more carefully.

We should suspect a pelvic avulsion in those cases in which the patient persists with difficulty sitting for prolonged periods or when running, once treatment has failed for a suspected apophysitis or hamstring muscle tear .

5.1. Ischial tuberosity avulsions [21]

- **Mechanism:** traction of the hamstring muscles (long head of the biceps femoris , semitendinosus and semimembranosus), after forced flexion of the hip with the knee extended.
- **Examples:** sprinting and kicking (typical injury in soccer players).
- **Diagnostic suspicion:** history of contralateral avulsion, patients younger than normal to present another type of pelvic avulsion. Hamstring syndrome may appear (pain radiating to the posterior aspect of the thigh in sitting position or in those maneuvers that elongate the sciatic nerve that becomes trapped between the muscle fibers). It must be treated with compartment and nerve release surgery .
- **Treatment:** some authors recommend operating when there is a displacement >15mm since the tensile forces of the muscles on the fragment can increase the nonunion ratio (plate fixation vs. percutaneous tenotomy vs. excision and reanchoration [22] vs. in situ with screws [23]), but there are no studies indicating the use of one over the other. Other treatments that have been tried in chronic cases is infiltration with PRP [24] or interventional radiology treatments [25].
- **Prognosis:** Needs the longest period of rehabilitation of all MMII avulsions (up to 6 months for full return to activity).

Figure 3. Avulsion of the ischial tuberosity. Image obtained from the work of Joosje Bomer and Herma Holscher. Juliana Children 's hospital, the Hague, the Netherlands: https://radiologyassistant.nl/pedi-atrics/hip/hip-pathology-in-children

5.2. Avulsions of the anterior superior iliac spine

[26] • **Mechanism:** traction of the sartorius muscle and the TFL when performing twists and turns. • **Examples:** baseball, jumpers, sprinters. • **Diagnostic suspicion:** it can often be confused with an avulsion of the AIS due to laterodistal displacement due to muscle contraction. In some cases it may present with meralgia paresthetica due to irritation of the femoral cutaneous nerve.

- **Treatment:** mainly conservative (2 months) but surgery is sometimes recommended (chronic pain or displacement >20mm). In the latter case, some authors add that there is an earlier return to physical activity but there is not sufficient evidence that the results are better with surgery [27].

Figure 4. Avulsion of the ASIS. Image obtained from : https://radiologyassistant.nl/pediatrics/hip/hip-pathology-in-children

5.3. Avulsions of the anterior inferior iliac spine

• **Mechanism:** straight head traction of the rectus femoris, when the hip is hyperextended and the knee is flexed. • **Diagnostic suspicion:** it is difficult in many cases to diagnose it with X-rays, for which reason MRI is usually used. If it goes unnoticed, it can cause acetabular impigement mechanism and lead to the development of early osteoarthritis, due, in part, to the appearance of exostosis [28]. • **Treatment:** preferably conservative with load limitation. Surgery is recommended in cases that have already been seen previously as general indications.

Figure 5. AIS avulsion. Own image published with the consent of the patient.

5.4. Other pelvic avulsions

5.4.1. Iliac crest avulsion: It occurs due to the traction of the abdominal muscles when performing a sudden turn or lateral flexion. Surgical treatment with cannulated screws has been proposed when displacement is >30mm [29].

5.4.2. Pubic symphysis avulsion: It is produced by the traction of the adductors in the kicking mechanism . In some cases it comes to associate soft tissue involvement and may be the result of athletic groin pain. Treatment is conservative [30].

5.5. Avulsions of the anterior tibial tuberosity [31]

- **Mechanism:** vigorous eccentric contraction of the quadriceps (ÿ1%). Generally- they tend to be produced with a higher energy mechanism than the rest of the lesions. In other words, it is a more traumatic injury than a sports one, but given the case, it occurs above all when jumping.
- **Classification** (according to Ogden):
  - o Type I: TTA avulsion (fracture of the secondary ossification center) . Darius)
  - o Type II: complete TTA avulsion (union fracture between the two ossification) o Type III: intra-articular involvement (most frequent type) o Type IV: complete proximal tibial avulsion o Type V: associated with a Salter-Harris type 4 lesion
- **Diagnostic suspicion:** it is one of the few cases in which, if displacement is observed , it is advisable to perform a CT to observe how far the avulsion fracture extends (they usually associate epiphysiolysis of the proximal tibia). They have the highest risk of compartment syndrome of avulsion fractures (4% per rupture of the anterior tibial recurrent artery). It will be necessary to make a diagnosis with Osgood-Schlatter disease, of which it is not known if it is a risk factor for TTA avulsion.
- **Treatment:** depends to a large extent on displacement and epi-/metaphyseal tibial involvement . Usually, if they do not present as an isolated nondisplaced avulsion, they are usually operated on (they rarely consolidate due to quadriceps traction). Osteosynthesis is usually done with compression screws. • **Prognosis:** In case of early physeal closure, it can cause angular misalignments and recurvatum.

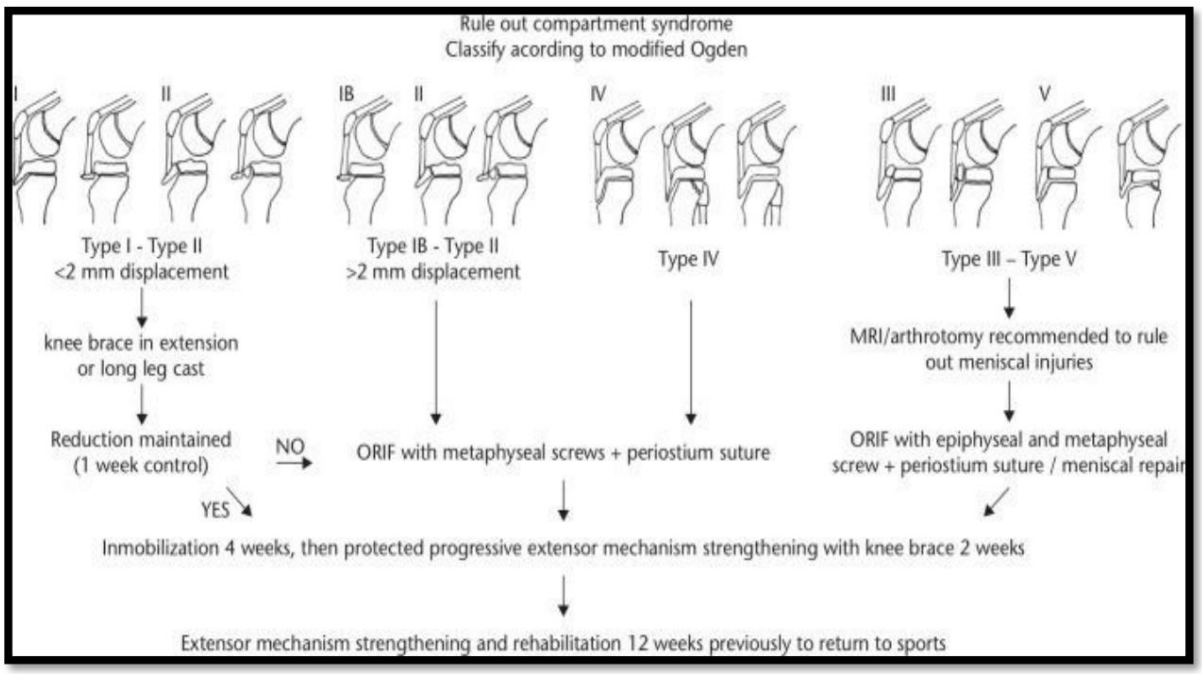

Figure 6. Therapeutic management proposed by Rodriguez I, et al. [31]

5.6. Other less frequent lower limb avulsions [1]

5.6.1. Calcaneus: it is produced by traction of the triceps surae and a differential diagnosis must be made with Sever's disease. Treatment is usually conservative.

5.6.2. Avulsion of the greater trochanter: through the gluteal abductor musculature. It is produced above all in obese patients by means of a hip flexion mechanism with external rotation. It can be treated in children with compression screws. In the elderly it can be a prequel or indicator of a pertrochanteric fracture [32].

5.6.3. Avulsion of the lesser trochanter (<1%): through the adductor and psoas muscles (performs hip elevation in a sitting position), especially when running or jumping. Type IV according to McKinney can be treated by excision and reanchoring of the muscle, the rest usually respond well with conservative treatment. In the elderly, underlying neoplasms should be monitored and may be the prequel to subtrochanteric fracture [33,34].

6. Conclusions

Avulsions are a sign of potentially serious underlying injuries. Perhaps not in the pediatric population, but whenever we encounter them, it is important to make an early diagnosis.

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