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Invited Review

Apophyseal injuries in children's and youth sports

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Abstract

Introduction: The authors reviewed the current English literature regarding apophyseal injuries affecting young athletes, to highlight the frequency and characteristics of these injuries, to clarify risk factors and specific prevention measures, and to identify future research objectives.

Sources of data: The authors performed a comprehensive search of the medical literature, using the Medline database, including all English articles. Various combinations of the Keywords 'injury', 'sports', 'athletic injuries', 'avulsion fractures', 'physeal', 'physis', 'apophysis', 'apophysitis', 'growth plate' were used.

Areas of agreement: Growth benefits from a moderate physical activity.

Areas of controversy: Growth deficit may occur in young athletes involved in intensive practice of sport following apophysitis.

Growing points: Apophyseal injuries occurring during sport are less common than overall rate of injuries affecting the adolescent population. Growth disturbance occurs only rarely after an apophyseal injury.

Areas timely for developing research: Further studies should consider analytical as well as descriptive components of apophyseal injuries, to allow the identification of new possible risk factors and preventive measures and to help early detection and proper treatment as well.

Key words: injuries, apophyseal, sports, children, adolescent

Introduction

Children need to play and exercise for their well-being and growth and development. Regular physical activity benefits long-term health, contributing to the development of the child.[1] The number of children participating in competitive sports is growing in Western countries, and athletes are getting younger and younger.[2,3] A regular exercise programme helps children and adolescents to attain optimal physical, intellectual and psychomotor development.[4]

However, it is still unclear how physical activities affect biological maturation of young athletes. Moderate physical activity is often considered to benefit growth, but concerns arise for young athletes who practice high demand and specialized sports for a long period of time.[2,5–8] Up to 40% of all injuries in adolescents happen while practicing sports. These injuries are difficult to avoid and are unique to the pre-pubescent-adolescent population because the apophyses are secondary growth centres that open up at about Age 9 and are not fully closed until upwards of Age 22.[5,9–11]

Prevention is especially important, but also difficult to be implemented because of the growing number of children participating in sport activities underling the importance of diagnosis and management of apophyseal injury in the young.[12,13]

Concerns have been raised for the tolerance limits of the apophysis. The apophysis is particularly susceptible to repetitive physical loading, as may be seen in different sports (e.g. distance running, baseball, gymnastics, etc.), and to mechanical stresses of high demand sports (e.g. football, hockey, etc.).[14–16] Nevertheless, length discrepancy, angular deformity, or altered joint mechanics are uncommon after apophyseal injuries, but long-term disability may persist, especially if the injury goes unrecognized.[4]

In this study, we reviewed the current literature relative to characteristics and frequency of apophyseal injuries in children and adolescents involved in organized sport, searching for recommendation of early diagnosis, incidence, treatment, as well as risk factors, and guidelines for future research.

Material and methods

We performed a comprehensive search in the Medline literature database, including all English articles. Various combinations of the keywords 'injury', 'sports', 'athletic injuries', 'physeal', 'physis', 'apophysis', 'apophysitis', 'avulsion fracture' and 'growth plate' were used. All articles reporting apophyseal injuries of tubular or long bones in young athletes were included. We excluded articles focusing on sport-related injuries.

Final included studies were mostly case series or case reports. These articles allowed for a comprehensive account of the characteristics and relative frequency of sport-related apophyseal injuries, but identification of risk factors or calculation of incidence rates was not possible from the lack of denominator data. Epidemiologic data were also analysed to identify prevalence and incidence of apophyseal injuries in children and youth practicing sports.[17]

Anatomic and physiological considerations

Bone growth occurs at the physis and at the epiphysis. Two types of epiphyses have been described: the pressure epiphyses and the traction epiphyses or apophysis. The apophysis is a normal bony outgrowth that arises from a separate ossification centre and fuses with the bone in course of time. The apophysis is a site of tendon or ligament attachment. An apophysis is subjected primarily to tensile forces at the point of insertion of major tendons.[5] Traction epiphyses are involved only in peripheral growth of the bone, thus an acute or chronic injury at the apophysis usually does not disrupt longitudinal bone growth.

Even if growth rate of the apopysis is not as fast as that of the epiphyseal plate, their anatomies are similar.[5,18] This different growth rate may be related to the different number of proliferative-layer cells and collagen fibres in the apophysis, where the proliferative-layers are less and the tensile forces are higher.[5] Apophyseal conditions associated with overuse have been described only in young patients who are not skeletally mature.[5,19]

Pre-adolescents and adolescents injuries

It is useful to understand the peculiar characteristics of the growing musculoskeletal system of children to comprehend injury mechanisms of the apophysis in young athletes. The musculoskeletal system of prepubescent and adolescents can be described as a chain. The strongest links are the ligaments, the tendons and the muscles, while the growth cartilage of the physis, adjacent either to an apophysis or an epiphysis, is the weakest link of this chain, and the most commonly injured structure during sport activities.[20] Long bone physes generally fuse earlier than apophyseal physis.[21] It is important to consider that these types of injuries are unique to young athletes and, as the same mechanisms causing muscle strains in adults, in this particular population of athletes it may cause serious injuries to the growth centre in the latter. Apophyseal injuries are often misdiagnosed or diagnosis is delayed because a muscle strain was first suspected.[22]

Muscles and bones heal faster in children and are more elastic.[23–25] Imbalance in strength and flexibility during the peak of linear growth is responsible for the higher risk of injuries in adolescents. Sudden overloads during exercises may lead bones to bow or buckle. Apophyseal injuries are more common during periods of rapid growth, but few studies on the topic are available.[3,26] Rapid growth periods are associated to structural changes of the growth centre, which becomes thicker and more fragile.[23] Pubescent growth spurt is also associated with transient deficit in bone mineralization. A lack of mineralization results in more porous bones, which are more susceptible to injury.[8] A higher injury rate in peripubertal female gymnasts has been reported.[27]

Acute injury of the apophysis

Apophyseal injuries occur most commonly during sport activities.[17,22] Acute apophyseal injuries lack of a systematic classification in literature. The severity of injury can be very different, ranging from pain (apophysistis) to avulsion of the secondary growth centre. Young athletes are at risk of apophyseal avulsion injuries, in particular during forceful and violent eccentric contractions, due to the inherent weakness across the unfused apophyseal growth plate. The cartilaginous growth plate is the most common structure involved in the injury mechanism. Separation and retraction of the partially ossified apophysis occurs. Chronic repetitive stress is a risk factor for acute and traction injuries. Pain and swelling of the involved area are usually observed after injury. Discomfort often worsen with passive stretching and activity, and is relieved when the patients rest.[28] Short periods of rest and exercise programmes of muscle conditioning, are usually sufficient to return to sport.[26]

Reports of apophyseal avulsion fractures are increasing, most likely because of increased participation of adolescents in competitive athletics. Onset, generally, is traumatic or sudden, but chronic traction injuries may also result in an avulsion fracture.[29]

Patients may report a 'popr' sensation at the same time with onset of discomfort, and the use of the limb may also become uncomfortable.[22] Sclerosis, collapse, fragmentation and changes in bony contour are common radiographic findings and increased uptake in the involved area can be seen with isotope bone scans.[30] A mechanical aetiology for this condition has been proposed, as the secondary nucleus in patients affected by apophysitis is more fragmented.[31]

Acute injuries of the apophyses are becoming more frequent in young athletes, but data can be retrieved only from case series and case reports (Table 1).[17]

Chronic injuries to the apophysis

Chronic apophyseal injuries can occur in patients undergoing long programmes of intensive sport training. These injuries occur along a spectrum from apophysitis to avulsion fracture with significant displacement therefore, they can be very severe, resulting in growth disturbance. Differential diagnosis may not be easy, but involvement of tendon attachment sites can help avoid this pitfall.[28] Injuries can be missed because of inaccurate history and lack of conventional radiography.[74]

Table 1 Case reports including data on acute sports-related apophyseal fractures

Study	No. cases	Age	Location	Injury type	Sport	Management	Outcome
Aitken 1965[32]	1 M	Not reported	Tibial tuberosity	Fracture of the tibial tuberosity	Not reported	Not reported	Reduction was accomplished and union occurred. However, premature ossification occurred with a resultant valgus and a recurvatum deformity that required osteotomy for correction.
Godshall and Hansen 1973[33]	1 M	14	Iliac crest	Separation of the anterior two to two and one-half centimeters of the left iliac epiphysis	Baseball	Conservative	Further roentgenograms made 8 weeks after injury showed solid healing with no evidence ofadditional displacement as the result of playing football.
Dickason and Fox 1982[34]	1M	12	Equator of the patella	Nondisplaced, transverse fracture of the patella	Soccer	Conservative	On final examination he was asymptomatic and fully active.
Mayba 1982[35]	1 M	15	The tibial tubercle apophysis	Avulsion fracture of the tibial tubercle apophysis with avulsion of patellar ligament	Jump	ORIF	Full function when last seen.
Danielsson *et al.* 1983[36]	3 M 1 F	9–14	Olecranon	Fragmentation and irregularity of the apophysis of the olecranon	1 Gymnastic training 1 Landhockey 2 None	Conservative	The symptoms improved with rest and later disappeared.
Khoury *et al.* 1985[37]	3	15–15–18	Anterior superior iliac spines	Acute avulsion of the anterior superior iliac spines	Teenaged sprinters	Conservative	Asymptomatic after 1 month.

Blatz 1989[38]	1 M	15	Bilateral anterior superior iliac spines. After 6 weeks of conservative management tibial tubercle avulsion fracture	Avulsion fractures of bilateral anterior superior iliac spines and tibial tubercle avulsion fracture	Run	Conservative for bilateral anterior superior iliac spines and surgical for tibial tubercle avulsion fracture	2 years: he was playing high school football without any residual problem.
Ross and Love 1989[39]	1 M	2	Lesser tuberosity of the humerus	Fracture of the Lesser tuberosity of the humerus	Wrestling	Conservative	The patient regained full range of motion and was free of pain.
Mader 1990[40]	1 M	15	Anterior inferior iliac spine	Avulsion fracture of the anterior inferior iliac spine	Track and field practice	Conservative	Asymptomatic at 6-month follow-up.
Sward *et al.* 1990[41]	2 F	13–16	Vertebral ring apophysis	Vertebral ring apophysis injury	Jump	Conservative	14 months after trauma they return to sport activities.
Mann *et al.* 1991[42]	1 M	16	Fracture of the lumbar vertebral apophysis	Lumbar vertebral apophysis	Football	Spine fusion	Competitive athletics at 1-year follow-up.
Canale and Williams 1992[43]	4 M	10–11–13–20	Tuberosity of the fifth metatarsal	Traction apophysitis of the tuberosity of the fifth metatarsal (Iselin's disease)	Gymnastic, basketball, volleyball	Conservative	They resumed playing sports.
Draper and Dustman 1992[44]	1 M	20 (but radiographs showed open physis)	Anterior superior iliac spine	Avulsion fracture of the anterior superior iliac spine	Collegiate distance runner	Rest followed by non-weight bearing graded exercise	He returned to competition 3 weeks after the injury.
Bruijn *et al.* 1993[45]	1 F	12	Distal pole of the patella	Sleeve fracture	Gymnast	Conservative	At 12 weeks after injury the radiographs showed ossification in the patellar tendon. The inferior fracture fragment was excised. At 6 months postoperatively the patient ha returned to all normal activities.

Continued

Table 1 *Continued*

Study	No. cases	Age	Location	Injury type	Sport	Management	Outcome
Lambert and Fligner 1993[46]	1 M	15	Iliac crest	Large avulsion fracture of the iliac crest	Baseball	Conservative	5 months: return to full sports activity.
Veselko and Smrkolj 1994[47]	1 M 1 F	15 14	Anterior superior iliac spine	Avulsion of the anterior superior iliac spine	Competitive athletes (not specified)	ORIF	Participated fully in recreational sports activities.
Birtwistle and Jacobs 1995[48]	1 F	14	Calcaneal	Acute avulsion fracture of the calcaneal apophysis	Amateur gymnast	ORIF	1 year: return to full activity.
Gill and Clark 1996[49]	1 M	12	Displacement of the ischial apophysis	Ischial apophysis	Sprinter	ORIF	He returned to normal sporting activities within 3 months.
Rosenberg *et al.* 1996[50]	2 M	15	Anterior Superior Iliac Spine	Acute while kicking a ball with his right leg during a soccer game	Soccer and recreational sport activity	Conservative	participated fully in recreational sports activities.
Maffulli and Grewal 1997[51]	2 M	14.5–15	Tibial tuberosity	Avulsion of the tibial tuberosity	Gymnast	ORIF	30 months: return to competitive school sport.
Saluan and Weiker 1997[52]	1 M	16	Anterior inferior iliac spine	Avulsion of the anterior inferior iliac spine	Football	ORIF	6 months: return to football.
Akova 2002[53]	1 M	18	Iliac crest	Avulsion of the iliac crest	Soccer	Conservative	6 weeks: no hip pain. After 2 months return to soccer. After 1 year no complaint whatsoever.
Aksoy *et al.* 1998[54]	1 M	18	Avulsion of the iliac crest apophysis	Avulsion fracture of the iliac crest	Soccer	conservatively with a nonsteroidal anti-inflammatory drug and rest	2 months later he could play soccer again without any complaint.
Lepse *et al.* 1988[55]	1 M	14	Tibial tuberosity	Bilateral avulsion fracture of the tibial tuberosity	Gymnast	ORIF	1 year: he resumed full sports activity.

Servant and Jones 1998[56]	1 M	16	Avulsion of the right ischial apophysis at the origin of the hamstring muscles	Avulsion of the right ischial apophysis at the origin of the hamstring muscles	Adolescent sprinter	ORIF	3 years postoperatively he had no limp, discomfort, or stiffness. He played rugby twice a week for his university.
Blohm *et al.* 1999[57]	1 M	13	Acute traction apophysitis, 'little league elbow'	Acute traction apophysitis	Intense badminton activity	Conservative	At 1 year of follow-up he could return to normal sports activity.
Naraen *et al.* 1999[58]	1 M	11	Coracoid process	Physeal injury of the coracoid process	Archer	Conservative	6 months: return to full sports activity.
Mannor and Lindenfeld 2000[59]	1 F	14	Spinous process of L4–L5	Apophysitis of the spinous process of L4–L5	Gymnast	Conservative	Within 2 months of the initial visit, her symptoms resolved and she returned to gymnastics to compete without problems.
Valdes *et al.* 2000[60]	1 M	17	Avulsion fracture of the iliac crest	Avulsion fracture of the anterior half of the iliac crest apophysis	Football player	The patient was told to avoid walking if in pain	7 months after the injury he could practice sports without pain.
Akova 2002[53]	1 M	17	Ischial tuberosity	Displacement of the avulsion <2 cm	Soccer	Conservative	Follow-up 6 years; return to sports activity.
Ozer *et al.* 2002[61]	1 M	17	Tibial tuberosity	Avulsion of the tibial tuberosity	Basketball	Surgical	4 months: full range of motion and almost the same quadriceps force when compared with contralateral side.
Pereira *et al.* 2002[62]	1 F	15	Anterior part of the iliac crest	Avulsion of the anterior part of the iliac crest	Gymnastic class	Conservative	After treatment, no pain or limitation of movement.
Ergun *et al.* 2003[63]	1 M	16	Bilateral tibial tubercle	Avulsion fracture	Basketball	Surgical	27 months: he resumed all daily functional activity, but he slightly lost his level of activity.
Parr and Burns 2003[64]	3 M	14–16	Olecranon	Painful intraosseous oedema	2 baseball pitchers 1 elite gymnast	Conservative	The symptoms improved with rest and later disappeared.

Continued

Table 1 *Continued*

Study	No. cases	Age	Location	Injury type	Sport	Management	Outcome
Levine *et al.* 2005[65]	1 M	14	Lesser tuberosity apophysis	Isolated fracture of the lesser tuberosity apophysis	Wrestling	ORIF	At 4 month follow-up, he had full range of motion, complete return of strength, and returned to competitive athletics.
Yildiz *et al.* 2005[66]	1 M	17	Anterior inferior iliac spine	Sequential avulsion fracture of the anterior inferior iliac spine	Long jump	Conservative	During the 2 year follow-up period no complication or re-injury occurred.
Depasquale and Maempel 2006[67]	1 M	18	Iliac crest apophysis	Avulsion fracture of the iliac crest apophysis	Various non competitive sports	Conservative	17 years: return to full activity.
Slobogean *et al.* 2006[68]	1 M	16	Bilateral tibial tubercle	Simultaneous bilateral tibial tubercle avulsion fractures	Run	ORIF	A residual 5-degree flexion deformity remained at 16 months post-injury.
Carney *et al.* 2007[69]	1 M	11	Olecranon apophysis	Olecranon apophyseal fracture	Running	ORIF	12 months postoperatively the patient had returned to full sports activity with no complaints.
Imai *et al.* 2007[70]	1 F	9	Calcaneal	Acute displaced fracture	Gymnast	ORIF	2 years and 6 months: full range of motion; complete return to strenght.
Steerman *et al.* 2008[71]	1 M	18	Avulsion fracture of the iliac crest apophysis	Some irregularities to the right iliac cres	Collegiate wrestler	Non-weight bearing until he could abduct the right leg pain-free. In 1 week, he went to partial weight bearing on crutches	After 18 weeks, he was able to return to his normal competitive training schedule without residual pain or weakness.

Harper *et al.* 2013[72]	5 M	12–14	Lesser tuberosity	Four displaced avulsion of lesser tuberosity, one bony opacities medial to the lesser tuberosity	Skier, football player, skater, snowboarder	Surgery to stabilize the lesser tuberosity (3), conservative treatment (2)	Not reported.
Koehler *et al.* 2014[73]	1 M	12	Apophysealsspinous process	Avulsion fracture of the L5 spinous processes	Tennis player	Surgery to remove the fracture fragment.	At 1 week postoperatively, the patient had complete resolution of back pain. He had no numbness, tingling, or loss of motor or sensory function. He began physical therapy. At 5 weeks postoperatively, the patient continued to be pain-free and resumed his competitive tennis regimen.

Many studies, mostly case reports, reporting chronic apophyseal conditions, affecting young athletes, can be found in the literature (Table 2). Injury outcome for these patients was mostly good with no growth disturbance. However, the length of follow-up was brief or not reported in some patients.

Data of apophyseal fractures related to sports

In the present study, we attempted to distinguish case series reporting acute or chronic apophyseal injuries, but most studies reported both acute and chronic cases (Table 3). Apophyseal injuries are more common during sport activities. The rate of avulsion fractures among included patients ranged widely. Involvement in different sports was reported and growth disturbance rarely occurred.

The frequency or severity of apophyseal fractures was not reported in the reviewed cohort studies, as only the nature and incidence of apophyseal fractures was described. It was also difficult to determine the outcome of injuries, as follow-up was variable and inconsistent.

A summary of findings of the reviewed cohort studies is provided in Table 4.

Reasons for concern

This review raises several important concerns related to apophyseal injury in the paediatric athlete population. First of all, young patients involved in sports are at risk of acute apophyseal injuries, accounting for up to 16% of all injuries.[130] However, this proportion may vary according to the type of sport. Malalignment may result from apophyseal injuries, therefore these lesions are not necessarily innocuous. Stress-related apophyseal injuries affecting young athletes involved in a variety of sports have been reported (e.g. long-distance running, baseball, football, basketball, soccer, gymnastics, track and field athletes, rugby).[132] Generally, these injuries resulted in no growth complication, but follow-up was brief. Stress-related premature partial or complete apophyseal closure have been reported.[133] Surgery may be necessary in patients with non-union of avulsion fracture, exostosis formation or significant displacement.[52,134] Differential diagnosis may be difficult, especially if not diagnosed early, as findings may mimic a neoplastic disease, requiring further investigations such as a biopsy.[87,135] Meralgia paraesthetica may result from avulsion fractures of the anterior superior iliac spine.[136–138] Osteomyelitis occurring after a closed injury has also been reported, and should be suspected if pyrexia or increasing pain after treatment are referred.[139] Pseudarthrosis may result in some cases, and surgery may be required.[140] Heterogeneous areas of immature callus and osseous resorption may occur during the healing process, in particular in sub-acute stages. Differential diagnosis should consider the possibility of infections or the presence of a Ewing's sarcoma.[141–143] Exostosis formation have been reported, but are uncommon.[144] Outcome of conservative management is usually good for most patients, especially if diagnosed early. Accurate history, physical examination and conventional radiography are key factors to early diagnosis.[74]

If conservative treatment fails, surgery may be necessary. Complications of a surgical management are: intraoperative fracture of the osseous fragment; distraction of the nerve during retraction or malposition of implant; nerve irritation after trapping of the nerve in the fracture gap; dislocation of previously fixed fragments.[119] Limitations of range of motion or malalignment of the limb may also occur.[119] Complications regarding displaced fragments may also occur. These complications are more common if the displaced fragments are widely separated, as only fibrous union may occur. Pain, weakness, limitations in sport activities and chronic disability may result.[56,119,145] Treatment of patients with tibia tuberosity apophysitis generally is conservative and no further treatment is required. However, if conservative treatment fails, surgery should be considered only after skeletal maturity.[146–149] Pain, permanent bump and displacement of the avulsion fracture of the tibial tubercle are other potential sequelae of an Osgood–Schlatter lesion. Further studies are warranted, in order to acquire consistent epidemiological data on patients involved in sport activities.

Prevention of acute and chronic apophyseal injuries is important, and should consider appropriate

Table 2 Case reports including data on sports-related apophyseal fractures

Study	No. cases	Age	Location	Injury type	Sport	Management	Outcome
Aitken 1965[32]	1 M	Not reported	Tibial tuberosity	Fracture of the tibial tuberosity	Not reported	Not reported	Reduction was accomplished and union occurred. However, premature ossification occurred with a resultant valgus and a recurvatum deformity that required osteotomy for correction.
Gooding and Hurwitz 1974[75]	1 M	13	Vertebral rim apophysis of L4	Avulsed vertebral rim apophysis	Judo	Surgical	The postoperative course was uncomplicated.
Torg and Moyer 1977[76]	1 M	16	Olecranon	Non-union of a stress fracture through the olecranon	Baseball pitcher	Surgical	During the year following the operation, he completed an entire season of competitive baseball pitching and had no complaints.
Hunter and O'Connor 1980[77]	1 M	15	Olecranon	Fragmentation and irregularity of the tip of the olecranon apophysis	Diving	Conservative	10 months: he returned to diving with only occasional symptomatology.
Fox 1986[78]	2 M 1 F	15–17	Iliac crest	Iliac apophysitis	Distance run	Conservative	3 weeks: return to full sports activity.
Ross 1989[39]	1 M	2	Lesser tuberosity of the humerus	Fracture of the Lesser tuberosity of the humerus	Wrestling	Conservative	The patient regained full range of motion and was free of pain.
Browne *et al.* 1990[79]	1 M	16	Lumbar ring apophyseal	Lumbar ring apophyseal fracture	Weight lift	Surgical	No information: 'Successively the patient has done well'.
Rockett 1990[80]	1 M 1 F	16 14	Anterior iliac crest apophysis	Avulsion injury of the anterior iliac crest apophysis	Cross-country athlete and soccer	Conservative	Not reported.
Crosby and McMullen 1993[81]	1 M	13	Calcaneal	Irregularity of the calcaneal apophysis	Tennis/basketball	Conservative	3 weeks: return to full activity.

Continued

Table 2 *Continued*

Study	No. cases	Age	Location	Injury type	Sport	Management	Outcome
Ishii *et al.* 1994[82]	1 F 2 M	8–11	Medial malleolus	1. Partial avulsion of the apophyseal cartilage 2. Fragmentation of the accessory centre 3. Avulsion fracture of apophyseal cartilage	Basketball, Baseball, Trampolining	Conservative	1–6 months: healing.
Banas and Lewis 1995[83]	1 M	16	Olecranon	Non-union of an olecranon ephiphyseal plate stress fracture	Wrestling	Surgical	2 months: regained the ability to throw with comfort.
Morisawa *et al.* 1996[84]	2 M 1 F	12, 14 13	Acromion	Apophysitis of the acromion		Conservative	
E-Fard and Packer 1997[85]	1 M	14	Olecranon	Irregular ossification of the olecranon epiphysis	Gymnast	Conservative	3 weeks: return to full activity.
Lokiec and Wientroub 1998[86]	1 M	15	Medial plantar apophysis of the calcaneus	Osteochondritis of the medial plantar apophysis of the calcaneus	Basketball	Conservative	No recurrence was noted during 3 years of follow-up.
Espejo-Baena *et al.* 2000[87]	1 M	12	Proximal patella	Apophysitis of the proximal patella	Soccer	Excisional biopsy and curettage of the lesion	At 10-month follow-up he exhibited no symptoms and was leading a normal life with no limitation of his sporting activities.
Mannor and Lindenfeld 2000[59]	1 F	14	Spinous Process of L4–L5	Apophysitis of the spinous process of L4–L5	Gymnast	Conservative	Within 2 months of the initial visit, her symptoms resolved and she returned to gymnastics to compete without problems.
Holmstrom *et al.* 2003[88]	1 F	15	Ischial apophysis	Avulsion	Gymnast	Surgical (Apophysiodesis of the ischium)	4 months: return to full sports activity.

Parr and Burns 2003[64]	3 M	14–16	Olecranon	Painful intraosseous oedema	2 baseball pitchers 1 elite gymnast	Conservative	The symptoms improved with rest and later disappeared.
Yamamoto *et al.* 2004[89]	1 M	13	Ischial tuberosity	Mild irregularity in the inferior margin of the left ischial tuberosity	Active baseball pitcher	Open biopsy and then conservative management	The patient's symptoms completely disappeared within 5 months postoperatively.
Doral *et al.* 2006[90]	1 M	14	Anterior superior iliac spine	Avulsion of the anterior superior iliac spine	Soccer	Surgical	8 weeks: return to full sports activity.
Nakano 2006[91]	1 M	10	Calcaneal	Calcaneal apophysitis	Basketball	Conservative	Not reported.
Pointinger *et al.* 2003[92]	1 M	18	Anterior superior iliac spine	Avulsion fracture of the anterior superior iliac spine following apophysitis	Athlete	ORIF	4 weeks postoperatively he returned to full weight bearing training.
Yamamoto *et al.* 2004[89]	1 M	13	Ischial tuberosity	Mild irregularity in the inferior margin of the left ischial tuberosity	Baseball as a pitcher	Conservative	The patient's symptoms completely disappeared within 5 months postoperatively.
Winkler *et al.* 1987[93]	1 M	18	Anterior superior iliac spine	Chronic avulsion of the anterior superior iliac spine	Break dance		Not reported.
Carpenter *et al.* 2008[94]	1 M	14	Trochanteric physis	Traction apophysitis of the trochanteric physis	Football	Conservative	By 6 months, a full return to sporting activity had been achieved.
Khan *et al.* 2014[95]	1 M	10	Anterior inferior iliac spine	Chronic avulsion of the anterior inferior iliac spine	Football	Conservative	The patient's symptoms resolved over a period of 6 weeks.
Schoensee and Nilsson 2014[96]	2 M 1 F	14–16	Ischial tuberosity	Ischial tuberosity avulsion fracture	Soccer/football (males) Cheerleading Dance (female)	Percutaneous needle fenestration	Two athletes reported elimination of pain, full functional recovery and return to sport without limitations; One athlete reported elimination of pain and full functional recovery and chose to return to a new sport.

Table 3 Case series including data on sports-related apophyseal fractures

Study	Total no of apophyseal injuries	Age	Location	No. apophyseal injuries associated with organized sports	No. of sports-related apophyseal injuries associated with growth disturbance
Lipscomb 1975[97]	8	12.75 (10–16)	5 elbow • 1 osteochondritis of the radial head • 3 osteochondritis of the capitellum • 1 avulsion of the medial epicondyle 3 shoulder • 2 widening of the epiphyseal • 1 avascular necrosis	7	None
Clancy and Foltz 1976[98]	21	16 (14–17)	16 anterior iliac crest 5 posterior iliac crest	21	None
McKenzie *et al.* 1981[99]	20	11.2 (9–14)	Calcaneal apophysis	20	None
Lombardo *et al.* 1983[100]	9	15.7 (15–17)	Iliac apophysis	7	None
Paty and Swafford 1984[101]	1	15.6 (13–18)	Iliac crest apophysitis	1	None
Priest 1985[102]	2	13.6 (11–19)	Elbow	2	None
Micheli and Ireland 1987[103]	137	11 (6–16)	Calcaneal apophysis	68	None
Wotton *et al.* 1990[104]	4	(14–18) 14–15–17–18	Ischial apophysis	4	None
Walling *et al.* 1990[105]	12		Calcaneal apophysis		Maldevelopment of the posterior (nonarticular) portion of the calcaneus
Epstein and Epstein 1991[106]	27		Fragmentation of the peripheral ring apophysis		None
Maffulli *et al.* 1992[107]	1	13.5 (11–18)	Elbow	1	None
Maffulli *et al.* 1992[108]	12	14.4 (11–19)	Olecranon apophysitis	12	None
Krueger-Franke *et al.* 1992[109]	11	12.6 (4–17)	7 avulsion fractures of the anterior cruciate ligament 4 avulsions of the tibial tuberosity	11	None
Watanabe1993[110]	5	14.2 (13–15)	Ischial tuberosity	5	None
Buhari *et al.* 1993[111]Acute	5	14.2 (11–16)	Tibial tuberosity	5	None
Sward *et al.* 1993[112]	52	20 (14–25)	Vertebral ring apophysis	52	None
Hajdu *et al.* 2000[113]	7	(13–16)	Avulsion fractures of the tibial apophysis	7	None
White *et al.* 2002[114]	10	14.8 (8–17)	Anterior Superior Iliac Spine	10	None

Connolly *et al.* 2004[115]	10	Not reported	Vertebral ring apophysis	Not reported	None
Ogden *et al.* 2004[116]	14	Not reported	Calcaneal apophysis	14	None
Bauer *et al.* 2005[117]	22	13 (12–16)	Tibial tuberosity	22	1 patient with recurvatum and leg length discrepancy following fracture of the anterior tibial tubercle
Rettig *et al.* 2006[118]	5	15 (13–17)	Olecranon apophyseal stress fractures non union	5	None
Haxhija *et al.* 2006[119]	25	12 (5–17)	Apophyseal avulsion fracture of the medial condyle	21	None
Gidwani and Bircher 2007[120]	6	15.2 (9–18)	Avulsion of the ischial apophysis	6	None
Hébert *et al.* 2008[121]	7	15.7 (14–16)	Iliac Crest Apophysis	7	None
Metzmaker and Pappas 1985[122]	27	15.2 (13–17)	11 ant. sup. Iliac spine; 6 ischium; 3 lesser trochanter; 4 ant. Inf. Iliac spine; 3 iliac crest	27	None
Sundar and Carty 1994[29]	32	13.8 (11–16)	7 anterior superior iliac spine; 8 anterior inferior iliac spine; 17 Ischial tuberosity	32	None

injury prevention programmes for coaches of young athletes who are often largely uninformed about the biological maturation of the apophyseal growth centre and the related injuries.

Prevention of injuries

According to our findings, young athletes are at risk of apophyseal injuries. It is important to treat apophysitis appropriately to prevent occurrence of chronicity, which might lead to important and irreversible complications.[57] Patients should also be informed about time of recovery and prognosis, to prevent further injuries (i.e. avulsion fractures) or development of the disease. This condition is often underestimated, but treatment and prevention of sport injuries is important, as they are related to significant medical expenses, reduced productivity, discomfort and in some cases lifelong disability.[150,151]

Preventive measures are thus important and are worthy of consideration. Involvement of sport coaches is important too: training loads should be reduced during the rapid growth period. This period may be identified through careful and correct measurements of the height of the young athlete, possibly every 3 months. Training programmes should involve the use of a variety of drills and activities, avoiding repetitive movements responsible for overuse injuries. Quality of workout is more important than training volume. Early diagnosis can be promoted introducing periodic physical examinations, directed to diagnose early stages of apophyseal injuries. A training programme including physical conditioning, strengthening, proprioceptive and range of motion exercises can reduce the risk of an acute or chronic injury of the apophysis, and should be warranted to young athletes. Periodization of training should also be considered as it may help to reduce mechanical stress-related injuries. Another important factor is to treat appropriately patients with apophyseal injuries during the whole healing process, even during return to practice. Involvement in contact sports should be interrupted for up to 6 months to prevent re-injury, and long-term follow-up is important especially in case of apophyseal injuries of lower limb or spine.

Table 4 Cohort studies including data on sports-related apophyseal injuries

Study	Design	Duration	Sample	# Participants	# Injuries	% Apohyseal injuries
Torg *et al.* 1972[123]	Retrosp	Not reported	Little league elbow	49	27	3
Gugenheim *et al.* 1976[124]	Prosp	1 season	Little league pitchers	595	113	22
Larson *et al.* 1976[125]	Prosp	1 season	Little league pitchers	120	Not reported	25
Zaricznyj *et al.* 1980[126]	Prosp	1 year	Sports-related injuries in school-aged children	25512	1576	Not reported
Kujala *et al.* 1985[127]	Retrosp	5 years	Running, ball games, ice hockey, track and field, gymnastics, other sports	367	Not reported	103
Mackie and Taunton 1994[128]	Retrosp	40 months	Female gymnasts	100	279	29
Lazovic *et al.* 1996[129]	Prosp	5 years	Track and field and gymnastics	Not reported	Not reported	243
Rossi and Dragoni 2001[130]	Retrosp	22 years	Competitive athletes (soccer, athletics, tennis, gymnastics, wrestling fencing, basketball)	1238	Not reported	203
Hang *et al.* 2004[131]	Prosp	1 season	Little league elbow	343	Not reported	37

At the same time, radiographic evaluation of the bone region affected by injury, at 3–6 month intervals, for at least 2 years, is important and should be always warranted.[73,152]

Physicians should also promote communication with the young athlete's coach, to identify promptly symptoms related to an apophyseal injury, and start treatment as soon as possible. The first and most important symptom to consider at early stages of the disease is always pain.[153] If pain is referred by a young athlete, exercises should be interrupted and prompt examination is warranted. Early detection of apophyseal injuries is key to better management and earlier return to sport without deleterious consequences.

Future research

Our systematic review highlights the importance of further studies, in particular prospective cohort studies, in order to define the distribution and determinants of aphyseal injuries affecting children and adolescents involved in sport activities. The most important aspect of this study is the meticulous research and documentation of apophyseal injuries reported in the English literature.

Further studies should consider analytical as well as descriptive components, to allow the identification of new possible risk factors and, if possible, plan preventive measures. Also type and level of involvement in sport activities should be described.[154] In particular, future investigations should clarify whether young patients during the rapid growth period are at higher risk of apophyseal injuries, and how this information can lead to design better training programmes.

Conflict of interest statement

None declared.

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