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REVIEW ARTICLE

Apophyseal injuries in soccer players

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Abstract

Soccer is the most popular sport worldwide, and it is associated with high injury rates, with most of these injuries occurring in the lower extremities. Particularly, in youth soccer players with immature skeleton, the physeal plate is two to five times weaker than the surrounding fibrous structures, and therefore more vulnerable to injury. The physeal plate consists of epiphyses and apophyses, with the former serving as tendon attachment sites and being subject to traction forces. There are two types of apophyseal injury: (i) apophyseal avulsion, which consists of an acute separation across the physeal plate; and (ii) apophysitis, an injury caused by chronic and repetitive contraction of musculotendon unit, leading to inflammation of the growth plate cartilage. Apophyses of the hip and pelvis are the most commonly injured in youth soccer players, due to vigorous contractions during sports activities and the fact that they tend to fuse later compared to other epiphyseal centers, making them more susceptible to injury. In this review, we will discuss the anatomy of lower limb apophyses and clinical and imaging findings of apophyseal injuries in youth soccer players, as well as briefly review treatment options and complications.

Keywords Apophysis · Apophyseal injury · Sports medicine · Soccer/injuries · Magnetic resonance imaging

Background

Soccer is the most popular sport worldwide, with approximately 200,000 professional players and 240 million amateur athletes [1], generating an estimated US$ 4.7 billion in revenue for the Fédération Internationale de Football Association (FIFA) during the 2022 World Cup in Qatar [2].

Key points
- Apophysitis presents with apophyseal and subapophyseal bone marrow edema and irregularities, with adjacent soft tissue inflammation. Apophyseal avulsion presents with displacement of apophyses and fluid in surrounding soft tissue.
- Apophysitis is more common than apophyseal avulsion, although differentiating them through imaging can be challenging. Therefore, considering the temporality of clinical presentation is essential for an accurate diagnosis.
- Displacement of apophysis and muscular edema show a significant correlation with the time to return to activity in anterior superior and anterior inferior iliac spine apophyseal injuries.
- Pubic symphysis apophysitis is an underrecognized cause of groin pain in youth athletes. Knowledge of its maturation is essential to make a proper diagnosis.

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Soccer has undergone an increase in physical demands that force athletes to work close to their maximum capacity, predisposing them to injury and to overloading their joints [3, 4]. It has been reported that soccer exhibits a high incidence of injuries, even when compared to many other sports, with epidemiological studies indicating that professional soccer players sustain 4 to 53 injuries per 1000 h of exposure [5–7]. The majority of soccer injuries occur in the lower extremities due to the unique demands of the game [5–8].

Musculoskeletal injuries are particularly relevant to elite soccer athletes. Besides the costs of athletes' absence from competitions and the impact on salaries and sponsor investments [9], frequent injuries can hinder an elite player's ability to reach their maximum skill level [10].

Similar to adult soccer athletes, young athletes also experience injuries such as contusions, sprains, and strains as common injury mechanisms [11, 12]. However, young athletes are particularly susceptible to growth-related injuries due to the presence of an open physis [12].

Specifically, in skeletally immature athletes, the physeal plate is two to five times weaker than the surrounding fibrous structures (ligaments, tendons, and joint capsule), making it more vulnerable to injury [9]. The physeal plate includes epiphyses and apophyses. Unlike epiphyses, apophyses do not

contribute to the longitudinal length of bones; they are secondary ossification centers and serve as attachment sites for tendons, making them susceptible to traction forces [9].

The purpose of this article is to discuss the anatomy of apophyses and the main clinical characteristics, epidemiology, and imaging findings of common and uncommon apophyseal injuries in skeletally immature professional soccer athletes, as well as briefly review treatment options and possible complications.

Soccer injury types and mechanisms

Overall, soccer injuries can be categorized into two main types: traumatic and overuse. Traumatic injuries represent about two-thirds of all soccer injuries and can be further subdivided into contact and non-contact injuries [10, 13]. In particular, contact injuries such as being tackled or colliding with an opponent (e.g., during a jump) account for approximately 50% of traumatic injuries, while non-contact injuries, resulting from actions like sprinting, turning, and heading, represent 26–58% of traumatic injuries [5, 7, 13, 14]. Overuse injuries account for 27–33% of the injury incidences and are caused by repetitive stress without sufficient time for the natural regenerative process to occur, leading to conditions such as apophysitis, tendinopathy, and stress fractures [10, 11, 14, 15].

Most studies consistently show that soccer players are up to ten times more likely to get injured during matches and competitions than during training [5, 7, 10, 13, 14]. Regarding athletes' positions, there is no consensus about which one carries the highest risk, varying among defenders, midfielders, and strikers [10, 13].

In skeletally immature athletes, there is a unique type of injury, known as growth-related injury, which includes epiphyseal and apophyseal lesions. Specifically, in youth soccer players, it has been reported that 94% of growth-related injuries occur in the lower limb's apophyses, with 75% resulting in time-loss injuries [12, 16].

Apophyseal injuries

Definition

There are two classic types of apophyseal injuries: apophyseal avulsion or avulsion fractures, and apophysitis. Apophyseal avulsion, technically a Salter-Harris type I fracture, is an acute separation across the physeal plate [9, 17–19]. Apophysitis (or "traction apophysitis") is an injury to the apophysis, usually caused by strong repetitive muscle contractions that lead to submaximal load at its bony attachment and inflammation of the growth plate cartilage [9, 17, 20, 21].

However, the precise definition and nomenclature of apophyseal injuries diverge in the literature. Some authors reserve the term "apophysitis" for chronic evolution lesions [9, 22–24], while others suggest that apophyseal avulsions result from prolonged apophysitis [25, 26]. In non-displaced apophyseal avulsions, it could be difficult to distinguish them from apophysitis in imaging modalities. Therefore, the clinical condition and emphasis on the temporality of presentation should be used as a reference for the imaging analysis [9, 27].

Epidemiology

There are few studies reporting apophyseal injuries, particularly in young soccer athletes, possibly due to apophyseal injuries being an underdiagnosed condition, as they are commonly treated as strains [17].

Overall, the reported incidence of apophyseal injuries in young soccer athletes ranges from 5.1 to 15.3% among all other musculoskeletal injuries over a season, with an injury rate of 0.35 per 1000 h of training exposure. Among these injuries, apophysitis was more common, accounting for 80.5 to 91.6%, compared to apophyseal avulsion, with most of them being primary (first-time) incidence [11, 12, 16, 17].

However, there is a high variation in the incidence of different types of apophyseal injury among studies. Gudelis et al. [17] showed that the pelvis and hip apophyses are the most common sites of apophyseal lesion, particularly the anterior inferior iliac spine (with an incidence of 43.3%). Le Gall et al. [11] and Materne et al. [12, 16] have shown that apophysitis of the anterior tuberosity of the tibia is the most common apophyseal injury (with an incidence ranging from 28.1 to 36.6%). Nevertheless, in Materne et al.'s [12, 16] study, all the pelvis and hip apophyseal injuries together are the most common (57.2%). Table 1 summarizes the relative incidence of apophyseal injuries.

Other studies have also investigated the incidence of apophyseal avulsions in immature skeleton adolescents, including non-soccer players. Rossi and Dragoni [18] reported the ischial tuberosity as the most common site of avulsion injury (53.7%) in competitive athletes overall, followed by the anterior inferior iliac spine and anterior superior iliac spine, with soccer being mainly responsible for the iliac spine injuries.

Notably, growth-related injuries are among the most burdensome injuries [28, 29]. Particularly, pelvis and hip apophyseal injuries account for up to 45% of all time-loss physeal injuries [16, 17]. Consistently, other studies have shown that hip apophyses are at a higher risk of injury compared to other joints due to vigorous contractions, particularly in high-performance soccer athletes [9, 21].

Table 1 Relative incidence of sites of apophysitis and apophyseal avulsion among all apophyseal injuries in elite youth soccer players

	Apophysitis	Apophyseal avulsion
Anterior superior iliac spine (ASIS)	4.9–6.2%	0.8–1.9%
Anterior inferior iliac spine (AIIS)	7.3–35.2%	4.6–8.1%
Ischial tuberosity (IT)	3.0–17.1%	0.4–1.9%
Iliac crest (IC)	1.4–4.9%	0.4–1.0%
Pubic symphysis	6.2–11.0%	-
Lesser trochanter (LT)	0.9–6.5%	0.5–2.4%
Greater trochanter	0.4%	-
Tibial tubercle	12.9–36.6%	1.0–7.3%
Patella	2.9–6.1%	0.4–1.4%
Calcaneus	2.4–10.6%	-
Fifth metatarsal	0.8–1.9%	0.4–2.4%

Data are based on references 11, 16, and 17

Interestingly, lower limb apophyses commonly fuse from distal to proximal, resulting in earlier fusion of the knee apophyses compared to the hip apophyses [12, 17, 18, 21]. As a consequence, knee apophyseal injuries tend to occur at earlier ages (10–12 years) compared to hip apophyseal injuries (12–14 years) [12, 17].

Clinical presentation and imaging findings

Clinically, apophysitis usually presents as gradual pain and swelling at the affected apophysis, which worsens as the athlete continues to train [20]. Apophyseal avulsion occurs due to a sudden and forceful contraction of the attaching musculotendinous unit, resulting in local pain and loss of function of the respective muscle group [9, 21].

The diagnosis of apophyseal injuries is based on (i) history and physical examination, particularly with the presence of a traumatic mechanism as well as pain and swelling at the site of tendon attachment, and (ii) imaging evaluation [17].

Apophysitis typically shows cortical irregularity of apophyses, with apophyseal and subapophyseal bone marrow edema, as well as inflammation of adjacent soft tissue. In apophyseal avulsion injury, the main finding is displacement of the apophysis, with bone marrow edema and fluid in surrounding soft tissue. General imaging findings of both of them are summarized in Table 2 [9, 20, 21, 30, 31].

The anatomy and age of ossification of the main injured apophysis in soccer athletes are described in Table 3. Particularities about specific apophyses and apophyseal lesions will be discussed further.

Sites of apophyseal injuries

Hip/pelvis

Anterior inferior iliac spine (AIIS) The AIIS arises just above the level of the anterior superior acetabular rim [32], and its secondary ossification center appears around the ages of 10 to 13 years and closes between 14 and 18 years [33]. It is the site of origin of the direct head of rectus femoris muscle [21], and iliocapsularis muscle, which stabilizes the femoral head in a deficient acetabulum [34].

Apophyseal avulsions of the AIIS (Fig. 1), also known as sprinter's fracture, typically occur during hip hyperextension and knee flexion. Athletes usually report hearing a sudden "pop" during physical activity associated with an acute onset of severe pain [21]. In apophysitis (Fig. 2), athletes usually report groin pain resembling athletic pubalgia [20].

Besides diagnosis, MRI can be an important tool in predicting the severity of apophyseal avulsion injuries in soccer players. Our group recently found that displacement of the apophysis and the presence of muscular edema showed a significant correlation in time to return to activity. In this study, an apophysis displacement of 3 mm might serve as a parameter to predict return to sports within 40 days with good accuracy, after physiotherapy treatment [9].

Conservative treatment involving rest, anti-inflammatory drugs, and physiotherapy is successful in most cases [9, 21]. Surgical treatment should be considered when there is a displacement of the apophysis bone fragment greater than 15–20 mm and in high functional demands athletes [24, 35], as it can shorten the time to return to sports.

Chronic injuries may demonstrate heterotopic bone formation at the AIIS and adjacent soft tissues [30, 32, 36]. This bony protrusion can result in extra-articular impingement, which is called subspine impingement (Fig. 3). Currently, the most common treatment for this condition is arthroscopic decompression of the subspine space [9, 36, 37].

Anterior superior iliac spine (ASIS) The ASIS apophysis serves as the origin of the sartorius muscle and part of the tensor fasciae latae [21]. Its secondary ossification center appears around the ages of 12 to 15 years and closes between 14 and 21 years in females and 17 and 22 years in males [33].

Apophyseal avulsions of the ASIS (Fig. 4) occur due to a sudden forceful strain in the origin of the respective muscles, typically during the starting phase of running or jumping, when the hip is extended and the knee is flexed [21, 23]. The avulsed fragment is usually displaced distally and laterally,

Table 2 Imaging findings of apophyseal lesions

	Apophysitis	Apophyseal avulsion
Radiograph and computed tomography (CT)	Radiographs are often non-specific and inconclusive	Radiograph may show mild or even no apophyseal displacement
	Apophysis may appear normal or show mild irregularity, fragmentation, and widening of its margins	CT is better for depicting displacement of bone fragment and heterotopic bone formation
Ultrasound (US)	Apophysis cortical irregularity Heterogeneous vascularized pseudomass representing inflamed apophysis	Mild or even no apophyseal displacement
Magnetic resonance imaging (MRI)	Enlargement or widening of the apophysis at the site of muscle insertion, with a normal shape of original apophysis Discrete or absent apophyseal plate separation Apophysis and subapophyseal bone marrow edema, as well as edema in periapophyseal structures	Apophyseal displacement, fluid or edema in the cartilage growth plate of the apophysis, as well as edema in the surrounding periapophyseal structures

which can be mistaken for an avulsion of the AIIS or even neoplasms or infectious process [21, 38]. More severely displaced fragments may also compress the lateral cutaneous femoral nerve, causing meralgia paresthetica [21, 39].

Similar to AIIS injuries, our group found that the displacement of the ASIS apophysis and the presence of muscular edema in avulsion injuries might predict the time to return to play with good accuracy [9].

ASIS apophysitis occurs due to traumatic inflammation of the apophysis, usually when there is active flexion and external rotation of the hip [20].

There are no specific treatment guidelines for ASIS apophyseal injuries, although conservative treatment is successful in most cases, especially for non-displaced or minimally displaced fragments [9, 21]. According to a recent meta-analysis, surgical treatment has a higher overall success

Table 3 Anatomy and age of ossifications of the apophyses

Apophysis	Muscle that originates from or inserts into the apophysis	Age of appearance (years of age)	Age of closure (years of age)
Anterior inferior iliac spine	Origin of direct head of rectus femoris and iliocapsularis muscles	10–13	14–18
Anterior superior iliac spine	Origin of sartorius muscle and part of the tensor fasciae latae	12–15	Female: 14–21 Male: 17–22
Ischial tuberosity	Origin of biceps femoris, semitendinosus and semimembranosus muscles	13–16	Female: 14–19 Male: 16–19
Pubic symphysis	Superior apophysis: origin of adductor longus and insertion of rectus abdominis aponeurosis	~16	20–25; reported as occurring until 35–40 years of age
	Inferior apophysis: origin of adductor brevis and gracilis musculotendon units		
Greater trochanter	Insertion of gluteus minimus and medius tendons	2–5	Female: 14–17 Male: 16–19
	Origin of vastus lateralis muscle		
Lesser trochanter	Insertion of iliopsoas tendon	7–11	Female: 14–17 Male 16–19
Iliac crest	Origin and insertion of the external and internal abdominal oblique muscles, transverse abdominis, gluteus medius and tensor fascia latae muscles	12–15	Female: 14–21 Male: 17–22
Tibial tubercle	Insertion of patellar tendon	Female: 8–12 Male: 9–14	Female: 14–18 Male: 16–20
Patella	Origin of patellar tendon	3–6	Variable age during adolescence
Calcaneus	Insertion of calcaneal tendon	Female: 5 Male: 7	Female: 10–16 Male: 14–17
Fifth metatarsal	Insertion of peroneus brevis tendon	Female: 10 Male: 12	Female: 11–12 Male: 14–15

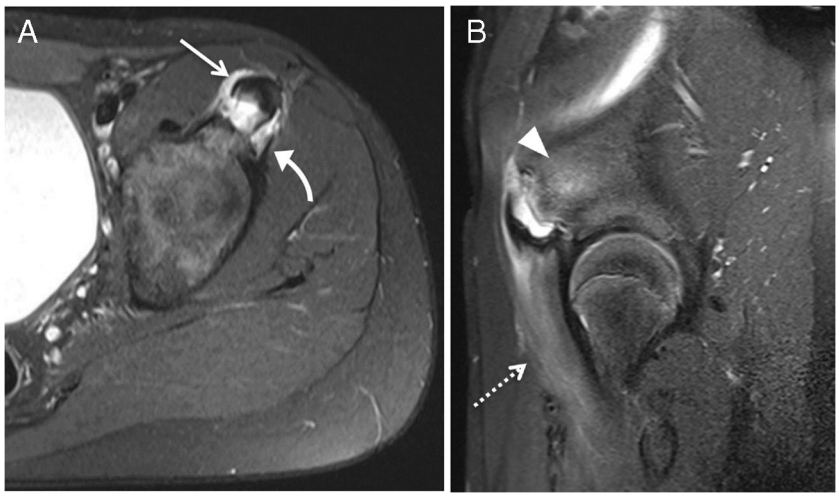

Fig. 1 15-year-old male, professional soccer athlete with apophyseal avulsion of the anterior inferior iliac spine, presenting with hip pain after trauma in a match. Axial T2-weighted fat-suppressed (**A**) and axial T1-weighted (**B**) MRI of the left hip show apophyseal avulsion of the AIIS apophysis (arrow), with fragment displaced distally and laterally by 1.0 cm. There is also bone marrow edema in the subapophyseal bone (arrowhead), as well as adjacent soft tissue edema in the iliac muscle (dotted arrow). There is peritendinous edema adjacent to the indirect head of the rectus femoris (curved arrow), which remains intact

rate, especially when the fragment is displaced greater than 15 mm and in high functional demand athletes [24].

Ischial tuberosity (IT) The IT apophysis serves as the origin of the long head of biceps femoris, semitendinosus, and semimembranosus muscles, known as hamstring muscles [21].

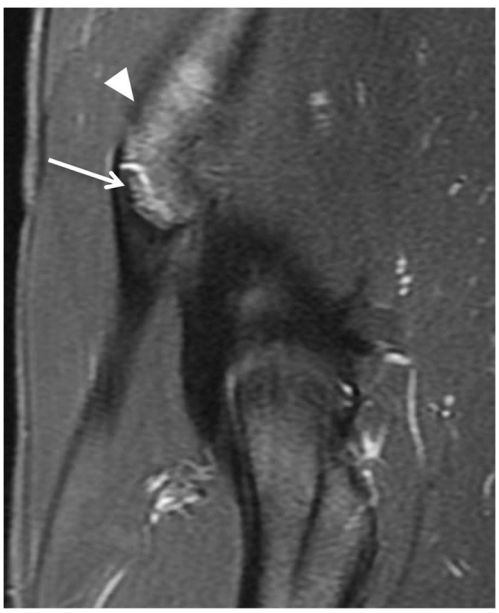

Fig. 2 15-year-old male, professional soccer athlete with anterior inferior iliac spine apophysitis. Sagittal T2-weighted fat-suppressed MRI of the hip shows apophysis (arrow) and subapophyseal bone marrow edema (arrowhead) of the AIIS, with no displacement of the apophysis

The adductor magnus muscle has a tendinous slip originating from the inferomedial aspect of the ischial tuberosity and is sometimes considered a component of the hamstring [40, 41]. Its secondary ossification center appears around the ages of 13 to 16 years and closes between 14 and 19 years in females and 16 to 19 years in males [33].

Apophyseal avulsion of IT (Fig. 5) is caused by sudden forceful flexion of the hip joint when the knee is extended, and the hamstrings are powerfully contracted [21, 23]. The avulsed fragment may also lead to compression of the sciatic nerve [21, 41].

IT apophysitis (Fig. 6) usually affects younger athletes compared to avulsion injuries [20, 42]. Due to its mild presentation, the diagnosis is often delayed, and many athletes continue their sports activities, leading to chronic irritation of the apophysis and loss of function [42].

Symptoms of the avulsion injury and the initial radiograph may also be misinterpreted as a bone-forming neoplasm due to heterotopic bone formation [21]. Operative treatment should be considered in cases of displacement of the avulsed fragment greater than 15–20 mm, loss of function in athletes with high physical demands, and a painful fibrous non-union of the fragment [21, 23, 42].

Pubic symphysis The pubic symphysis is a non-synovial diarthrodial joint between the pubic bodies, composed of a fibrocartilaginous disc interposed between hyaline cartilage overlying the medial borders of pubic bones [43, 44]. The maturation of the pubic symphysis is a long process, and it is the last part of the human skeleton to mature, starting

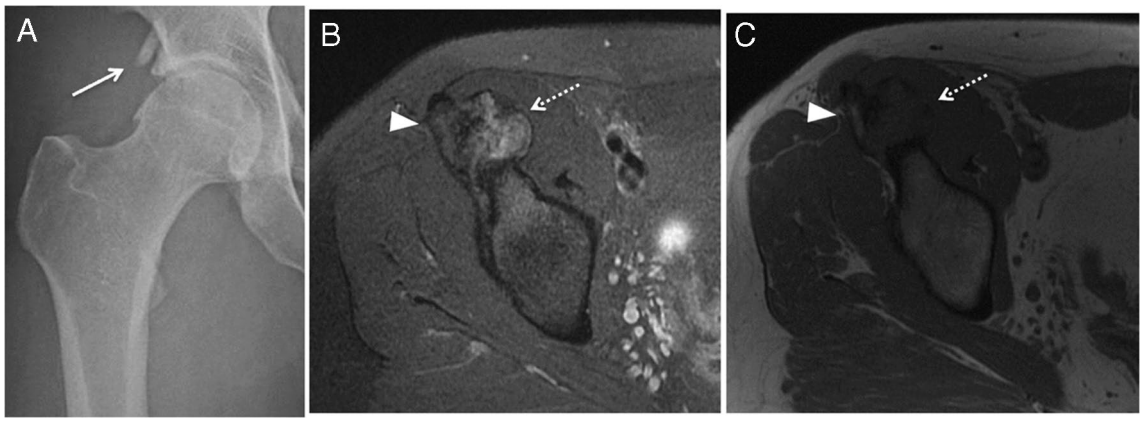

Fig. 3 Sequelae of avulsion of the anterior inferior iliac spine in two different soccer athletes. Frontal radiograph of the hip (**A**) shows a 36-year-old male with a previous avulsion of the AIIS and a bony protrusion in its location, along with other heterotopic ossification in adjacent soft tissue (arrow), predisposing to subspine impingement. Axial T2-weighted fat-suppressed (**B**) and axial T1-weighted (**C**) MRI of the hip of a 20-year-old male different athlete show sequelae of apophyseal avulsion of the AIIS (arrowhead), with osteohypertrophic reaction and granulation tissue (dotted arrow) between the fragment and adjacent bone, also predisposing to subspine impingement

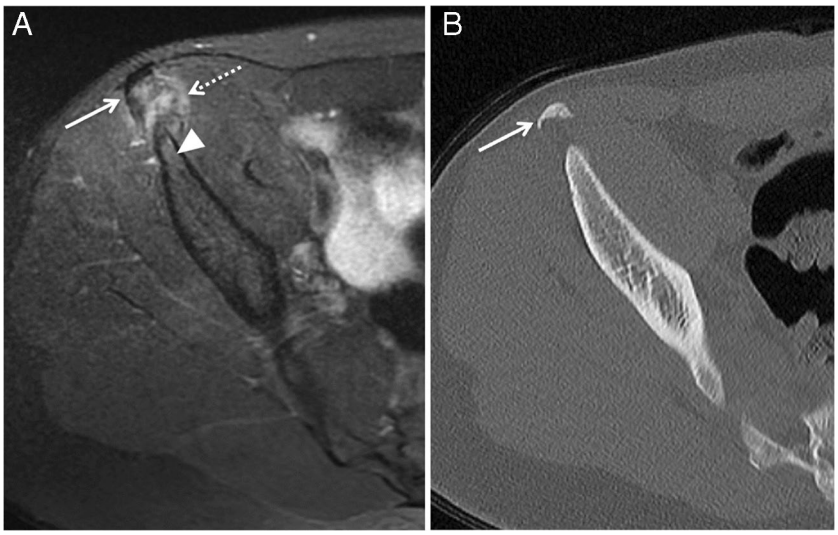

Fig. 4 16-year-old male, soccer athlete with apophyseal avulsion of anterior superior iliac spine, presenting with hip pain after trauma in a match. Axial T2-weighted fat-suppressed MRI (**A**) and axial CT (**B**) of the right hip show apophyseal avulsion of ASIS (arrow), with the fragment displaced distally and laterally by 1.0 cm. There is also bone marrow edema in the displaced fragment and subapophyseal bone (arrowhead), as well as adjacent soft tissue edema in the iliac muscle (dotted arrow)

around 16 years of age, with developmental activity reported to occur until 35–40 years of age [31, 45, 46], but it usually fuses around 20–25 years of age [45].

The anatomy, maturation, and pattern of apophyseal injuries related to the pubic symphysis are significantly complex. In this section, we aimed to provide an overview of these topics and to recommend references for further reading.

Recently, it has been demonstrated that the pubic apophysis can be divided into two different apophyses: superior and inferior [45]. The superior apophysis serves as the origin of the adductor longus muscle, along with the insertion of a thin anterior rectus abdominis aponeurosis [45, 47], and the inferior apophysis serves as the origin of the adductor brevis and gracilis musculotendon units [45]. De Maeseneer et al. [47] found that adductor longus fibers insert perpendicularly into the pubic bone through a fibrocartilage enthesis. Interestingly, these fibers cross-connect along the anterior pubic ligament into the contralateral tendon, which may explain why symptoms of pubalgia are commonly bilateral [47].

Apophyseal avulsion of the pubic symphysis is rare, usually occurring in soccer athletes, resulting from excessive turning movements. In contrast to other avulsion injuries in the hip, adductor injuries often present as isolated soft tissue injuries, without bone fragments [21].

Apophysitis has been recently described as a cause of groin pain in athletes [31], probably underrecognized, since Koh and Boyle [45] showed a prevalence of 92% of pubic apophysitis among Australian Football League skeletally immature players with groin pain, with inferior pubic apophysitis being more prevalent compared to superior apophysitis.

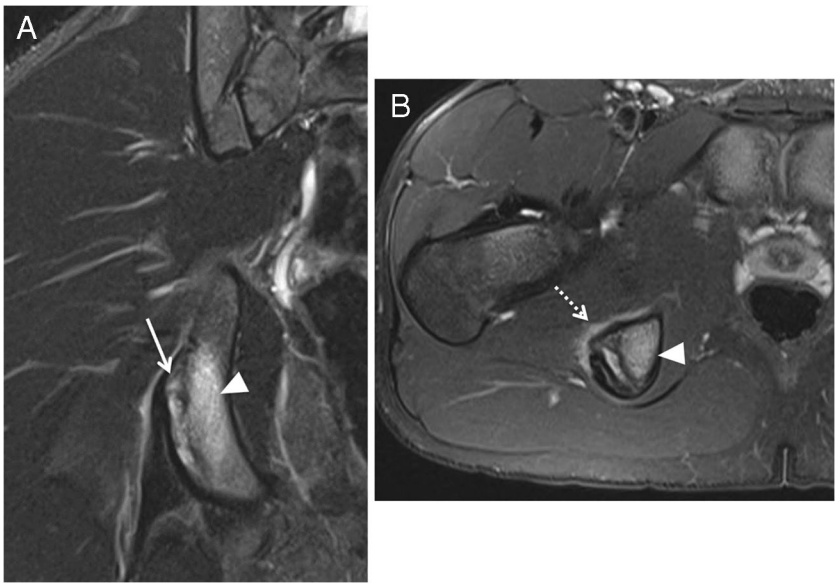

Fig. 5 13-year-old male, soccer athlete with apophyseal avulsion of the ischial tuberosity, presenting with posterior acute hip pain after a sprint during training. Coronal (**A**) and axial T2-weighted fat-suppressed (**B**) MRI of the right hip show mild separation (< 2 mm) of the ischial tuberosity apophysis (arrow), with interposed laminar fluid. There is also subapophyseal marrow edema (arrowhead) and soft tissue edema (dotted arrow)

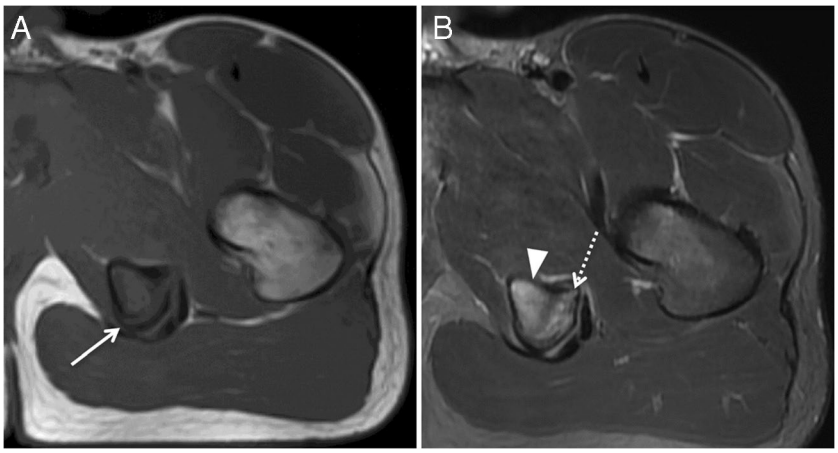

Fig. 6 14-year-old male, soccer athlete with ischial tuberosity apophysitis, presenting with posterior hip pain for 1 month. Axial T1-weighted (**A**) and axial T2-weighted fat-suppressed (**B**) MRI of the left thigh show hypertrophy of the apophysis (arrow) of the ischial tuberosity, with bone marrow edema of the apophysis (dotted arrow) and subapophyseal bone (arrowhead). These findings are consistent with apophysitis

The knowledge of the stage of maturation of pubic symphysis is essential to interpreting normal imaging findings that may simulate lesions [31].

Sailly et al. [31] described 4 developmental groups of apophysis maturation—stage 1, open apophyseal plate without secondary ossification center; stage 2, open apophyseal plate with secondary ossification center; stage 3a, closed apophyseal plate without secondary ossification center; stage 3b, closed apophyseal plate with remaining secondary ossification center (Fig. 7).

The pubic bodies, apophysis, and surrounding capsuloligamentous tissues constitute an area of biomechanical weakness that endures considerable forces during athletic practice [31, 44]. Interestingly, professional athletes often exhibit delayed maturation of the pubic symphysis apophysis, due to local chronic repetitive stress [21, 31, 45].

Imaging findings of apophysitis are similar to those at other sites, including bone marrow edema in the apophysis and subapophyseal bone, subchondral cysts, and subapophyseal bone irregularities/erosions or sclerosis [31, 45]. Apophysiolysis is another finding reported in pubic apophysitis, characterized by an ill or well-defined intermediate signal between the superficial apophysis and ossified subapophyseal bone, leading to a widening appearance of the apophysis (Fig. 8) [45].

In our group's experience, apophysitis may mimic classical signs of athletic pubalgia, particularly apophysiolysis. Superior pubic apophysitis can simulate the superior cleft sign, which designates the detachment of the rectus abdominis-pyramidalis/adductor longus aponeurosis in the mature skeleton, as the widening appearance of the nonfused apophysis resembles a tendon tear (Fig. 9) [48, 49]. Similarly, inferior pubic apophysitis can simulate the secondary cleft sign, which designates the detachment of the adductor brevis/gracilis common origin (Fig. 10) [49, 50].

Sequelae of apophysitis result in incomplete apophyseal fusion (Fig. 11), particularly in players who continue playing despite apophyseal stress, developing chronic symptoms [31]. There are no specific guidelines for the treatment of

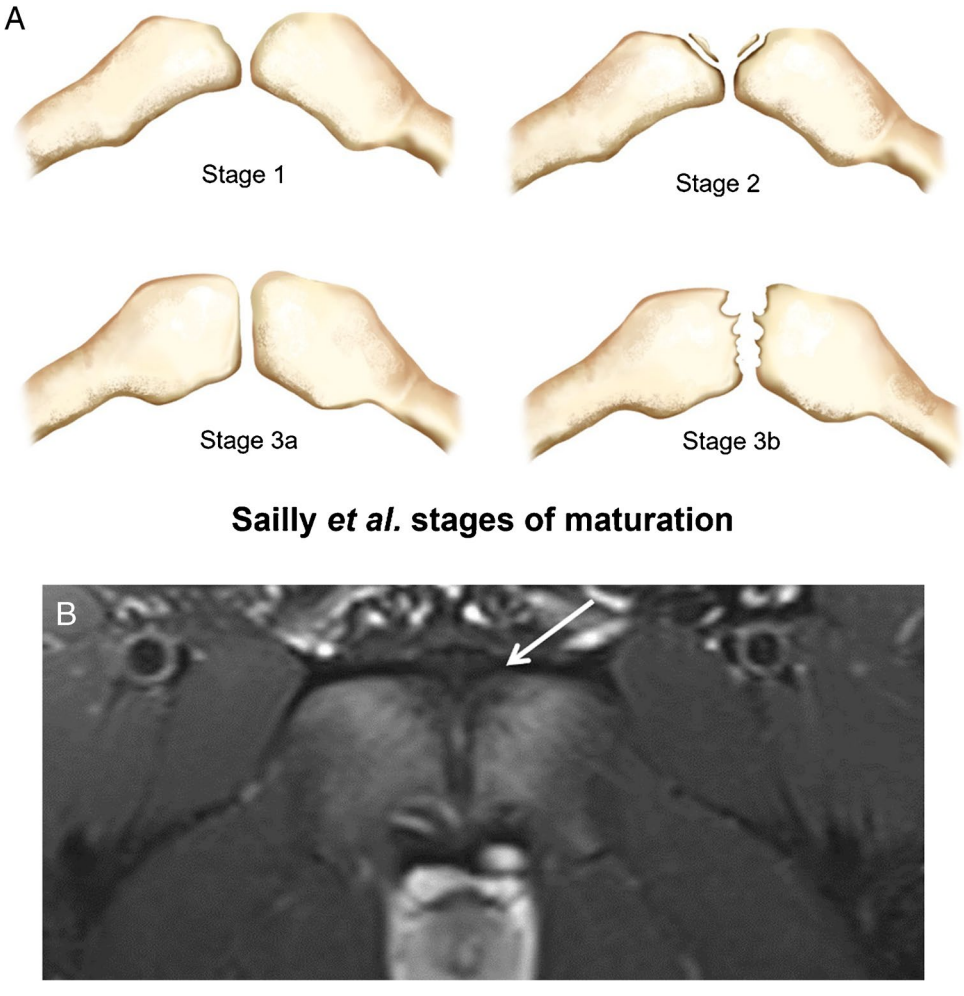

Fig. 7 Stages of maturation of the pubic symphysis (Sailly et al.) (**A**). Stage 1, open apophyseal plate without secondary ossification center; stage 2, open apophyseal plate with secondary ossification center; stage 3a, closed apophyseal plate without secondary ossification center; stage 3b, closed apophyseal plate with remaining secondary ossification center. Axial T2-weighted fat-suppressed MRI (**B**) shows stage 2 maturation of a normal superior pubic apophysis (arrow) Schematic illustration reproduction kindly authorized by Dr. Matthieu Sailly

pubic apophysitis, but in Sailly et al.'s [31] study, conservative treatment has been successful in most cases, with time to return to play of 6 weeks to 4 months.

Greater femoral trochanter The greater femoral trochanter serves as the insertion site of gluteus minimus and medius muscles, and it is also the origin of the vastus lateralis muscle [51, 52]. Its secondary ossification center appears around the ages of 2 to 5 years and closes between 14 and 17 years in females and 16 to 19 years in males [20, 33].

Apophyseal avulsion and apophysitis of the greater trochanter are very rare [51–53], manifesting clinically as gait disturbance and hip pain [20, 53]. The rarity of these injuries can be explained by anatomical and biomechanical characteristics, as first postulated by Heimkes et al. [54]. They demonstrated that the entire vastus lateralis muscle originates from the greater trochanter apophysis and is bound to the insertions of gluteus medius and minimus by a thick fibrous connection [51], acting as a muscle stabilizer [52, 55].

Importantly, apophyseal avulsion of the greater trochanter in skeletally immature individuals increases the risk of avascular necrosis of the femoral head. This risk is heightened because the intramedullary blood supply is not yet established, relying on the lateral ascending cervical artery, which passes near the greater trochanter [53].

There are no specific treatment guidelines for greater trochanter apophyseal avulsion or apophysitis. Most authors consider conservative treatment as the first choice, typically resulting in favorable clinical outcomes [51, 53].

Lesser femoral trochanter The lesser femoral trochanter serves as the insertion for the iliopsoas tendon [23]. Its secondary ossification center appears around the ages of 7 to 11 years and closes between 14 and 17 years in females and 16 to 19 years in males [33].

Apophyseal avulsions (Fig. 12) are rare [24] and occur typically due to forceful muscle contraction of the iliopsoas in an attempt to accelerate or decelerate the body [56]. In contrast to adults, where lesser trochanter fractures may indicate an underlying bone malignancy, such fractures in skeletally immature athletes are almost always benign and respond well to conservative treatment [23, 57].

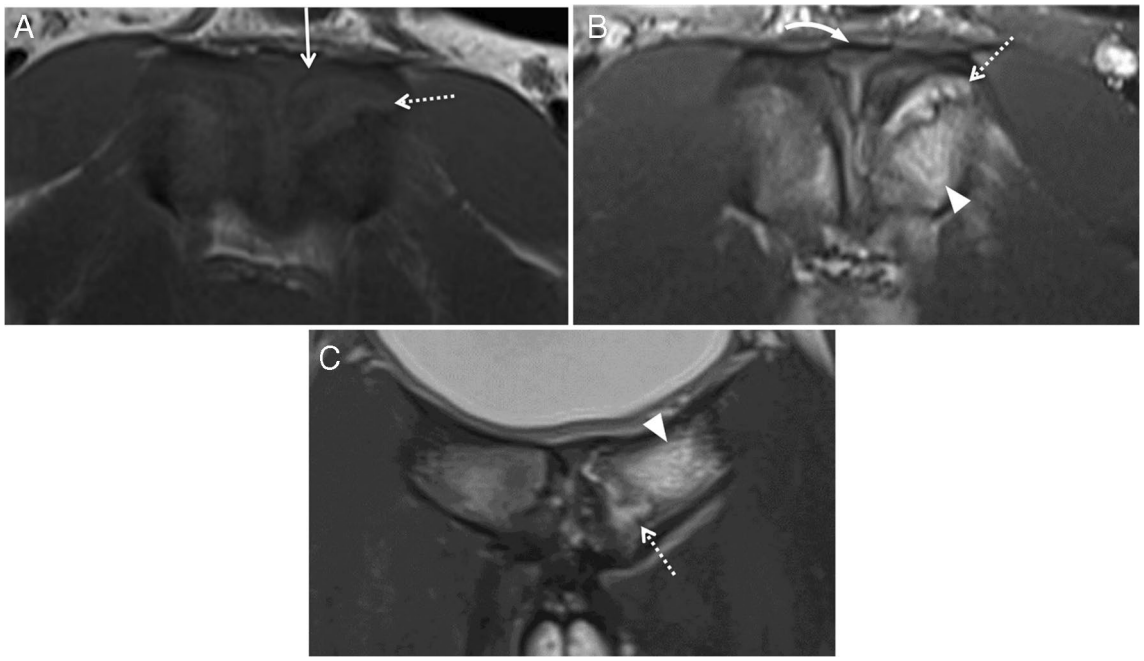

Fig. 8 14-year-old male, soccer athlete with superior pubic symphysis apophysitis. Axial T1-weighted (**A**), axial (**B**), and coronal T2-weighted fat-suppressed (**C**) MRI show apophysiolysis of the left superior apophysis (arrow) with a well-defined high signal (dotted arrow) between the superficial apophysis and the ossified subapophyseal bone. There is also bone marrow edema (arrowhead) in the pubic bone extending to the pubic ramus. These findings are consistent with apophysitis. The anterior pubic ligament, which connects the fibers of the adductor longus tendons, can also be visualized (curved arrow)

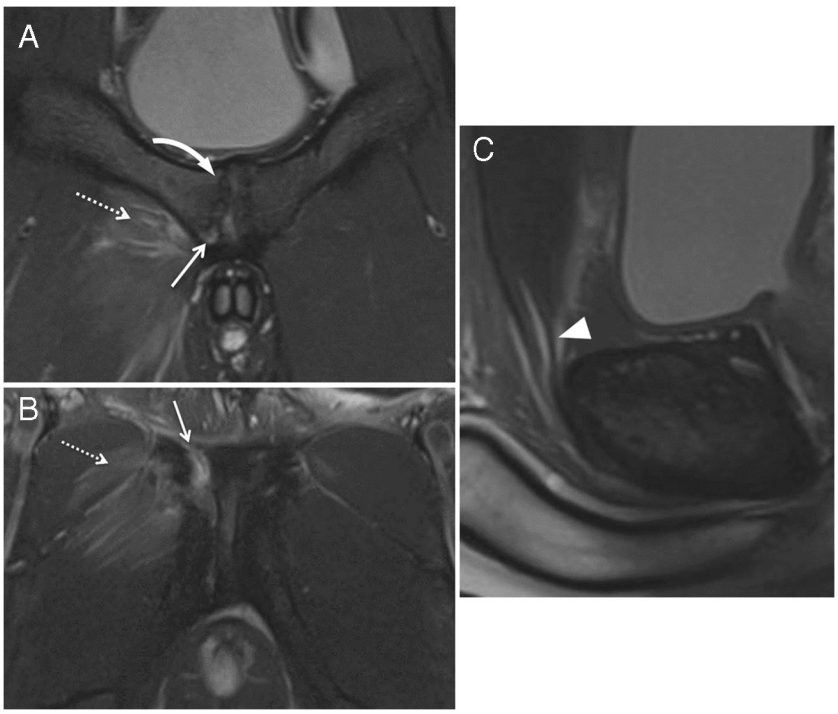

Fig. 9 20-year-old male, professional soccer athlete with superior pubic apophysitis simulating the superior cleft sign. Coronal (**A**), axial (**B**), and sagittal T2-weighted fat-suppressed (**C**) MRI show a high signal linear band/partial detachment (arrow) along the superior apophysis, at the insertion of the adductor longus, associated with edema of the myotendinous transition of the rectus abdominis (arrowhead) and peritendinous edema (dotted arrow). Cortical irregularities of the symphysis and subapophyseal bone (curved arrow) are also observed, consistent with apophysitis

Iliac crest The iliac crest serves as the origin and insertion site of the external and internal abdominal oblique muscles, transverse abdominis, gluteus medius, and tensor fascia latae muscles [20]. Its secondary ossification center appears around the ages of 12 to 15 years and closes between 14 and 21 years in females and 17 to 22 years in males [33].

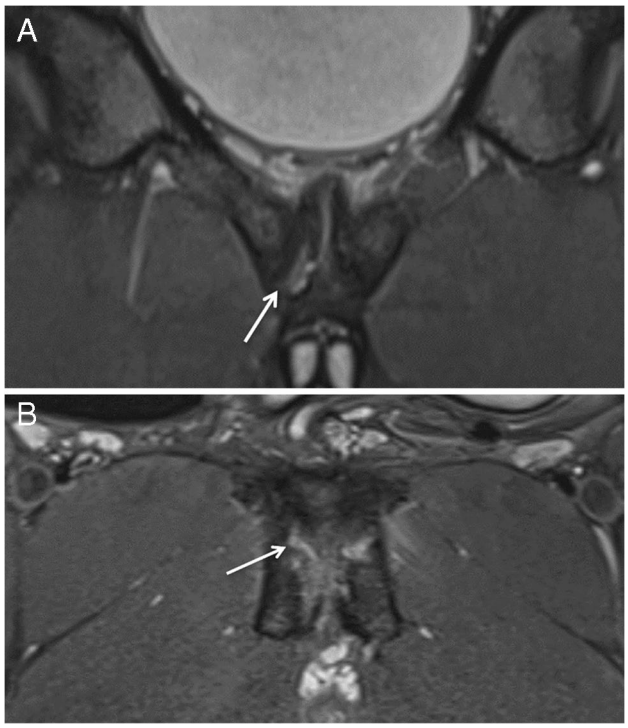

Fig. 10 22-year-old male, professional soccer athlete with inferior pubic apophysitis simulating the secondary cleft sign, presenting with pubalgia for months. Coronal (**A**) and axial T2-weighted fat-suppressed (**B**) MRI show a high signal linear band (arrow) at the conjoint insertion of the adductor brevis and gracilis, associated with peritendinous edema (arrowhead), simulating the classic secondary cleft sign (detachment of adductor brevis-gracilis tendon), described in athletic pubalgia in adults. Cortical irregularities of the symphysis and subapophyseal bone (dotted arrow) are also observed, consistent with apophysitis. Similar findings are seen on the contralateral side

Apophyseal avulsions are rare and result from a rapid, forceful eccentric lateral flexion and/or rotation of the torso, causing excessive strain of abdominal muscles [21]. The most common mechanisms are kicking and running [58]. Conservative treatment is generally sufficient for complete recovery within 4–6 weeks, but surgery may be considered if avulsion fractures are displaced more than 3 cm or if fragments encroach on nerves or vascular supply [58, 59].

Knee

Tibial tubercle The tibial tubercle serves as the site of insertion of the patellar tendon [20]. Its secondary ossification center appears around the ages of 8 to 12 years in females and 9 to 14 years in males and closes between 14 and 18 years in females and 16 to 20 years in males [33].

Apophyseal avulsion fractures are uncommon, accounting for less than 1% of all physeal injuries, and typically occur in well-developed athletic males, who are approaching skeletal maturity (14–17 years old) [60]. The main mechanisms of avulsion fractures are (i) abrupt knee flexion with quadriceps contraction and (ii) forceful quadriceps contraction with a fixed foot. Both of these mechanisms usually occur during jumping activities [60, 61].

The treatment aims to restore the extensor mechanism and ensure the congruency of the articular surface of the tibia [60]. Non-displaced fractures are usually treated with cast immobilization. Displaced fractures require open reduction and internal fixation [60, 62]. The prognosis and outcome are generally excellent, even in cases in which the fracture line passes across the proximal physis of the tibial into the joint [60].

The tibial tubercle apophysitis, or Osgood-Schlatter disease (OSD), is caused by repetitive microtrauma to the apophysis and generally occurs in children and adolescents between 9 and 14 years old [20, 63].

Clinically, OSD presents as activity-related local pain, accompanied by soft tissue or bony prominence of the apophysis [20, 64]. Treatment is usually conservative, as it is a self-limited condition. Surgical treatment is reserved for patients who do not respond to conservative treatment and may involve procedures such as drilling of the tubercle, removal of loose fragments, autogenous bone peg insertion, tibial tubercle excision, and sequestrectomy [64].

Patella The inferior pole of the patella serves as the origin of the patellar tendon [20, 23]. Its secondary ossification center appears around the ages of 3 to 6 years and closes at variable ages during adolescence [33, 65].

Apophyseal avulsions are rare and most commonly occur in individuals aged 8–12 years. Usually, the mechanism involves a vigorous contraction of the quadriceps muscle applied to a flexed knee. Plain radiographs reveal a small bone fragment inferior to the lower pole of the patella, patella alta, and joint effusion. MRI is frequently needed to assess the extent of injury in the extensor mechanism and to provide a better depiction of the bone fragment [66].

The inferior pole of the patella apophysitis is also called Sinding-Larsen-Johansson disease or "jumper's knee" (Fig. 13). It occurs most commonly between 9 and 13 years of age and is frequently associated with running, jumping, and kicking [20, 23]. Treatment is often conservative, with surgery reserved for refractory cases, which may involve the excision of the ossification in the patellar tendon [23].

Foot and ankle

Calcaneus The calcaneus apophysis serves as the insertion site of the calcaneal or Achilles tendon. Its secondary ossification center is usually multifocal, with the superior and

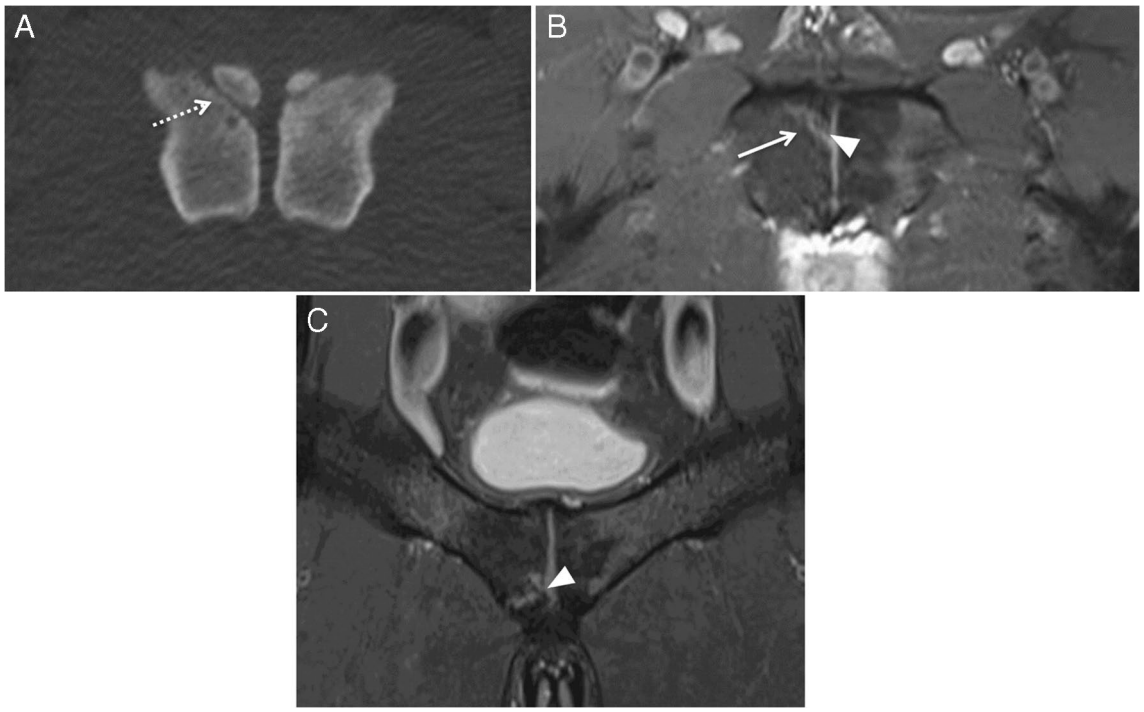

Fig. 11 Delayed apophysis maturation/incomplete apophyseal fusion of the symphysis apophyses in different athletes. Axial CT (**A**) shows subchondral bone irregularity (dotted arrow) in a 25-year-old male with unfused ossification centers. Axial (**B**) and coronal T2-weighted fat-suppressed (**C**) MRI of a 25-year-old male show subchondral bone irregularity (arrow) and mild enlargement (arrow) between the secondary ossification center and subapophyseal bone, consistent with apophysiolysis. In this case, apophysiolysis is simulating the superior cleft sign (detachment of adductor longus-rectus abdominis/pyramidalis aponeurosis) described in athlete's pubalgia in adults

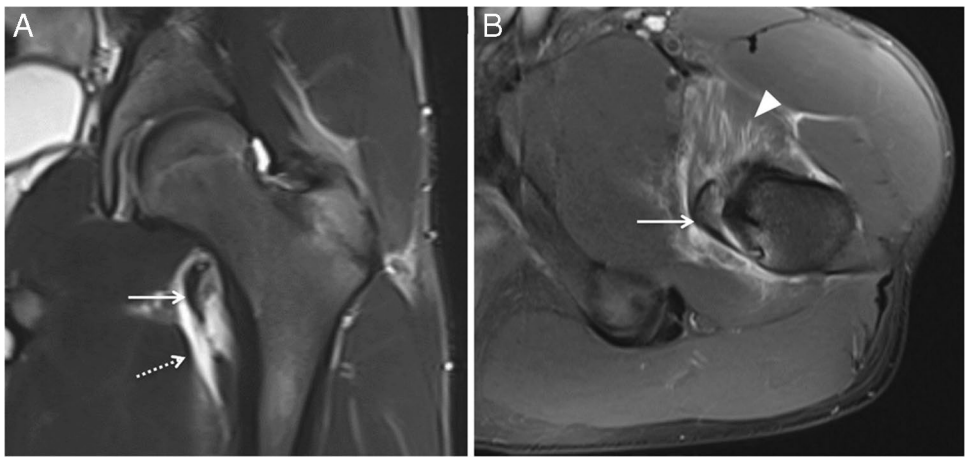

Fig. 12 15-year-old male, soccer athlete with apophyseal avulsion of the lesser trochanter. Coronal (**A**) and axial T2-weighted fat-suppressed (**B**) MRI show an avulsion of the lesser trochanter apophysis, with a displaced fragment (arrow), along with edema in the iliopsoas muscle fibers (arrowhead), and fluid in the surrounding soft tissue (dotted arrow)

inferior aspects of the apophysis being the last to ossify. It appears around 5 years old in females and 7 years old in males. Its complete fusion is a complex process, typically closing around 10–16 years in females and 14–17 years in males [67, 68].

Calcaneal apophyseal fractures are rare, usually occurring due to excessive traction stress on the Achilles tendon produced by excessive dorsiflexion [69, 70].

Apophysitis, also known as Sever's disease, is an overuse injury caused by chronic and repetitive microtrauma [23, 67], being bilateral in 60% of cases, particularly in activities involving running [20, 23]. Clinically, apophysitis presents as pain in the posterior aspect of the heel, exacerbated by activity [20].

Treatment of apophysitis is usually conservative, with the option of immobilization and temporary discontinuation of

Fig. 13 12-year-old male, soccer athlete with inferior pole of the patella apophysitis (Sinding-Larsen-Johansson disease). Sagittal T2-weighted fat-suppressed MRI of the knee shows bone marrow edema of the apophysis (arrow) of the inferior pole of the patella, as well as edema in the soft tissue of adjacent infrapatellar fat pad (arrowhead), consistent with apophysitis. There is no significant displacement of the apophysis

sports activities [67]. Apophyseal avulsion might require surgical treatment, if closed reduction attempts fail [70, 71].

Fifth metatarsal The base of the fifth metatarsal serves as the insertion site of the peroneus brevis tendon [72]. Its secondary ossification center appears around the age of 10 years in females and 12 years in males and closes by the ages of 11–12 years in females and 14–15 years in males [73].

Apophysitis of the proximal fifth metatarsal, known as Iselin's disease, occurs in young athletes, particularly in activities that require jumping, inversion stresses, and running [74, 75].

Fifth metatarsal apophyseal avulsions commonly occur following acute ankle inversion injuries [73]. To distinguish between apophyseal avulsion and apophysitis, it is important to note that avulsions occur perpendicular or oblique to the long axis of the metatarsal, whereas in apophysitis, the apophysis is oriented parallel to the long axis of the metatarsal and does not extend proximally into the joint [72, 73, 75].

Conservative treatment is sufficient for the majority of cases of apophysitis and apophyseal avulsion [73, 76]. Failure of conservative management of apophysitis can lead to non-union, which may require surgical excision of the bone fragment [77].

Conclusion

Apophyseal injuries in skeletally immature soccer players are among the most burdensome injuries, with the pelvis and hip apophyses being more susceptible to injury due to vigorous contractions in high-performance athletes. Apophysitis is more common than apophyseal avulsion, although distinguishing between them might be challenging. Diagnosis relies on clinical history and imaging evaluation, considering the temporality of presentation as a guide for imaging analysis. Therefore, radiologists should have a thorough understanding of normal anatomy, apophyseal development, imaging findings, and potential complications associated with apophyseal injuries.

Declarations

Conflict of interest The authors declare no competing interests.

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