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# Overuse Injuries to the Physes in Young Athletes: A Clinical and Basic Science Review

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**Abstract:** Although it is accepted that growth plates in children are a weak link in the immature skeleton, the location within the growth plate and the various mechanisms of injury are a subject of debate. Factors affecting physeal injuries include the forces exerted on the physis, the morphology of the physis, the age of the patient, and the status of the surrounding perichondrial complex. The purpose of this review is to discuss the relevant basic science literature, focusing on anatomic and finite element analysis models in the context of specific growth plate injuries in the young athlete.

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## Introduction

Based on a study of epiphyseal separations in skeletally immature human cadaver specimens, Foucher [22], in 1863, stated "there is one constant: the separation never goes cleanly through the heart of the cartilaginous tissue." Foucher also described the forces required to produce a separation of the epiphysis as a "motion of inclination combined always with torsion or rotation" [22]. Subsequent authors have explored the factors contributing to these injuries.

The hypertrophic zone of the growth plate has been implicated as the weak link in the physis in acute injuries. Salter [46] described the production of physeal injury with closed manipulation, such as manual hyperextension. He described the microscopic appearance of experimental separation as a plane of cleavage invariably on the diaphyseal side of the plate, through the area of hypertrophied cartilage. Shear fractures at various stages of chondrooseous maturation have also been created in a rabbit model. The load to failure increased with increasing age, and the location of failure at increasing age changed from the columnar zone in younger animals to the hypertrophic zone in older animals [45]. A shear stress was applied to the proximal tibial epiphyses of immature rats after the specimens were denuded of all soft tissue attachments. A decrease in strength was noted at pubescence. Fifteen percent of the fractures traversed the physeal-metaphyseal junction and 85% of the fractures traversed at least partially through the upper proliferative layer [6]. Chung [15] obtained hips post mortem from children 5 days to 15 years and tested them to failure for shear strength. Fractures through the hypertrophic zones were found in children under 14 years of age, and a weaving fracture passing through different zones of the plate was found in the specimens from older children.

There is abundant evidence to suggest that musculoskeletal growth and remodeling is partially modulated by mechanical factors, and that there exists a range of loads over which a given physis may function optimally. Thus, both disuse and overuse may damage the physis, resulting in symptoms and alteration in growth. Just as hemiatrophy of a limb may be associated with polio and other neuromuscular diseases, hypertrophy of both the humerus and radius has been described in professional tennis players. [42]

Several relatively common overuse injuries of the physis have been described in immature athletes resulting from chronic repetitive stresses that exceed the physiologic capacity of the physis. This fatigue failure of physeal function contrasts with the static failures observed in acute physeal injuries as classified by Salter and Harris [46]. Forces involved in loading the physes include compression, tension, and shear, although the predominant form of overload may be unique to each type of injury. Examples include damage to the distal radial physis in gymnasts (compression), epiphysiolysis of the proximal humerus in throwing athletes (tension, shear), and elbow injuries including the secondary ossification centers at the medial epicondyle (tension). These injury types will be discussed from a clinical perspective and applicable basic science literature pertaining to the mechanism of injury will be presented.

## Distal Radial Physis (Compression)

Cumulative mechanical overload of the distal radial physis has been well described in competitive gymnasts. A spectrum of pathology is observed, ranging from mild discomfort without radiographic changes to disabling mechanical symptoms, attributable to the anatomic alterations. These alterations are associated with permanent, asymmetric physeal damage. Recognition of this problem allows for early treatment by decreasing mechanical loading, which subsequently may prevent late deformity. The predilection for involvement of the radial physis may be explained by biomechanical studies that have demonstrated that approximately 80% of compressive loads across the wrist are transmitted through the radius [20].

Wrist pain is common in competitive gymnasts who often use their upper extremities for weightbearing. Mandelbaum et al. [32] identified significant wrist pain in 22% of males and 33% of females in a collegiate program. The extent of physeal overload correlates with the level of competition, number of hours of training per week, as well as the number of years of participation. Whereas a certain cumulative load may result in mild symptoms and a "physeal stress reaction," a greater period of loading may create partial physeal arrest resulting in ulnar overgrowth [32].

The natural history of chronic injury to the distal radius has been elucidated by the progression of radiographic changes, which may correlate with the cumulative load. Roy et al. [44] identified widening of the physis, irregularity of the metaphyseal margins, metaphyseal cystic changes, a beaked epiphysis, and haziness in the physis. Shih et al. [48] correlated plain films with magnetic resonance imaging scans in patients with normal radiographs. These findings included metaphyseal bone bruises, vertical fractures through the physis, and physeal cartilage extension. In those with abnormal plain films, changes included horizontal fractures, physeal widening, and physeal cartilage extension. Extension of physeal cartilage into the metaphysis was believed to represent a healing response.

Persistent overload results in decreased growth at the radial physis, with gradual development of positive ulnar variance, which was identified in all of the 20 gymnasts studied by Mandelbaum [32]. In addition, asymmetric arrest of the ulnar and volar portions of the distal radial physis may create an acquired Madelung's deformity [54].

Treatment begins with early recognition, as activity modification may allow healing without permanent sequelae in early cases. Roy et al. [44] noted that patients without radiographic changes healed after 4 weeks, whereas those with radiographic changes required 3 months of rest before becoming asymptomatic.

Finite element analysis computer models have been used to describe the influences of mechanical stress on chondroosseous development [12,13]. Results suggest that in diarthrodial joints, cartilage is present in areas that experience a high magnitude of hydrostatic pressure, and that tangentially oriented tensile strains reduce the magnitude of hydrostatic pressure, which promotes vascular invasion and subsequent endochondral ossification. It is theorized that a diminished vascular invasion leads to a reduction of cartilage thickness. One may extrapolate these diarthrodial joint model principles to the growth plate. The growth plate orientation is essentially perpendicular to the maximum principal stresses created during normal physical activity. This creates an area that minimizes shear stress and theoretically maximizes the environment for interface strength and cartilage viability while minimizing cartilage degeneration and ossification. This model applies to the early changes in cartilage thickness found in gymnasts. The increased thickness of the growth plate has further been attributed to "stress changes" or stress fractures of the epiphyseal plate [9,14,18,28,43,44,53]. No consensus exists whether these changes represent a Salter-Harris type I, II, or V fracture. Others have found an association between metaphyseal injuries and an increase in thickness of the hypertrophic cell layer in rabbits [28,53]. Experiments have yet to characterize the repetitive forces on the growth plate that allow appropriate maintenance of cartilage thickness, or the amount of excessive load that disrupts this balance, causing irreversible damage and physeal arrest.

A chondral remodeling theory was suggested by Frost. This theory states that tension and compression can stimulate growth under certain circumstances, whereas increases in compression and decreases in tension can inhibit growth [23]. The Hueter-Volkmann Law however, states that compression forces inhibit growth and tensile forces stimulate growth.

Although each of these laws applies to certain clinical scenarios, different forces act simultaneously in vivo, and the exact relationship between the type and quantity of the load and the response of the growth plate is not yet known.

The biological effects of mechanical factors on growth-plate cartilage metabolism has been assessed [26]. A single high-compressive force or a multiple intermittent low-compressive force was placed on distal femora explants from immature rabbits. A direct relationship was noted between the type of force and the type of metabolic response. Radiolabeling of different cartilage layers demonstrated that the proliferating cell layer is the most affected by the mechanical stress.

## Proximal Humerus (Shear)

Proximal humeral epiphysitis, or "little league shoulder" is manifested as mechanical pain in adolescent pitchers. This problem is associated with widening of the proximal humeral physis. This finding is best seen on an anteroposterior view in external rotation [2,8,19,27,41,51]. It has been suggested that widening of the epiphysis in this injury is attributable to microfractures of the growth plate. This has also been referred to as the first stage of a stress fracture [8]. A recent study reviewed 23 cases of Little Leaguer's shoulder and demonstrated that 21 (91%) of patients treated with rest for an average of 3 months were subsequently asymptomatic [11]. Complications included a premature closure of the proximal humeral physis, and a Salter 3 fracture of the proximal humeral epiphysis. Treatment recommendations include 2 months of rest from throwing, followed by a gradual return to throwing. Kanematsu et al. recently examined 909 adolescent boys competing in a summer baseball tournament. 3.2% of the boys were diagnosed as having Little League shoulder based on examination and roentgenograms [29]. This same group treated 98 cases of Little League shoulder, and described three cases of varus discrepancy greater than 10 degrees and four cases of humeral length discrepancy greater than 2 cm. Prevention by limiting pitches thrown, early detection, and treatment by restriction from throwing is advocated for these athletes. The American Academy of Orthopedic Surgeons recommends limitations on pitches thrown and innings played for growing children. No determination has been made to define the exact limit on the number of pitches to be thrown. A reasonable approach however, consists of a maximum of 80 to 100 pitches per game and 30 to 40 pitches per practice. Players should follow the guidelines of their baseball association regarding the maximum innings pitched per week. Proper education of coaches and players regarding appropriate stretching, strengthening, and throwing techniques is also recommended.

## Medial Epicondyle (Distraction)

Overuse problems involving the secondary ossification centers in the distal humerus and proximal ulna have been observed in throwing athletes, especially pitchers. The forces experienced at the elbow during pitching have been described for each phase of this motion. In the cocking phase there is tension on the medial structures with compression laterally. These forces may neutralize during the acceleration phase. The follow-through involves both compression and shear laterally (forearm pronation), with tension at the olecranon [52]. The term "little leaguer's elbow" has been used to describe the effects of repetitive muscular contraction on the flexor-pronator mass of the elbow. This repetitive force on an apophysis at the muscle insertion may produce subsequent inflammation, which is termed a traumatic apophysitis. An irregular ossification of the medial epicondyle may correlate with pain during pitching and on palpation. Non-operative treatment, including rest and splint use, is recommended. Torg [51] studied 450 adolescent baseball players and obtained roentgenograms on the elbows and shoulders of 49 pitchers. Asymmetrical enlargement of the medial epicondylar apophysis with fragmentation was noted in the pitching arm of two players (4%). Other factors that may contribute to medial sided elbow pathology include the number of innings pitched, the number of pitches thrown, the type of pitches thrown, ligamentous laxity, and the degree of chondro-osseous development. Repetitive forces on the medial aspect of the elbow of the medial musculature may cause microtrauma to the medial chondro-osseous structure. Adolescent athletes have been demonstrated to avulse part or all of the medial epicondyle. Smith [50] noted that occasionally this avulsed fragment does not unite and requires excision if painful. The complete secondary center avulsion fracture in the adolescent frequently occurs with one throw. Repetitive traction may then cause a failure of physeal fusion leading to a picture analogous to non-union.

Ogden [39] studied samples of skeletal tissue from patients with traumatic avulsions at various limb levels. The Ogden type 1 fracture was found to involve the hypertrophic zone. In other types of fractures, the separation was primarily found through the junction of column formation and hypertrophy, with propagation into the primary spongiosa. In older patients with a diminished zone of hypertrophy, the zone of separation was found between the cartilage and bone. Factors which may affect the fracture pattern include the degree of maturation, the undulation of the physis, the direction of loading and rate of loading on the physis.

Quantitative stress and strain results were used to evaluate the tensile properties of the growth plate cartilage [16]. Columns of tissue were cut across the physis, parallel to the long axis of the femur, in skeletally immature cows. Specimens were harvested from nine anatomic sites at the distal femur. When distracted to failure, the strength and stiffness of the physis varied with the anatomical site. These tensile property variations correlated with the collagen content. Regardless of the undulations of the physis, the hypertrophic cells were noted to be aligned nearly parallel to the diaphyseal shaft.

## Perichondrial Ring Influence

The groove of Ranvier is a collection of densely packed cells that are the progenitors for the osteoblasts, providing circumferential growth of the physis. These cells determine the eventual widening of the epiphysis and physis, with consequent metaphyseal flaring. The perichondral ring of La Croix provides stability to the physis and may play a significant role in certain injury patterns in skeletally immature patients. A fibroblast, fiber bundle layer provides a circumferential mechanical support for the growth plate. Moen and Pelker studied the biomechanics of the growth plate that was unsupported by the perichondral ring of La Croix [38]. Columns were sectioned from the central portions of skeletally immature bovine femora and tibia. Compression caused failure in the zone of provisional calcification and the metaphysis. Tension caused failure in the upper zone of columnation and shear loads caused failure between the upper zone of columnation and the lower zone of hypertrophy. Ogden [39] noted several instances of what he described as unsuspected Ogden type I incomplete physeal fractures that propagated to the zone of Ranvier, but did not disrupt the periosteum. These fracture lines extended through the junction between columnar formation and hypertrophy of the columnar cells. The ring of La Croix has a lower elastic modulus than the surrounding bone and periosteum that may act as a checkrein on the epiphysis once the cartilage plate has failed [6].

## Conclusion

Greater numbers of children in the United States are participating in sports at earlier ages, with increased levels of training and competition. Although chondrooseous development is affected by a variety of factors, including hormonal, vascular, and diffusion influences, physical forces play a significant role. A knowledge of the relevant basic science models and mechanisms of physeal damage may assist the practitioner in treating these injuries.

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