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Growth Plate Injuries in Children and Adolescents: A Narrative Review of Mechanisms, Risk Factors, and Clinical Implications

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***Abstract*—** Growth plate injuries are common in children and adolescents, particularly in those engaged in sports or high-impact activities. Due to the unique anatomy and physiology of the physis, these injuries can lead to growth disturbances, angular deformities, and limb length discrepancies if not appropriately diagnosed and managed. This narrative review summarises current evidence regarding the mechanisms, risk factors, clinical presentation, diagnostic strategies, and treatment options for growth plate injuries. Both non-operative approaches, such as rest, immobilisation, and physical therapy, and operative interventions, including physeal-sparing techniques and epiphysiodesis, are discussed. Emerging therapies, including stem cell applications and growth modulation, are also highlighted. Emphasis is placed on early detection, load management, and education of athletes, parents and coaches to minimise long-term complications. Understanding the epidemiology, biomechanics, and management of physeal injuries is essential for optimising functional outcomes and ensuring safe participation in athletic activities.

Keywords— growth plate, physeal injury, children, adolescents, Salter–Harris classification, pediatric orthopaedics, sports-related injury, skeletal development

1. Introduction

Anatomical and biomechanical differences between the immature musculoskeletal system of children and adolescents and that of adults result in substantial variations in both injury patterns and treatment strategies. The key distinguishing feature is the presence of the epiphyseal (growth) plate, a specialised cartilaginous structure located between the epiphysis and metaphysis, which is responsible for longitudinal bone growth [1][2].

Injury to the growth plate may disrupt normal skeletal development, leading to growth disturbances, angular deformities, and limb length discrepancies [2][3]. At the same time, children and adolescents are increasingly engaged in both recreational and organised sports, many of which involve high-impact activities and repetitive mechanical loading [4][16]. As a consequence, the incidence of physeal injuries has risen, particularly among physically active youth [3][4].

This narrative review aims to summarise current knowledge on the growth plate, with particular emphasis on injury mechanisms, risk factors, diagnostic considerations, and potential long-term clinical consequences.

2. ANATOMY AND PHYSIOLOGY OF THE GROWTH PLATE.

The growth plate is a highly specialised cartilaginous structure composed of five histologically distinct zones arranged from the epiphyseal side toward the metaphysis. These include the **resting zone**, the **proliferative** zone, the **hypertrophic** zone, the zone of **calcification** and the zone of **ossification** [6][7].

Longitudinal bone growth occurs through endochondral ossification at the physis. Chondrocytes in the proliferative and hypertrophic zones undergo a highly organised sequence of division, maturation, hypertrophy, and apoptosis, followed by replacement of cartilage with bone tissue [7].
This tightly regulated process ensures proper bone elongation and maintains its structural integrity. Disruption at any stage of endochondral ossification, whether caused by trauma, infection, or metabolic disturbances, can impair normal bone development and predispose to angular deformities or limb length discrepancies.

The biological activity of the physis varies depending on its anatomical location, as well as the patient's age and sex, which influences both growth potential and susceptibility to injury [1][8].

The physis is particularly vulnerable to injury because it is the **weakest region of the immature skeleton**, especially at the hypertrophic zone, which is less resistant to shear and compressive forces.
Moreover, periods of rapid growth, such as the adolescent growth spurt, may further increase susceptibility to physeal injury due to a temporary biomechanical imbalance between bone, cartilage, and surrounding soft tissues [7].

Due to the relatively greater strength and elasticity of ligaments, tendons, and joint capsules in children and adolescents, traumatic forces are more likely to result in physeal injury rather than disruption of the ligamentous structures [19][12][37].

3. VASCULAR SUPPLY OF THE PHYSIS

The blood supply of the growth plate is distinct from that of the adjacent epiphysis and metaphysis, as there are no direct vascular anastomoses between the two regions at the level of the physis [39]. Instead, the peripheral regions of the physis, particularly near the epiphyseal cartilage, rely on diffusion of nutrients from the epiphyseal vessels [39]. In contrast, the deeper zones of the growth plate, especially near the zone of ossification, receive metabolic support from metaphyseal blood vessels [20]. This unique pattern of vascularisation contributes to the relative fragility of the physis, as its central cartilage relies on diffusion rather than a robust, direct arterial supply [1]. Because of this arrangement, injuries that disrupt the delicate balance of nutrient delivery, such as trauma or compression, can impair normal physeal function and increase the risk of growth arrest or abnormal bone development [1]. The figure below presents the vascular supply of the bone.

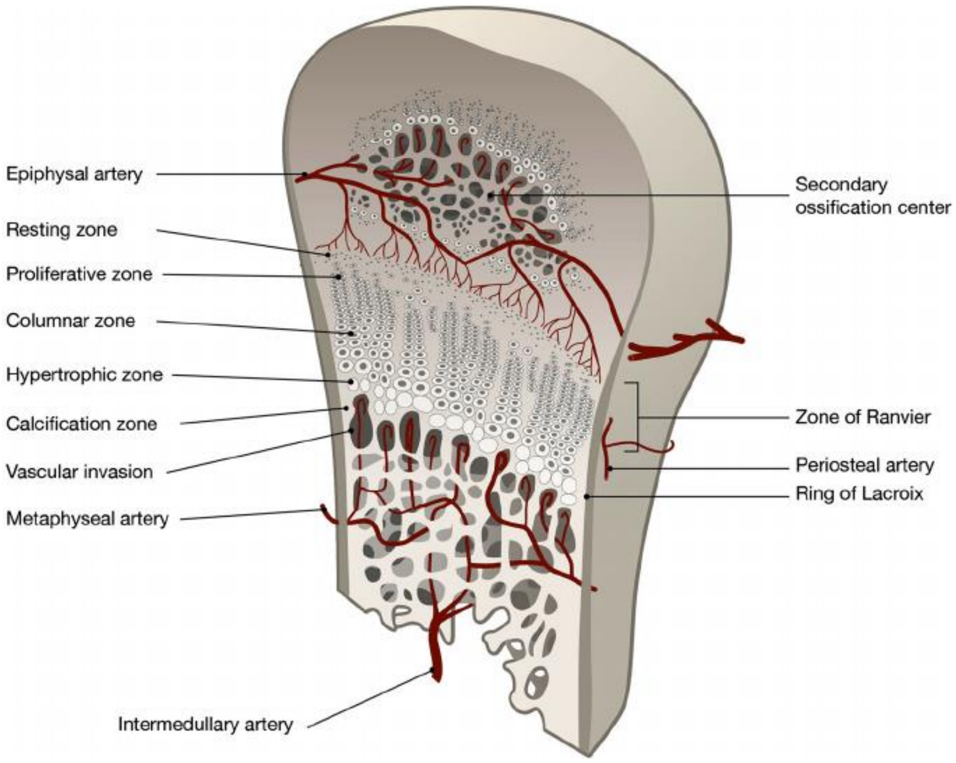

Fig.1 Diagram of vascular supply of the physis [24]

4. EPIDEMIOLOGY OF GROWTH PLATE INJURIES

Growth plate injuries constitute a significant proportion of musculoskeletal trauma in the pediatric population, accounting for approximately 15–30% of all fractures in children and adolescents [23].
The incidence of physeal injuries is closely related to age, with a peak observed during periods of rapid skeletal growth, particularly in early and mid-adolescence [16][13]. Boys are affected more frequently than girls, which is thought to reflect differences in activity levels, timing of skeletal maturation, and exposure to high-risk activities [1]. In the general pediatric population, many physeal injuries result from low-energy mechanisms such as falls during play or everyday activities [13].

Among athletic pediatric populations, the prevalence of growth plate injuries is substantially higher, especially in children and adolescents participating in organised sports involving high-impact forces, rapid changes of direction, or repetitive loading [11][14]. Sports such as football, basketball and gymnastics have been consistently associated with an increased risk of physeal injury [11–20]. In this group, both acute traumatic injuries and overuse-related physeal stress injuries are commonly observed, reflecting the cumulative mechanical demands placed on the immature skeleton during training and competition [14][9].

The most commonly affected anatomical sites include the **distal radius**, **distal tibia**, **distal femur**, and **proximal tibia**, which together account for the majority of reported physeal injuries [23][1][13]. Injury patterns vary according to the mechanism and site of trauma, with Salter–Harris type II fractures being the most frequently reported across both general and athletic pediatric populations [23][16]. Injuries involving the **distal femur** and **proximal tibia** are of particular clinical concern due to their high growth potential and increased risk of growth disturbance or angular deformity following injury [5][10].

One representative example of growth plate–related pathology in the pediatric athletic population is **calcaneal apophysitis**, commonly known as **Sever's disease**. This condition most frequently affects physically active children between 9 and 13 years of age, coinciding with periods of rapid skeletal growth of the foot and increased participation in sports activities [19].
The calcaneus develops similarly to long bones, with distinct regions of ossification including a growth plate and a secondary ossification centre called the apophysis. The calcaneal apophysis serves as the attachment site for the Achilles tendon and is therefore subjected to substantial tensile forces during locomotion.

Sever's disease is particularly prevalent among children involved in sports that require repetitive running and jumping, such as soccer, basketball, and athletics. Recurrent traction forces from the Achilles tendon, combined with repetitive mechanical loading, cause irritation and microtrauma of the apophyseal cartilage, resulting in inflammation and pain localised to the posterior heel. The risk of calcaneal apophysitis diminishes significantly after **fusion of the apophysis**, which typically occurs around 15–16 years of age.

A key biomechanical factor contributing to Sever's disease is **repetitive impact loading during running**. High volumes of running with a typical heel-strike pattern (where the heel contacts the ground first) generate vertical ground reaction forces up to 1.5–3 times body weight, transmitting stress through the immature calcaneus. Additionally, muscle imbalances—particularly strong knee extensors and plantarflexors relative to weaker flexors and dorsiflexors—can increase tensile forces on the apophysis. These cumulative microtraumas are characteristic of overuse injuries in young athletes and contribute substantially to the onset of Sever's disease. Figure 2 illustrates the apophysis of the calcaneus, the site of attachment of the Achilles tendon and the region affected in Sever's disease

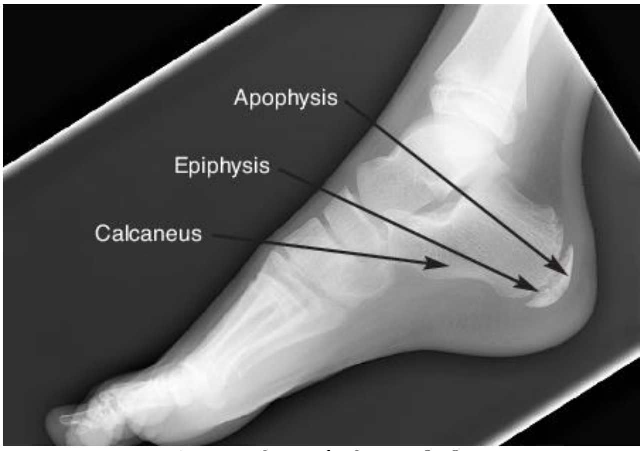

Fig.2 Apophysis of calcaneus [38]

5. CLASSIFICATION OF GROWTH PLATE INJURIES

To classify the extent and pattern of growth plate injuries, the Salter–Harris classification was introduced and remains the most widely used system in pediatric orthopaedics. It categorises physeal fractures into five types based on the relationship between the fracture line, the physis, the metaphysis, and the epiphysis. [19]

Type I injuries involve a **complete separation through the physis**, with no involvement of the metaphysis or epiphysis. The fracture line runs entirely within the growth plate, and these injuries often have a favourable prognosis if properly managed.

Type II fractures are the most common and consist of a **physeal separation** accompanied by a fracture extending into the **metaphysis**, while the epiphysis remains intact.

Type III injuries involve a fracture that traverses the **physis** and extends into the **epiphysis**, with the fracture line running horizontally across the growth plate and vertically into the epiphysis

Type IV fractures traverse the metaphysis, physis, and epiphysis, crossing the growth plate completely.

Type V injuries are characterised by a **compression** or **crushing injury** to the **growth plate** without an obvious fracture line on initial radiographs. This type is considered the most severe, as the damage to the physeal cartilage may be irreversible, often leading to premature growth plate closure, limb length discrepancy, or angular deformities.

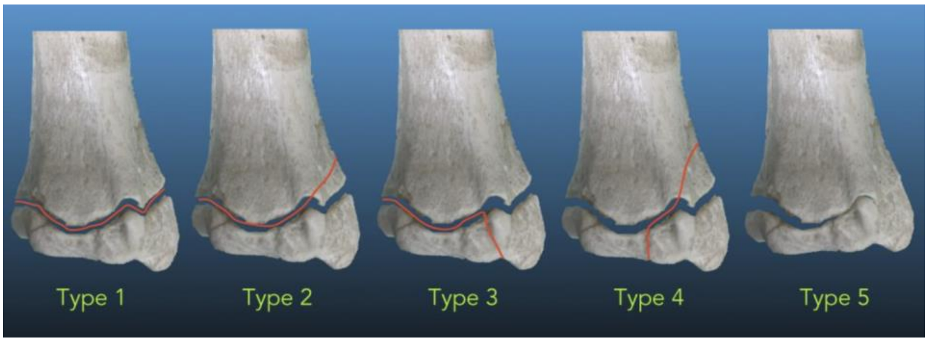

Fig.3 Salter-Harris classification of growth plate fracture [25]

6. CLINICAL PRESENTATION AND DIAGNOSIS

Typical symptoms of growth plate injuries include pain localised to the affected region, tenderness on palpation, and limitation of motion, which may be intermittent in early stages or more persistent in acute trauma [1][2][3]. Overuse injuries may present with subtle pain during activity, often worsening with continued stress, while acute traumatic injuries (e.g., falls, fractures, sports trauma) typically cause sudden onset of pain and functional impairment [35][10].

Physical examination may reveal swelling, localised tenderness, and pain with resisted movements or passive stretch. Specific provocative tests are limited in pediatric patients due to pain tolerance and cooperation, which can make early diagnosis challenging [35][10][39].

Imaging plays a critical role in the evaluation of physeal injuries. Plain radiographs remain the first-line modality, allowing assessment of displacement, angulation, and alignment [20][28]. MRI is particularly useful for detecting subtle injuries, cartilage damage, and early stress-related changes not visible on X-ray [16][15]. CT can provide a detailed assessment of complex fractures and is occasionally used for preoperative planning [28][16].

Diagnostic challenges in children and adolescents arise from anatomical variability due to ongoing growth, differences in skeletal maturity, and the limited sensitivity of early imaging [8–10]. Misinterpretation or delayed diagnosis can increase the risk of growth disturbances, angular deformities, and limb length discrepancies [26][13][37].

7. Management strategies

Because skeletal maturation differs substantially between children, adolescents, and adults, treatment strategies in pediatric orthopaedics vary accordingly. **Non-operative** management is generally preferred whenever possible, as the presence of open growth plates allows for spontaneous correction and remodelling. Conservative approaches typically include rest, immobilisation and targeted physical therapy to support healing while minimising mechanical stress on the injured physis [32].

When **surgical** intervention is required, particular caution must be taken to avoid iatrogenic damage to the growth plate. Physeal-sparing techniques and osteosynthesis are commonly employed to stabilise fractures or correct deformities while preserving growth potential. Procedures such as temporary or permanent **epiphysiodesis** are used to manage angular deformities (e.g. genu valgum or genu varum) and limb-length discrepancies. Temporary epiphysiodesis selectively inhibits growth on one side of the physis, allowing gradual correction through continued growth on the opposite side, with implants removed after achieving the desired alignment. Permanent epiphysiodesis results in irreversible growth arrest at the targeted physis and is primarily used to address significant limb-length inequality [19][33].

Emerging regenerative therapies, including mesenchymal **stem cell** (MSC) transplantation, show promise in experimental models. MSCs delivered to injured growth plates have been demonstrated to reduce the formation of bony bars, prevent angular deformities, and restore more normal physeal function. While these approaches remain largely investigational, they highlight the potential of biologic therapies to complement traditional treatment strategies and improve long-term skeletal outcomes [21][34].

8. Prognosis and long-term implications

Growth plate injuries carry a variable prognosis depending on the type, location, and severity of the lesion. Injuries that disrupt the physis, particularly Salter–Harris types III–V, pose a higher risk of growth arrest, angular deformities such as genu valgum or genu varum, and limb length discrepancies [27][22]. Functional outcomes are generally favourable when injuries are detected early and managed appropriately, allowing return to sports activities; however, repetitive or severe injuries can lead to chronic musculoskeletal problems, including altered joint mechanics and early-onset osteoarthritis [20][39]. Strategies to minimise long-term complications include timely intervention, careful monitoring of growth, and use of physeal-sparing surgical techniques when indicated [9].

9. Prevention and practical recommendations

Preventive strategies focus on reducing excessive stress on the growth plate while promoting safe athletic participation. Training modifications, such as limiting high-impact loads, ensuring gradual progression of intensity, and incorporating rest periods, are key to mitigating risk [13]. Early detection through regular screening and monitoring of symptoms allows for prompt intervention before permanent damage occurs [11]. Education of athletes, parents, and coaches on proper biomechanics, warning signs of physeal injury, and the importance of rest and recovery is essential to reduce injury incidence and protect long-term musculoskeletal health [13][11]

10.CONCLUSION

Growth plate injuries are a significant concern in pediatric and adolescent populations, particularly among physically active youth exposed to high-impact or repetitive activities. The unique anatomy and physiology of the physis render it vulnerable to trauma and overuse, with potential consequences including growth disturbances, angular deformities, and limb length discrepancies. Accurate diagnosis relies on a combination of clinical assessment, physical examination, and appropriate imaging, while classification systems such as the Salter-Harris framework guide prognosis and management.

Non-operative treatment remains the first-line approach whenever feasible, emphasising rest, load modification, and targeted rehabilitation, whereas surgical interventions—including physeal-sparing techniques, osteosynthesis, and growth modulation strategies—are reserved for more severe or complex injuries. Emerging therapies, such as stem cell applications, hold promise but require further research.

Clinicians, coaches, and parents should prioritise early detection, careful monitoring, and education to minimise long-term complications. Future studies should aim to better elucidate risk factors, optimise prevention strategies, and evaluate long-term functional outcomes in this population.

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