Upper extremity injuries in pediatric athletes

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Abstract: Upper extremity injuries in the pediatric patient are common, but are often more difficult to diagnose compared to their adult counterparts due to the gradual progression of cartilage ossification. Common pediatric upper extremity injuries include fractures and soft tissue trauma. Less prevalent injuries include sport specific overuse injuries. Fractures in the pediatric population are best described using the Salter-Harris classification, which has management and prognostic implications. Most pediatric upper extremity injuries can be managed with an initial trial of immobilization and early range of motion, followed by surgical intervention if necessary. Children have a robust healing response to bony and soft tissue injuries, and have good outcomes with appropriate management.

Keywords: Pediatric athletes; upper extremity; Salter-Harris; overuse; injury

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Introduction

Upper extremity injuries are common in pediatric athletes. They typically present due to an acute or overuse etiology. As a result of skeletal immaturity, injury patterns in pediatric patients are different than in adults. Most of these sports injuries respond well to conservative measures, including modification of the activity and physical therapy. Adolescents experience injuries more typical of an adult as they reach skeletal maturity. Identification of the injury and appropriate surgical indications are key to preventing complications and returning athletes to competition safely. In many sports, athletes use their arms to brace themselves during falls leading to upper extremity injuries. Examples include sliding headfirst into a base, diving to make a catch, tumbling during gymnastics and sparring in martial arts (1).

Anatomy

The wrist is a condyloid joint involving a complex set of motions between the radius, ulna and carpal bones. The joints are constrained by a network of ligaments that are primarily named after their attachment sites. The proximal row consists of the scaphoid, lunate and triquetrum. The distal row consists of the trapezium, trapezoid, capitate and hamate. The pisiform is considered a sesamoid bone within the flexor carpi ulnaris tendon. The concave cavity is formed by the articular surface of the distal radius and the articular disc of the triangular fibrocartilage complex (TFCC).

The most important carpal bone is the scaphoid. Cartilage covers 80% of the scaphoid surface, limiting attachment sites for ligaments and vascular channels. The proximal pole of the scaphoid is constrained by the scapholunate ligament and the scaphoid fossa of the radius. Distally, the scaphocapitate, scaphotrapezotrapezoidal and radioscaphocapitate ligaments tether the scaphoid to the distal row. With hyperextension of the wrist, the scaphoid is susceptible to fracture due to its anatomy and biomechanics.

Ossification of the carpal bones occurs in an expected order, starting with the capitate and ending with the pisiform. At birth, there is no calcification in the carpal bones. Although there is variability, ossification is initiated

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as follows: capitate: 1–3 months, hamate: 2–4 months, triquetrum: 2–3 years, lunate: 2–4 years, scaphoid: 4–6 years, trapezium: 4–6 years, trapezoid: 4–6 years, and pisiform: 8–12 years.

Extrinsic ligaments connect the radius and ulna to the carpal bones. Intrinsic ligaments originate and insert on carpal bones. Important intrinsic ligaments include the scapholunate ligament and the dorsal intercarpal ligament. The scapholunate ligament complex is important for carpal row stability. The scapholunate joint is stabilized by two distinct transverse intercarpal ligaments (palmar and dorsal) and a fibrocartilaginous membrane. The dorsal ligament is a thick collection of fibers, slightly obliquely oriented, and plays a key role in scaphoid stability. The triquetrum-scaphoid-trapezio-trapezoid ligament, also known as the dorsal intercarpal ligament, originates from the triquetrum and crosses the midcarpal joint to fan out and insert onto the scaphoid, trapezium, and trapezoid.

The distal radioulnar joint is a pivot joint between the concave distal radial sigmoid notch and the ulnar head (2). The TFCC further supports the articulation of the distal ulna with the lunate and triquetrum. Support is provided by the fibrous meniscus-like articular disk, which runs from the sigmoid notch to the ulnar styloid, as well as the surrounding soft-tissue attachments.

The metacarpophalangeal (MCP) joints are condyloid joints. The interphalangeal (IP) joints are hinge joints. Ligament anatomy and attachments along the finger joints are relatively consistent at the level of MCP and IP joints with similar structures and attachments. The radial and ulnar collateral ligaments (UCLs) arise from their respective condyles. The collateral ligaments are divided into two components based on their insertion site. The proper collateral ligament attaches obliquely to the volar third of the proximal region of the phalanx. The accessory component inserts on the volar plate.

Salter Harris (SH) Classification (3)

Fractures of the physis are unique to children and have implications not seen in the adult population. Robert Salter and Robert Harris came up with an effective classification system that describes these injuries and has general prognostic implications.

Type I: complete separation of the epiphysis from the metaphysis without any bony injury. Reduction is usually straightforward and patients have a good prognosis.

Type II: most common type with the fracture line through a portion of the physis extending into the metaphysis. The growing cells on the physis are intact and attached to the epiphysis, leading to an excellent prognosis.

Type III: this is intra-articular where the fracture line extends from the articular surface to the physis and out to the cortex. Anatomic reduction of the articular surface is critical. The prognosis is good as long as the blood supply to the epiphysis is intact.

Type IV: the fracture extends from the articular surface through the physis and into the metaphysis, producing a complete split. Anatomic reduction of the joint and physis is critical. Open reduction is often necessary if there is any displacement.

Type V: the result of a severe crushing force to the physis. Since displacement is unusual, the injury is often missed on initial X-rays. The prognosis is poor due to the high rate of premature physeal closure.

Fractures

Distal radius fracture

Pediatric distal radius fractures are common injuries. They are either complete bicortical injuries or incomplete fractures. Incomplete fractures, such as torus or buckle fractures, are failures of the compression cortex. Greenstick fractures involve cortical failure of the tension side. Incomplete fractures are considered stable injuries and are treated with immobilization using a short arm plaster splint or fiberglass cast for about 3 weeks.

In complete fractures with deformity, closed reduction should be attempted. In children, an acceptable reduction is considered a coronal or sagittal plane deformity of less than 15 degrees or less than 1 cm of shortening (4). These fractures tend to completely heal on average in 6 weeks and are remodeled by 8 months. Bayonette apposition of less than 1 cm that does not block rotation is acceptable in patients less than ages 8 to 10 (5).

A cast index less than 0.8 has been shown to significantly decrease loss of reduction (5,6). This is a ratio of the cast dimension on the AP and lateral radiograph at the level of the fracture. A well molded short arm cast is just as effective at maintaining a reduction as a long arm cast for fractures of the distal third forearm (6).

Surgical fixation with smooth pins is indicated for failure to achieve or maintain an acceptable closed reduction (7). Open reduction is often necessary if patients present 2 to 3 weeks post-injury due to rapid healing in children. In our

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institution, all open fractures are treated in the operating room with thorough irrigation and debridement, internal stabilization and casting. The incidence of infection and osteomyelitis is low, but the consequences include long-term antibiotics, multiple surgeries and physis injury.

Approximately 70% to 80% of the radius growth occurs distally, and the rate of premature growth arrest after distal radius fracture is approximately 4% (8). Fracture through the physis should be reduced and carefully monitored even after full healing. Disproportionate growth of the ulna leads to ulna abutment syndrome that may affect wrist function in repetitive loading sports.

Scaphoid fracture

Scaphoid fractures in children are uncommon. The classification system describing pediatric scaphoid fractures depends on the degree of ossification (9,10). Endochondral ossification of the scaphoid begins with the appearance of an ossific nucleus around age 4 to 5 and is completed around age 13 to 15 (11). Type I fractures are purely chondral or may involve part of the ossific nucleus in children younger than 8. Due to the chondral involvement, these fractures are usually diagnosed by MRI. Type II fractures are osteochondral fractures that occur in ages 8 to 11. Type III fractures are the most common and occur in children greater than 11 with nearly completely ossified scaphoids (12). Scaphoid fractures can also be characterized based in location: proximal pole, waist and distal pole (13-15).

Injury to the scaphoid can result from a direct compression force or indirectly from forced dorsiflexion. Patients will have pain over the anatomic snuffbox or directly over the distal pole of the scaphoid. Ossification occurs from distal to proximal which favors distal pole fractures. In older children with fully ossified scaphoids, waist fractures are more frequent.

Standard radiographic views include AP, lateral, oblique and scaphoid views. The scaphoid view is taken with the wrist in maximal pronation, dorsiflexion and ulnar deviation. 13% of fractures do not appear on radiograph until 1 to 2 weeks from the initial injury. If there is high clinical suspicion and negative radiographs, MRI or CT is recommended (16). In our practice, MRI is generally recommended to avoid radiation.

Initial management of scaphoid fractures should be with a long arm thumb spica cast to immobilize a very active pediatric population. Short arm spica casting is indicated for incomplete or avulsion fractures. In 2 weeks, the long arm spica cast may be continued or transitioned to a short arm thumb spica cast. Waist fractures are at higher risk for non-union and further immobilization with a long arm spica cast or even surgical management are indicated (17-20). Despite excellent outcomes with non-operative management, surgical management should be considered in patients near or at skeletal maturity with displaced fractures and in those with non-union (9). Autogenous bone grafting, bone graft wedge, k wire fixation and headless compression screw fixation have a union rate of near 100% and provide excellent range of motion and long term pain relief (14,20-32).

Stress fractures of the scaphoid can occur due to repetitive microtrauma and forearm muscle fatigue (33). This occurs in athletes with repetitive loading of the wrist in a dorsiflexed position, such as in gymnasts, divers or tennis players (22,34,35). Once diagnosed, management is the same as acute fracture.

Scaphoid impaction syndrome can occur with forced dorsiflexion of the wrist that may cause the contact between the scaphoid against the dorsal rim of the radius (36,37). Patients can present with pain along the dorsoradial aspect of the wrist with dorsiflexion. Radiographs may show a small ossicle or bony hypertrophic ridge along the dorsal scaphoid. Management consists of rest and avoidance of wrist dorsiflexion. If this fails, surgical cheilectomy of the dorsal scaphoid ridge or dorsal radius rim may be indicated (22,38).

Other carpal fractures

Isolated fractures of the hamate are uncommon in children. They are the result of a direct blow to the hand, and seem to be associated with other carpal fractures (39-41). If suspicion is high for a hamate fracture on radiographs, MRI is an effective diagnostic tool (40). Conservative treatment in a short arm cast is recommended for at least three weeks. Treatment with k-wire fixation may be indicated if there is significant displacement or dislocation (41).

Pisiform injuries have been rarely documented in the pediatric population (42). The center of ossification appears between 7.5 to 10 years of age, and is the last carpal bone to ossify. The bone is fully developed by age 12, but prior to this, there may be multiple sites of ossification. This can give the pisiform a fragmented appearance, which should be distinguished from fracture. Radiographs or MRI are useful to make this distinction. Specific radiographic views include the reverse oblique view, 20 degree supinated lateral wrist view and carpal tunnel view. Closed reduction is generally preferred with immobilization in a short arm cast (42).

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Metacarpal fractures

Head

Metacarpal head fractures are uncommon in children. They often affect the 5th metacarpal and are SH II injuries. Sequelae include physeal growth arrest and avascular necrosis (AVN). Closed reduction should only be performed once due to the increased risk of physeal damage with multiple reduction attempts. If closed reduction is not acceptable, open reduction with k-wires should be considered (43,44). Anatomic reduction is recommended for displaced articular fractures.

Neck and shaft

Metacarpal neck and shaft fractures are often sustained in fights. Angulation is most often apex dorsal due to the deforming forces of intrinsic muscles (45). Shaft fractures are often the result of torsional forces, leading to a spiral or oblique pattern. Rotational deformity is assessed by having the patient flex the MCP and PIP joints, while keeping the DIP joint extended. All the fingers should aim at the scaphoid. Closed reduction with splinting or casting in an intrinsic plus position (MCP flexion, PIP and DIP extension) is the preferred treatment for 4 weeks.

Reduction is achieved with the Jahss Maneuver. The MCP and PIP joints are flexed to 90 degrees, followed by applying a dorsal force using the proximal phalanx to reduce the metacarpal head. The second and third metacarpals can tolerate up to 15 degrees of angulation in the neck and 10 degrees in the shaft, and the fourth and fifth metacarpals can tolerate up to 30 degrees in the neck and 20 degrees in the shaft. Rotational deformity with scissoring of the fingers is not acceptable (45).

Base

Metacarpal base fractures are common injuries, especially impacted metacarpal base fractures of the thumb and small finger (46). 30 degrees of ulnar or radial angulation is acceptable in the thumb metacarpal. Early follow up within one week is recommended due to robust callous formation in pediatric patients. A thumb spica splint or cast should be worn for four weeks. Radial angulated fractures are stable, but ulnar angulated fractures are typically unstable and are more likely to require open reduction and percutaneous pinning. Displaced or subluxed Bennett fractures are indicated for open reduction percutaneous pinning with possible transmetacarpal pinning (46,47).

Phalanx fractures

Proximal

Proximal phalanx fractures are often the result of lateral deviation combined with rotational forces. SH II fractures of the little finger, or extra octave fractures, result in finger abduction and extension. The closed reduction maneuver is traction, metacarpophalangeal flexion and adduction. Angulation of 10 degrees is considered acceptable, but rotational deformity should not be tolerated (48,49). The small finger naturally overlaps slightly with the ring finger, and the contralateral side should be examined before determining the presence of rotational deformity. Slight scissoring at mid-arc is well tolerated and patients can make a full fist without functional deficit. Immobilization in an ulnar gutter splint for three to four weeks is recommended (49).

Articular fractures of the proximal phalanx head are unicondylar, bicondylar or T condylar. Angulation of 5 degrees or displacement of 2 mm are indications for reduction with k wires. Up to 40% of patients may develop stiffness and the outcome can be unpredictable (49,50).

Oblique fractures and subcondylar/neck fractures are unstable (50). Adequate visualization is difficult due to finger overlap, which can be mitigated by a fan finger lateral. The palmar plate and collateral ligaments can displace into the PIP joint, blocking the reduction. If closed reduction with splinting does not achieve anatomic alignment, open or closed reduction with percutaneous pinning is necessary (50,51).

Middle

Middle phalanx fractures are often minimally displaced and have good outcomes with immobilization. Fractures proximal to the flexor digitorum superficialis (FDS) tendon insertion have apex dorsal angulation, and fractures distal to the FDS insertion have apex volar angulation. Buddy tapping the adjacent longer finger or splinting with the MCP joint in 70 to 90 degrees of flexion and the PIP joint in 15 to 20 degrees of flexion is often successful. The most common complication is malrotation (15,49). Open versus closed reduction and percutaneous pinning is indicated after closed reduction when there is greater than 30 degrees of residual angulation in children less than age 10 or greater than 20 degrees in children greater than age 10.

Epiphyseal fractures of the middle phalanx are uncommon injuries. SH I and II fractures should be treated by restoration of length, alignment and rotation. SH III and

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IV fractures with greater than 25% articular involvement or greater than 1.5 mm of displacement should be treated with open reduction and percutaneous pinning. Otherwise, they can be treated with immobilization (50).

Distal

Distal phalanx fractures are commonly crush injuries. They are often SH I or II injuries and are associated with nail bed injuries. If there is concern for nail bed injury, the nail plate should be removed to evaluate the nail bed and repair if necessary. Crush injuries with soft tissue involvement should be debrided and any apparent nail bed laceration should also be repaired (50,52,53). The DIP joint should be splinted for two to three weeks (52).

Seymour fractures are subset of open distal phalanx fractures that occur through or around the physis. Since it is an open fracture, the finger should be thoroughly irrigated and debrided. These open fractures are often misdiagnosed and undertreated. The nail plate should be removed and the nail bed should be carefully examined. Soft tissue interposition prevents fracture reduction and can lead to physeal growth arrest. We generally prefer open reduction and internal fixation with a smooth pin. Inadequate reduction and debridement can lead to finger tip deformity, growth arrest and osteomyelitis (52-54).

Tuft fractures occur through the most distal aspect of the distal phalanx. Most can be immobilized with an alumifoam splint or buddy taping. However, a subungual hematoma suggests a nail bed injury and open fracture. The nail should be removed, finger irrigated and debrided and nail bed repaired. It is acceptable to prescribe antibiotics upon discharge, but may not significantly lower the incidence of infection (55).

Mallet fingers are a particular class of distal phalanx fractures that involve an avulsion of the dorsal articular surface with the extensor tendon. This is due to forced flexion of an extended finger, such as from jamming a finger. Patients will not be able to extend the DIP joint. Treatment consists of placing the DIP in an extension splint for 6 weeks (50). Strict compliance is challenging for pediatric patients, and some require complete cessation of sports.

Sport specific injuries

Climbing Related middle phalanx fracture

Repetitive stresses from intense rock climbing have been associated with fracture of the dorsal part of the middle finger epiphysis. The full crimp position (DIP extension and PIP flexion) produces excessive loading in this part of the hand, leading to physeal overload, consolidation, partial necrosis and eventual growth plate fracture. Treatment consists of immobilization, finger therapy and a cessation of rock climbing for several months (56).

Tennis related lunate stress fracture

Stress fractures of the lunate should be considered in the differential diagnosis of adolescent elite tennis players presenting with dorsal sided wrist pain. Pain is often worse with forehand groundstrokes or other activities with wrist extension. Symptoms improve with rest (1). It is thought to develop from repetitive overloading and microtrauma of the wrist in extension and ulnar deviation. Radiographs are often normal, but MRI shows bone marrow edema often of the distal facet without a fracture line. Treatment consists of semi-rigid wrist immobilization for six weeks, non-steroidal anti-inflammatory drugs (NSAIDs), physical therapy, grip change and weight lifting adjustment to offload the wrist (1).

Gymnast's wrist (distal radial epiphysitis) and Madelung's deformity

The prevalence of wrist pain in pediatric gymnasts ranges from 56–67% in high quality studies (57-59). Gymnastics is a demanding sport, necessitating forceful loads through an extended wrist during activities like tumbling and vaulting. This leads to inflammation and irritation of the growth plate. Patients usually have pain in the dorsoradial region of the wrist and the radiographic findings include enlargement and blurring of the distal radius physis, metaphyseal bone cysts and distal wedging of the epiphysis. Treatment consists of NSAIDs and rest from impact activities for 3 to 6 months. Chronic cases lead to the development of long-term positive ulnar variance and bone bar formation in the distal radius physis. Operative treatment in chronic symptomatic cases involves resection of the physeal bar in small closures or ulnar epiphysiodesis and shortening with or without a radial osteotomy in large physeal closures.

Madelung's deformity is a partial deficiency of growth of the distal radial physis that results in excessive radial inclination, volar tilt, and ulnar carpal impaction. It is common in gymnasts and soccer goalies, predominantly in adolescent females. Etiologies include repetitive trauma with dysplastic arrest of the ulnar volar physis, an abnormal Vickers ligament, or genetic conditions such as Leri-

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Weill dyschondrosteosis or Turners Syndrome. Symptoms resemble those of ulnar impaction and median nerve pathology. Patients have increased pain, decreased forearm rotation and grip strength (60). If the etiology is due to an abnormal Vickers ligament, the ligament can be released surgically with bar resection and physis fat grafting. If related to repetitive trauma, corrective radial osteotomy with or without distal ulnar shortening osteotomy may be necessary.

Soft tissue injures

TFCC injuries

Injuries to the TFCC are often missed in pediatrics. When they coexist with distal radius fractures, the length of time for immobilization for the fracture usually allows enough time for healing of the TFCC (61). An examiner should have a high index of suspicion if the patient sustains a twisting injury to the wrist, has tenderness at the ulnar fovea and pain with passive supination. Patients should be placed in a long-arm splint or cast to fully limit rotation for 6 weeks. Short-arm splint or cast can be applied for additional 2 to 4 weeks. Tears that do not heal with immobilization and prolonged conservative measures can be treated with surgical repair (62). TFCC injuries can be difficult to treat, and some patients have chronic ulnar sided pain despite adequate treatment. While we have had positive experience with TFCC debridement and/or repair in chronic symptomatic patients, we are still very cautious with surgical recommendation. We feel more confident with our indication in the presence of DRUJ (distal radial ulnar joint) instability and MRI confirmation of a TFCC tear.

Extensor carpi ulnaris (ECU) tendonitis or subluxation

Many sports include forceful wrist extension (racquet sports, golf, rowing) and ECU tendonitis can occur in the pediatric athlete. On physical exam, patients will have pain and potentially swelling over the ECU tendon in the ulnar groove. The initial treatment is rest, immobilization with a wrist splint or short arm cast, and NSAIDs (63,64). Patients should also refrain from aggravating sports or activities for a period of 6 to 8 weeks. The ECU can also dislocate if the subsheath has ruptured or become attenuated. These patients usually improve with immobilization in pronation and slight radial deviation, and activity modification for approximately 12 weeks (65). If conservative management fails, the patient is symptomatic and unable to participate in sports, the subsheath can be directly repaired or reconstructed with an extensor retinaculum flap (66).

Flexor carpi ulnaris (FCU) tendonitis

FCU tendonitis can occur with repetitive wrist loading from racquet or club sports, hand ball, and in martial arts where patients hit with an open fist. Patients experience pain with resisted wrist flexion. Treatment is strictly conservative and includes rest, immobilization with a wrist splint and stretching. Patients should refrain from return to play until symptoms have resolved (66).

Boutonniere deformity

A boutonniere deformity is characterized by PIP flexion and DIP extension. It is the result of rupture or loosening of the extensor tendon central slip, often due to blunt trauma or burns. Injury to the central slip results in an imbalance between finger flexors and extensors, and the FDS subsequently becomes the dominant deforming force leading to PIP flexion. The lateral bands experience increased tension and migrate volarly over time. The transverse retinacular ligaments eventually shorten leading to DIP hyperextension.

Boutonniere deformities are extremely rare in the pediatric population. In the literature, there has been one case report of pediatric boutonniere deformity seen after blunt trauma in a 9 year old girl. She was placed in a boutonniere deformity splint, placing the PIP in extension while allowing range of motion of the DIP and MCP joints. After 3 weeks of splinting and an additional 2 weeks of nighttime splinting, the deformity had significantly improved (67).

Scapholunate ligament injuries

The scapholunate (SL) ligament is important for carpal stability and has three components: dorsal, proximal and volar components. The dorsal component provides the greatest constraint to translation between the scaphoid and lunate bones. SL ligament injuries are rare in the pediatric age group. The diagnosis is difficult to make in children and adolescents due to the developing carpus. The scaphoid and the lunate are usually not visible on plain radiographs until the age of four to five years. Furthermore, there is often uneven carpal development, thus comparison radiographs of the contralateral wrist are unreliable. To address this

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problem, age- and gender-based normative values of SL distances as seen on PA wrist radiographs in children between the ages of 6 and 14 years have been described (68). Pediatric patients can often have ligamentous laxity with wrist pain. Scaphoid shift test can be positive with dorsal subluxation along the rim of the dorsal radius. The contralateral wrist must be examined to assess patient's baseline laxity. In our experience, MRI has not been reliable for identifying SL ligament tears. Several authors have recommended non-operative treatment for partial tears. Many case reports have been published, as well as one larger series, discussing percutaneous pinning of Geissler II injuries. There is no standard treatment protocol for Geissler III and IV scapholunate ligament tears in pediatrics.

Thumb UCL injury

Thumb UCL injuries (Skier's thumb) in pediatric patients often involve a large articular component due to the increased strength of pediatric ligaments relative to bone. The thumb UCL is injured by forced thumb abduction and hyperextension. The injury typically involves a SH III fracture of the thumb proximal phalanx. If the fragment is displaced by less than 2 mm, nonsurgical management is indicated. Fractures with more than 2 mm of displacement require open reduction internal fixation. Younger children may also suffer from SH I and II proximal phalanx fractures, whereas adolescents can show avulsion fractures and rupture of the UCL as seen in adults (69,70).

Carpal bone AVN

Kienbock's disease

Kienbock's disease, or lunate AVN, is rarely reported in the pediatric age group and most commonly occurs in adults between the ages of 20 and 40 (71,72). However, the limited literature of case series does suggest the younger patients tend to have better outcomes than adults with both operative and non-operative treatment. Non-operative treatment includes prolonged periods of immobilization in casts and subsequently splints from 15 weeks to 6 months. Studies of children over 12 treated with operative management have also generally shown excellent and pain free outcomes (73-77).

Capitate AVN

Capitate AVN has only been documented in a couple of pediatric patients. Repetitive wrist motions may cause capitate microtrauma and subsequent AVN. The reported cases have been atraumatic or from repetitive microtrauma (78,79). Non-operative treatment involves immobilization and gradual return of activity. Capitate curettage and iliac crest bone grafting were successful in a girl who failed conservative treatment.

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