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MUSCULOSKELETAL IMAGING

Magnetic resonance imaging of elbow injuries in children

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Abstract
Evaluating elbow injuries is challenging because of the complex anatomy of the joint. In children, injury patterns depend on the sports-specific mechanism as well as the stage of skeletal maturity. This article reviews the anatomy of the elbow and common injury patterns seen in children, with an emphasis on MRI and the throwing athlete. Imaging pitfalls specific to children are described.

Keywords Adolescents · Children · Elbow · Injury · Magnetic resonance imaging · Osteochondral injury · Throwing athlete · Ulnar collateral ligament

Introduction

There has been a substantial increase in the number of children participating in organized competitive sports. In the young athlete, the weakest part of the musculoskeletal system is the physis. After puberty, when longitudinal growth slows, the physes have largely fused and the tendons and ligaments become most vulnerable to stress injuries. Thus, characteristic injury patterns in the pediatric elbow are driven by the patient age and mechanism of injury. Overhead sport/throwing athletes are at increased risk for several causes of elbow pain, both acute and chronic repetitive overuse injuries of the elbow [1].

Imaging technique

Patient positioning

MR imaging of the elbow can be challenging if the elbow is not positioned correctly. If the elbow is not isocenter in the magnet, field inhomogeneity and degradation of signal to noise result in poor image quality. Small children can be imaged in the supine position, off-center on the imaging table with the arm by the side. The arm of interest should be in the center of the magnet in anatomical position (supinated). A large or small flex coil can be used depending on patient size. In larger children or casted children, prone positioning is preferred to bring the elbow to isocenter. The arm is placed over the child's head ("Superman" or "swimmer's position"), with the arm extended in the non-casted child [2, 3]. The child then can find a comfortable position, which is usually with the arm pronated. At our institution, a large flex coil is placed on top of the arm and a spine coil is placed below.

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Image acquisition

Coverage of the elbow should extend from the distal humeral metaphysis to the bicipital tuberosity of the radius, to ensure coverage of the biceps tendon insertion. Coronal MR imaging planes are prescribed based on the axial image so that the humeral condyles are oriented parallel to a line bisecting both epicondyles. Sagittal images are obtained in a plane orthogonal to the coronal images. A combination of T1-weighted and fluid-sensitive/proton-density pulse sequences with and without fat suppression are obtained. Gradient echo sequences can be useful if cartilaginous lesions or loose bodies are of concern.

In the adolescent thrower, MR arthrography provides added value. Distention of the joint with fluid allows for improved distinction of partial versus complete ligamentous tears as well as depiction of chondral injuries and loose bodies [4]. MR protocols performed at our institution are provided (Table 1).

Table 1 Elbow MR protocols

Sequence	Coverage area	Matrix	FOV (cm)	Slice thickness/gap	TR (ms)	TE (ms)
Routine indications: apophysitis, osteochondral lesion, medial/lateral collateral ligament tear, tendon						
Coronal T1-W	Parallel to anterior humerus at the condyles	256×204	14–16	3.0/0.3 mm	400–800	15
Axial T2-W FS TSE	Perpendicular to coronal plane; humeral metaphysis through radial tuberosity	256×204	12–14	3.0/0.3 mm	3,800	7
Coronal PD TSE	Parallel to anterior humerus at the condyles	256×256	14–16	3.0/0.3 mm	2,500	30
Coronal T2-W FS TSE	Perpendicular to coronal plane; humeral metaphysis through radial tuberosity	256×256	14–16	3.0/0.3 mm	3,800	73
Sagittal T2-W TSE	Perpendicular to coronal	256×256	12–14	3.0/0.3 mm	4,120	73
MR arthrogram indications: intra-articular body, medial/lateral collateral ligament evaluation, osteochondral lesion						
Axial T1-W FS	Perpendicular to coronal plane; humeral metaphysis through radial tuberosity	512×512	12–14	3.0/0.3 mm	760	10
Coronal T1-W TSE	Parallel to anterior humerus at the condyles	320×320	12–14	3.0/0.3 mm	650	11
Coronal T2-W FS TSE		320×320	12–14	3.0/0.3 mm	5,000	73
Sagittal T1-W FS	Perpendicular to coronal	320×320	12–14	3.0/0.3 mm	760	11
Sagittal 3-D DESS		320×320	12–14	0.80/0 mm	14	5

DESS dual-echo steady state, *FOV* field of view, *FS* fat-suppressed, *PD* proton density, *TE* echo time, *TR* repetition time, *TSE* turbo spin echo

Anatomy

Elbow maturation

Maturation of the elbow is complex and the appearance of secondary ossification centers occurs in a predictable sequence according to age that follows the acronym "CRITOE" (Table 2) [5]. Fusion of the ossification centers is less predictable. Generally, this pattern occurs earlier in girls than boys, by up to 2 years [6]. It is important to note that in these secondary ossification centers, the growth plate is initially spherical, surrounding the ossification center with ample epiphyseal or apophyseal cartilage. With advancing maturity, the growth plate transitions into a hemispherical shape as the ossified portion of the apophysis/epiphysis enlarges and abuts the primary physis of the distal humerus; hence it can be designated as a "metaphyseal equivalent" [4].

Elbow stabilizers

The elbow has three osseous articulations that are supported by a network of ligamentous and myotendinous attachments. It serves as a hinge joint at the humeroulnar and radiocapitellar articulations and provides rotation of the forearm at the radiocapitellar level. This allows for flexion, extension, pronation and supination of the forearm [2]. The articulations are enclosed by a common synovial capsule. The joint capsule is thickened medially and laterally to give rise to their respective collateral ligament complexes [7].

The ulnar collateral ligament (UCL) is the most important stabilizer of the elbow to valgus stress and is composed of three bands: anterior, posterior and transverse (oblique). The anterior band of the UCL lies deep to the common flexor tendon unit and extends from the anteroinferior aspect of/undersurface of the medial humeral epicondyle to the sublime tubercle of

Table 2 CRITOE: Sequential appearance of the ossification centers in the elbow [5]

	Site	Age of appearance on radiography	Age at fusion
C	Capitellum	0–2 years	14 years
R	Radial head	4–5 years	16 years
I	Medial epicondyle (Internal)	6–7 years	15 years
T	Trochlea	8–10 years, multiple and irregular	14 years
O	Olecranon	10 years	14 years
E	Lateral epicondyle (External)	11 years	16 years

medial coronoid process of the ulna [8]. The ligament is thicker at the origin and tapers distally. In younger children, the anterior band of the UCL demonstrates high signal with a striated pattern at the epicondylar origin because of high elastin content and low type 1 collagen, which should not be mistaken for pathology [9]. The UCL posterior band forms the floor of the cubital tunnel and the ulnar nerve and posterior recurrent artery and vein run superficial to the UCL posterior band. A thin arcuate ligament frequently covers the contents of the cubital tunnel [3, 8]. Given its relatively superficial location, the ulnar nerve is not well protected from trauma. Of note, the transverse band of the UCL is not readily imaged on routine MR imaging.

The radial collateral ligament complex is composed of the radial collateral ligament (RCL), the lateral UCL (LUCL), and the annular ligament. This complex acts as a main restraint to varus stress. The RCL extends from the distal aspect of the lateral epicondyle to the annular ligament, deep to the common extensor tendon unit. The annular ligament courses around the radial head to insert on the posterior and anterior aspects of the sigmoid notch of the ulna. The LUCL, the most important posterolateral stabilizer of the elbow, originates posterior to the RCL and deep to the common extensor tendon and courses behind the radial head to attach to the supinator crest of the ulna. The LUCL is not consistently seen in its entirety and oblique imaging can be performed to evaluate the LUCL integrity, particularly if posterolateral rotatory instability is of concern [3, 10].

Synovial plicae are folds of synovial tissue with no known function. They are remnants of embryonic septa of normal articular development and are usually asymptomatic. There are several synovial plicae within the elbow joint. The posterolateral plica (also called “synovial fringe” or “synovial fold of the radiocapitellar joint”) is most frequently identified and is located between the radial head and capitellum. A posterior plica can be found at the superior margin of the lateral olecranon recess [8]. Elbow plicae can cause pain (elbow synovial fold syndrome) if they become hypertrophied or inflamed from direct trauma, repetitive sports activities or other elbow conditions [11].

The muscles involved in the biomechanics of the elbow joint can be divided into four major groups: the flexor and extensor muscles of the forearm, the biceps brachii and the triceps. The common flexor tendons have a common origin at the medical epicondyle and function to pronate the forearm and flex the wrist. The common extensor tendons originate on the lateral epicondyle and supinate the forearm and flex the wrist. The anterior compartment consists of the biceps brachii and brachialis. The biceps brachii functions to flex the elbow and attaches on the radial tuberosity. Posteriorly, the triceps inserts in a broad tendon on the olecranon process of the ulna and acts to extend the elbow.

Anatomical and pediatric considerations

Several physiological elbow entities can be mistaken for pathology.

Pseudodefect of the capitellum

The capitellum has a smooth, rounded surface that tapers along its inferolateral margin. The junction of the capitellar articular surface and the nonarticular surface of the lateral epicondyle is abrupt with a notched appearance. This trough-like indentation of the posterolateral margin of the capitellum is known as a pseudodefect of the capitellum (Fig. 1). Familiarity with the typical location of this structure on sagittal imaging prevents a mistaken diagnosis of an osteochondral lesion, which is typically located more anteriorly along the curved capitellar articular surface [12].

Fig. 1 Pseudodefect of the capitellum. Sagittal T2-weighted fat-suppressed MR image of the elbow in a 14-year-old girl. Pseudodefect (*arrow*) represents the normal posterior tapering of the capitellum at its posterolateral margin. This should not be mistaken for an osteochondral lesion

Pseudodefect of the trochlear groove

The trochlear groove is the large curved depression of the proximal ulna that articulates with the distal humerus. At the junction of the olecranon and coronoid process, there is a focal region without cartilage in the center of the trochlear groove (Fig. 2). Given that this area appears as an irregularity or step-off of the articular cartilage, this can be erroneously called an osteochondral fracture [6, 13]. On sagittal imaging, the medial and lateral aspects of this narrow waist devoid of cartilage can be prominent, termed cortical notches. There might be a small ridge in this region of absent articular cartilage that can be mistaken for an osteophyte or healed fracture [13].

Pre-ossification center

Prior to the appearance of the secondary ossification center, there is an increase in free water and cellular cartilage volume that leads to T2 prolongation. This normal stage of development is appreciated as a well-defined focus of high signal intensity in the region of the developing ossification center on fluid-sensitive images (Fig. 3). It is a temporary phenomenon that is replaced by ossification. Given its fluid-like signal intensity, this can be mistaken for infection or edema from ischemia or inflammation [14].

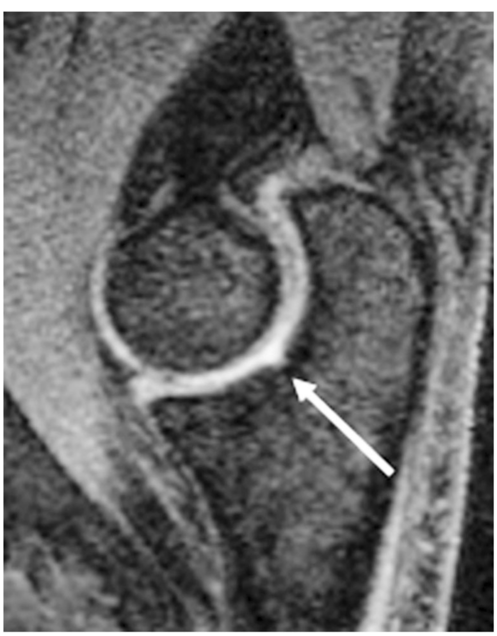

Fig. 2 Pseudodefect of the trochlear groove in a 15-year-old girl. Sagittal dual-echo steady-state (DESS) gradient MR image of the elbow at the level of the ulnohumeral joint. At the junction of the olecranon and coronoid process, there is a focal region devoid of cartilage that should not be mistaken for an osteochondral fracture

Fig. 3 Trochlear pre-ossification center in a 6-year-old girl. Coronal dual-echo steady-state (DESS) gradient MR image demonstrates diffusely increased signal within the small rounded early trochlear ossification center (*arrow*). This is a normal physiological stage of ossification and should not be mistaken for pathology

Sports injuries

A significant portion of MR imaging of the elbow in children is performed to evaluate sports-related injuries. Several activities in particular show a high incidence of elbow injuries: baseball, javelin, football, water polo, tennis, handball and gymnastics. These injuries occur during overhead throwing, power gripping (racquet sports) or weight bearing (gymnastics) [7]. Along with increased play, factors such as overuse, poor mechanics, inadequate rest and baseball pitch selection have been cited for the rise in the number of injuries [15].

Overuse injuries result from repetitive stress on the musculoskeletal system without sufficient recovery time. These types of injuries are seen in both the elite young athlete who is training at a consistently high level, as well as the unconditioned athlete during periods of increasing demand. The increased incidence of overuse injuries of the elbow has paralleled the trend toward sports specialization at a young age, resulting in adolescent athletes concentrating on a specific sport year-round. Overuse injuries commonly occur in adolescents because of the combination of rapid physical growth and imbalances between muscle strength and flexibility.

The baseball pitch is the most common cause of overhead throwing overuse injuries. The pitch sequence consists of six phases: windup, stride, arm cocking, acceleration, deceleration and follow-through [15]. Children typically develop the stages of throwing by age 9 years. The baseball throwing motion generates extreme valgus and extension forces within the elbow, particularly during the late cocking and early

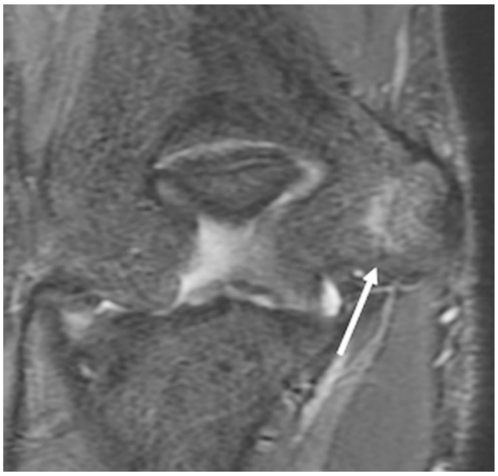

Fig. 4 Medial epicondyle apophysitis in a 14-year-old boy, a baseball pitcher with medial elbow pain. Coronal T2-weighted fat-suppressed MR image demonstrates mild irregularity and increased signal in the medial epicondylar physis, with a small amount of adjacent marrow edema (*arrow*). This is caused by repetitive valgus strain in the throwing athlete, which preferentially affects the chondro-osseous junctions of the physis at this stage of skeletal maturity

acceleration phases. The valgus stress results in distraction across the medial compartment and produces tremendous compression forces within the lateral compartment [16]. The characteristic injury patterns incurred comprise the wide spectrum of injuries known as "Little Leaguer's Elbow." The pathology depends on the skeletal maturity of the athlete [15]. A compartment approach to evaluating pediatric elbow overuse injuries on MRI is provided.

Medial compartment injuries

Medial compartment injuries fit under the umbrella term "valgus overload injuries," with the specific insult dependent on the skeletal maturity of the athlete. In skeletally immature children, repetitive valgus forces affect the medial epicondylar physis, the weakest link in the medial compartment. This results in a traction apophysitis and manifests radiographically as widening of the medial epicondylar physis, often with a ragged appearance. The epicondyle and apophysis might demonstrate sclerosis and trabecular thickening. On MRI, medial epicondylar apophysitis appears as widening of the physis with increased fluid-sensitive signal along both sides of the physis (Fig. 4). If the physis is near closure, there might not be significant widening. On T1-weighted imaging, the apophysis demonstrates loss of the expected fatty hyperintense marrow signal. With continued repetitive injury, there might be complete avulsion of the entire apophysis. Alternatively, small fragments from the inferior surface of the medial epicondyle might be avulsed because of repetitive traction from valgus stress on the UCL (Fig. 5). This occurs because the apophysis is surrounded by a spherical growth plate and the chondro-osseous junctions are the weakest part of the immature skeleton [1, 17]. Children with medial epicondylar apophysitis typically present with decreased throwing effectiveness, medial elbow pain and tenderness [5]. Primary treatment of medial epicondylar apophysitis is rest and anti-inflammatory medication. Physical therapy and reinforcement of proper throwing mechanics might help to prevent recurrence of symptoms [18].

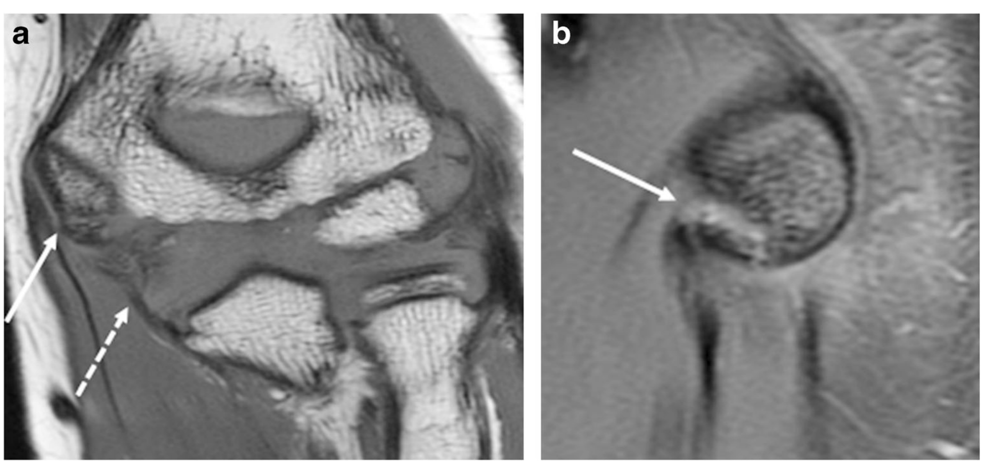

Fig. 5 Medial epicondyle apophysitis in a 15-year-old boy, a baseball pitcher with medial elbow pain. **a** Coronal T1-weighted MR image of the elbow demonstrates avulsion of the inferior aspect of the medial epicondylar apophysis (*solid arrow*), caused by repetitive traction injury from the ulnar collateral ligament (*dashed arrow*), which also demonstrated abnormal signal on fluid-sensitive imaging compatible with partial tear (not shown). **b** Sagittal T2-weighted fat-suppressed MR image of the medial epicondylar apophysis demonstrates the small avulsion injury along its inferior aspect (*arrow*)

In older adolescent athletes, injury shifts to the UCL and the common flexor tendon unit. As the physes close, mixed lesions are common, with physeal edema and tears of the UCL occurring concomitantly. UCL injuries in adolescents are similar to those in adults, with midsubstance tears being most common [19], although both proximal and distal avulsions also occur [20]. Low-grade sprains of the UCL manifest as periligamentous edema with grossly intact fibers [21]. Higher-grade injuries of the anterior band of the UCL are evident on MRI as increased fluid signal within the ligament, with varying degrees of fiber discontinuity and adjacent edema. In complete tears, ligament discontinuity and abnormal fiber laxity is present. Partial UCL tears are more variable in clinical and radiologic presentation and might be more difficult to depict on MR imaging, with subtle fraying along the articular surface of the ligament. Tears are often accompanied by edema in the sublime tubercle or surrounding soft tissues in the acute setting (Fig. 6). Thickening and signal heterogeneity of the UCL are commonly seen in overhead throwing athletes as an adaptation to chronic repetitive valgus stress and might be seen in asymptomatic patients [22].

Insinuation of arthrographic contrast agent is useful in depicting partial- versus full-thickness tears because complete ligament rupture shows contrast extravasation into the adjacent soft tissues (Fig. 7) [23]. But caution is required because iatrogenic contrast extravasation can mimic pathology [24]. Fluid or arthrogram solution undermining the distal UCL insertion at the sublime tubercle is commonly referred to as the “T-sign” (Fig. 8). Originally described as indicative of an undersurface tear of the distal

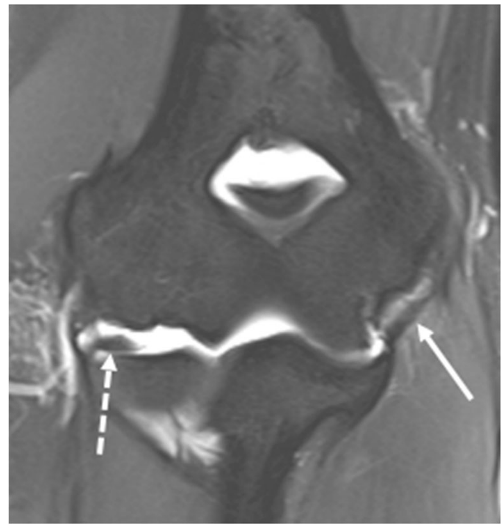

Fig. 7 Partial undersurface tear of the ulnar collateral ligament (UCL) in a 17-year-old male baseball pitcher with medial elbow pain. Coronal T2-weighted fat-suppressed MR image of the elbow after intraarticular injection of gadolinium contrast agent demonstrates abnormal thickening of the anterior band of the UCL. There is increased signal and partial disruption of the deep fibers with fraying in the proximal aspect of the UCL (*solid arrow*). There is no seepage of intraarticular contrast agent within the adjacent soft tissues to indicate full-thickness tear. Evidence of lateral compartment injury is shown with thickening of the posterolateral plica (*dashed arrow*)

UCL, recent anatomical studies in adults have shown the UCL insertion can normally lie up to 3 mm distal to the articular cartilage, mimicking the T-sign. Recently, Lin et al. [25] determined that in young athletes, the T-sign is likely not an anatomical variation, supporting the idea that repetitive overhead throwing sports play a role in its

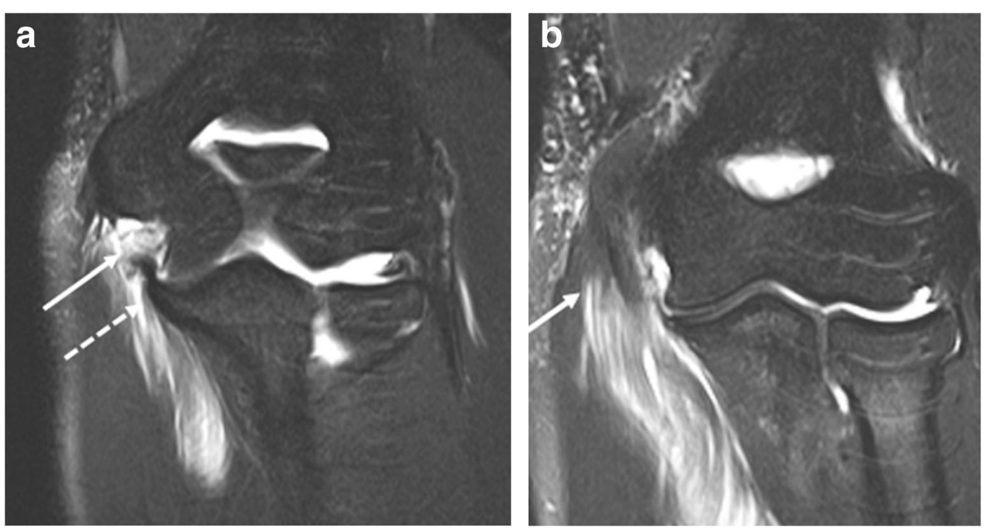

Fig. 6 Ulnar collateral ligament (UCL) tear with partial tear of the common flexor tendon in an 18-year-old male javelin thrower with medial elbow pain. Two coronal T2-weighted fat-suppressed MR images of the elbow after intraarticular injection of gadolinium contrast agent. **a** There is complete disruption of the anterior band of the UCL at its mid-substance (*solid arrow*). Extravasation of contrast agent is seen within the soft tissues of the medial elbow (*dashed arrow*). **b** Partial tearing of the common flexor tendon (*arrow*)

Fig. 8 Partial thickness distal anterior band ulnar collateral ligament (UCL) tear in a 21-year-old male quarterback with medial elbow pain, worse after throwing. Coronal T2-weighted fat-suppressed arthrographic MR image of the elbow shows the T-sign. Gadolinium contrast agent separates the distal UCL (*arrow*) and the sublime tubercle (*arrowhead*)

development. However, the T-sign alone was shown to be a poor predictor of symptoms and need for surgery. Edema in the sublime tubercle or soft tissues adjacent to the UCL insertion accompanying a T-sign in a symptomatic child suggests a partial-thickness tear. Surgical treatment of UCL tears in children is patient-specific and based on both the presenting pathology and future athletic goals of the child [26].

In addition to ligamentous tear or avulsion, distal UCL injuries can present as an avulsion fracture or stress reaction of the sublime tubercle (Fig. 9). These injuries present as band-like bone marrow edema [5], with or without a discrete linear fracture, in the setting of an intact or chronically thickened UCL [27].

Lateral compartment injuries

In the lateral compartment, repetitive valgus compression overload usually results in Panner disease in the young athlete (6–12 years of age) and capitellar osteochondral lesions in the adolescent player. These two overuse conditions are postulated to represent the same process, just at different stages of skeletal maturation and with different clinical outcomes [9].

Panner disease is a self-limiting osteochondrosis of the developing capitellar ossification center. The cause is presumed to be chronic ischemia to the tenuous small posterior perforating end arteries that traverse the pliable and compressible epiphyseal cartilage of the capitellum, similar to Legg–Calvé–Perthes disease of the hip. Children present with dull elbow pain and swelling that is exacerbated with activity [17]. On radiographs, the capitellum appears fragmented with areas of sclerosis and irregularity of the trabecular markings. The entire capitellum is affected in Panner disease. On MRI, the capitellar ossification center demonstrates low T1-weighted signal and variable fluid-sensitive signal depending on the viability of the underlying tissue and stage of disease progression (Fig. 10) [1]. Panner disease is not associated with chondral abnormalities and the prognosis is excellent. Children are treated with rest and anti-inflammatory medication. After conservative management, normal growth resumes without long-term sequelae [17].

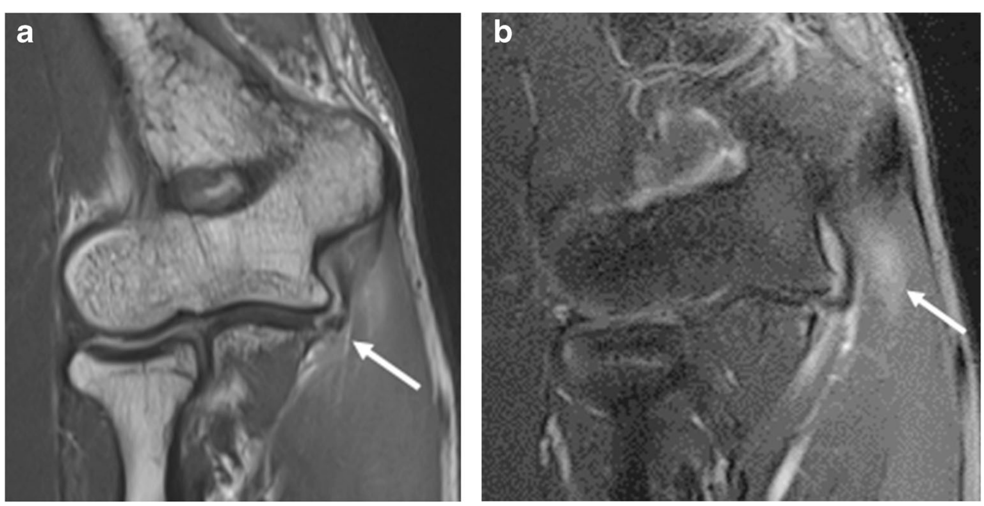

Fig. 9 Sublime tubercle avulsion in a 15-year-old boy with persistent medial elbow pain after football injury. **a** Coronal T1-weighted MR image of the elbow shows a sublime tubercle avulsion (*arrow*). **b** Coronal T2-weighted fat-suppressed MR image demonstrates feathery edema from strain in the flexor pronator mass (*arrow*). The anterior band of the ulnar collateral ligament is intact

Fig. 10 Panner disease in a 10-year-old male baseball pitcher with medial elbow pain. Sagittal T1-weighted MR image of the elbow at the level of the mid capitellum. There is abnormal diffuse low signal intensity within the capitellum (*arrow*) with loss of the expected fatty marrow signal. Findings represent an osteochondrosis of the developing capitellar ossification caused by chronic ischemic change from chronic repetitive trauma

In older children, nearing or at skeletal maturity, lateral compartment compression injuries consist of osteochondral lesions. The lesion occurs along the anterolateral aspect of the capitellum, along the periphery of the ossifying epiphysis and deep to the articular surface. At skeletal maturity, the lesion affects the articular cartilage and the prognosis is worse [1]. Children and adolescents present with pain and stiffness and report symptoms of grinding and locking. Radiographs demonstrate a focal radiolucent irregular or fragmented lesion within the capitellum, sclerosis, and possibly loose bodies. In addition to standard anteroposterior (AP) and lateral radiographs, assessment of the osteochondral lesion might be enhanced by imaging the elbow in the semi-flexed oblique position [1]. MRI can assess the integrity of the cartilage and size of the osteochondral lesion and evaluate the overall stability. The earliest MRI finding is a crescentic focus of low T1-weighted signal along the anterolateral aspect of the capitellum with corresponding increased signal abnormality on fluid-sensitive images (Fig. 11). Advanced lesions are associated with full-thickness chondral defects (Fig. 12). Criteria for instability differ compared with adults. In children, the most useful findings of instability are a high-signal fluid-intensity rim, multiple breaks in the subchondral bone plate, and a second rim of low intensity peripheral to the rim of fluid signal. In addition, large cyst-like changes are associated with instability (Fig. 13) [1, 28, 29]. MR arthrography improves the staging of capitellar osteochondral lesions (Fig. 14) [6]. Given that the etiology of these lesions in throwers is a valgus extension overload phenomenon, it is common to see both medial and

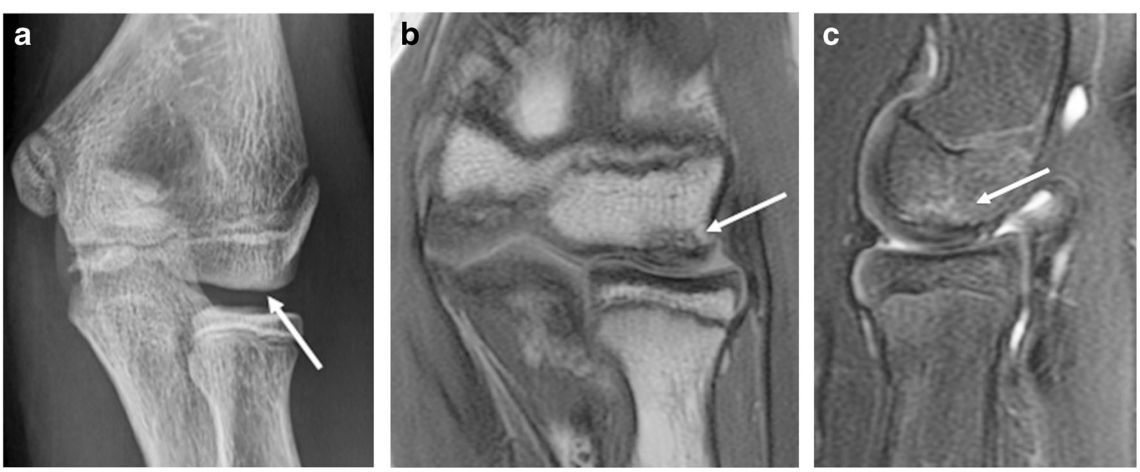

Fig. 11 Osteochondral lesion of the capitellum in a 13-year-old male baseball pitcher with medial elbow pain. **a** Anteroposterior (AP) radiograph of the elbow demonstrates minimal subchondral lucency within the anterolateral aspect of the capitellum with adjacent sclerosis (*arrow*) indicative of an osteochondral lesion. **b** Coronal T1-weighted MR image of the elbow shows a small amount of subchondral hypointensity within the capitellum (*arrow*). **c** Sagittal T2-weighted fat-suppressed MR image demonstrates a small focus of subchondral marrow edema (*arrow*) with intact overlying cartilage

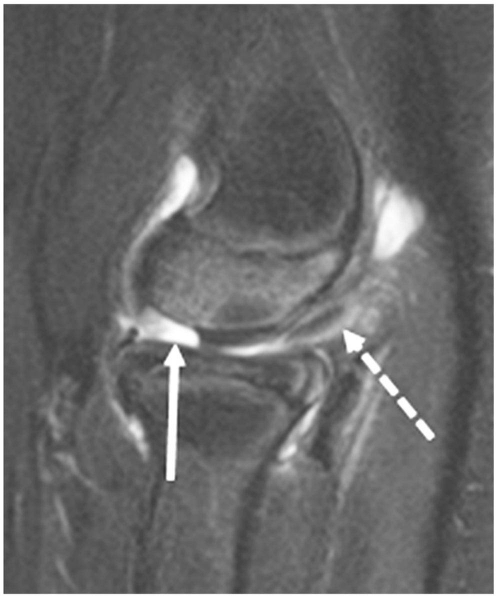

Fig. 12 Osteochondral lesion of the capitellum with displaced chondral fragment in a 14-year-old male pitcher with medial elbow pain and locking. Sagittal T2-weighted fat-suppressed MR image of the elbow at the mid to lateral capitellar level. There is a full-thickness chondral defect along the anterolateral aspect of the capitellum (*solid arrow*). A displaced chondral fragment is seen within the posterior aspect of the joint space (*dashed arrow*)

lateral compartment injuries concomitantly (Fig. 15). Surgical treatment of unstable osteochondral lesions and lesions that have failed to heal with conservative management includes reduction and fixation of the chondral fragment, lesion debridement, subchondral drilling and abrasion chondroplasty [26].

Osteochondral lesions also occur in the lateral trochlea and are an uncommon cause of elbow pain. They are typically seen in the inferior portion of the lateral trochlea and are likely the result of olecranon abutment from microinstability caused by collateral ligament insufficiency/laxity in the throwing or tumbling athlete. This region of the trochlea is vulnerable to ischemia because it is a relative watershed zone with diminished blood supply occurring between the non-overlapping medial and posterior vascular arcades [30]. AP radiographs might show a focal subchondral lucency within the lateral trochlea (trochlear hole). MR imaging findings are similar to those of osteochondral lesions of the capitellum (Fig. 16). Lesions are typically 10–14 mm in greatest dimension [30].

Posterior compartment injuries

Posterior compartment injuries are uncommon in children and are caused by repetitive contraction of the triceps during the deceleration and follow-through phases of throwing. In skeletally immature athletes, repetitive traction manifests as olecranon apophysitis and appears similar on MRI to medial epicondylar apophysitis with widening of the physis and increased fluid-sensitive marrow signal along both sides of the physis [31]. In chronic injury, the olecranon physis might not fuse, termed “persistence of the olecranon physis” (Fig. 17) [1]. During or after closure of the olecranon physis, children are at risk for developing stress reactions or stress fractures of the olecranon [26]. MRI is useful when radiographs are inconclusive and demonstrates a fracture line and adjacent marrow edema. Older, skeletally mature adolescents with

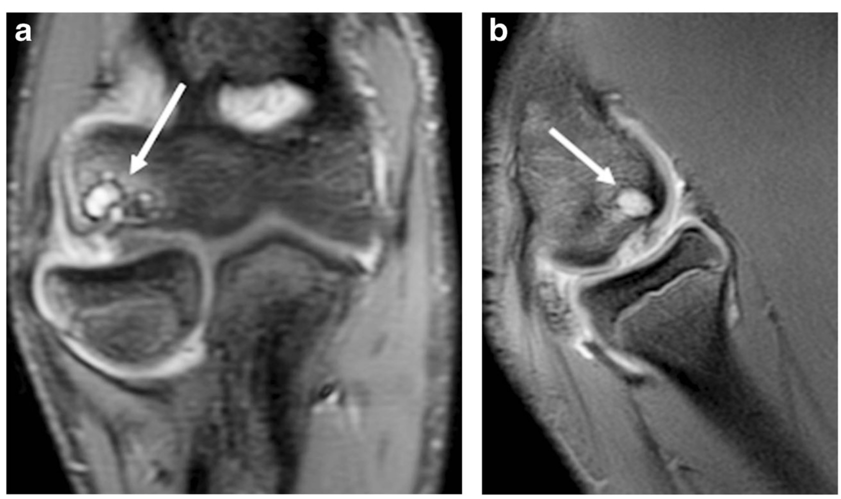

Fig. 13 Unstable capitellar osteochondral lesion in a 15-year-old boy, a baseball pitcher with medial elbow pain. **a**, **b** Coronal (**a**) and sagittal (**b**) T2-weighted fat-suppressed MR images of the elbow show an osteochondral lesion of the capitellum. There are large cyst-like lesions within the subchondral bone (*arrows*), with irregularity of the overlying cartilage. These findings suggest instability

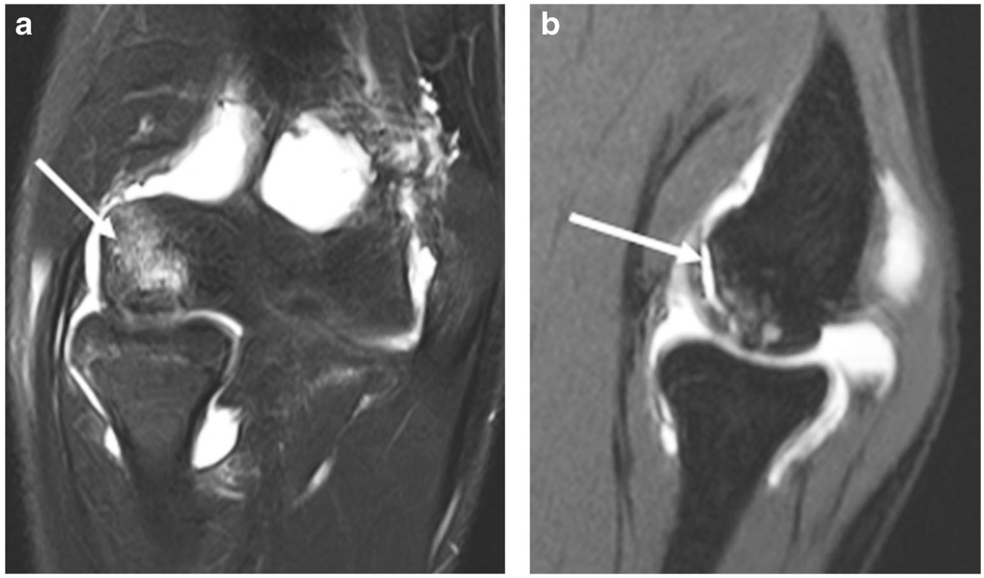

Fig. 14 Unstable osteochondral lesion of the capitellum in a 17-year-old girl, a gymnast with medial elbow pain. **a, b** Coronal T2-weighted fat-suppressed (**a**) and sagittal T1-weighted fat-suppressed (**b**) MR images of the elbow after intraarticular injection of gadolinium contrast agent show an osteochondral lesion within the capitellum. **a** Marrow edema is seen surrounding the lesion (*arrow*). **b** Gadolinium contrast agent delaminates deep to the osteochondral fragment, consistent with an unstable lesion

posterior overuse injuries also present with triceps tendinopathy.

Dislocations

Elbow dislocations are relatively uncommon in children (3–6% of all elbow injuries), with a peak incidence between the ages of 10 and 15 years, more frequently in boys. The most common mechanism is a fall on an outstretched hand while the forearm is supinated with the elbow in either full extension or partially flexed [6, 32]. Posterior dislocation is the most common, with the posterolateral type occurring in 70% of cases. Rarely there is disruption of the proximal radioulnar joint (divergent type). The ulna dislocates posteriorly, in part because of the diminutive size of the coronoid process in children. Approximately 2/3 of all dislocations have other injuries, which include fractures of the medial epicondyle, radial head and neck, and rarely the coronoid process. Intraarticular entrapment of the medial epicondylar apophysis occurs in 5–18% of dislocations [33]. Elbow dislocations are usually associated with disruption of collateral ligaments (Fig. 18). Injuries to the lateral UCL often accompany injuries to the common extensor tendon and are seen with lateral condylar abnormalities [34]. Treatment is somewhat controversial; however most surgeons advocate for conservative management. Open reductions are necessary if there is an entrapped fragment [6]. Children must be watched closely for neurovascular complications such as ulnar neuropathy, median nerve entrapment and brachial artery compromise (Fig. 19). Vascular compromise is more common in open dislocations [32].

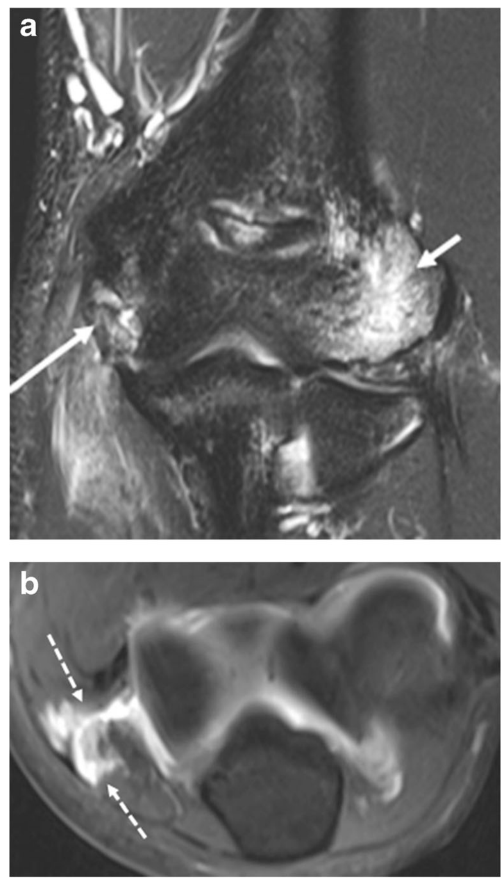

Fig. 15 Valgus extension overload injuries in an 18-year-old male baseball pitcher with diffuse elbow pain, worse with throwing. **a, b** Coronal T2-weighted fat-suppressed (**a**) and axial T1-weighted fat-suppressed (**b**) MR images of the elbow after intraarticular injection of gadolinium contrast agent show complete tear of the anterior band of the ulnar collateral ligament (*long solid arrow*) from repetitive valgus stress along the medial aspect of the elbow. Note the extravasation of contrast agent within the medial soft tissues on the axial image (*dashed arrows*). Chronic compressive lateral compartment injury is seen with edema within the capitellum and irregularity of cortex (*short arrow*)

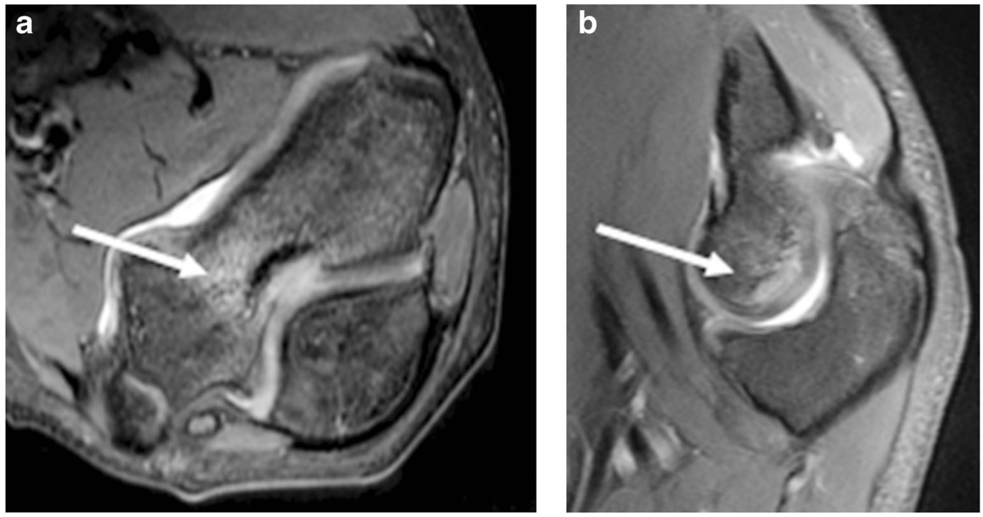

Fig. 16 Lateral trochlear osteochondral lesion in a 14-year-old boy, a baseball pitcher with medial elbow pain. **a, b** Axial (**a**) and sagittal (**b**) T2-weighted fat-suppressed MR images demonstrate an osteochondral lesion with adjacent marrow edema within the lateral trochlear crista (*arrow*). The osteochondral lesion is within a watershed region and is thought to occur from repetitive abutment of the olecranon on the inferior posterior lateral trochlea during the deceleration and follow-through phases of throwing

Isolated radial head dislocation is uncommon in children and typically occurs in combination with a proximal ulnar fracture (Monteggia injury). The "Monteggia-equivalent" is seen in pediatric injuries with radial head dislocation and associated ulnar plastic deformation, greenstick fractures of the radius or ulna, or ulnar metaphyseal fractures [6]. These injuries are readily diagnosed on radiographs and generally do not require MRI.

Fracture complications

An uncommon but very important complication of elbow fractures is the "fishtail deformity" of the distal humerus (Fig. 20). Fishtail deformities are delayed complications of distal humeral fractures in children, most commonly occurring after supracondylar fractures. The proposed mechanism is post-traumatic avascular necrosis of the lateral trochlea. The trochlea has a precarious blood supply that is vulnerable to injury [35]. Children typically present several years after the initial injury with limited flexion and extension, stiffness and pain. Fishtail deformities are also associated with osteoarthritis, loose bodies, cubitus valgus deformity, proximal migration of the ulna, and radial head subluxation. Osteochondral lesions of the capitellum are associated with the lesion because of overload within the lateral compartment. MRI is useful for determining the extent of articular incongruence, cartilage damage and presence of loose bodies and can aid in surgical management (Fig. 21). Management

Fig. 17 Persistence of the olecranon physis in a 16-year-old boy, a baseball pitcher with posterior left elbow pain (left-hand dominant). **a** Lateral radiograph of the left elbow shows linear lucency in the region of the olecranon physis (*arrow*) with adjacent sclerosis. **b** Lateral radiograph of the asymptomatic right elbow demonstrates a normal closed olecranon physis. **c** Sagittal T2-weighted fat-suppressed arthrographic MR image demonstrates widening and increased signal within the olecranon physis (*arrow*), with a small amount of adjacent marrow edema

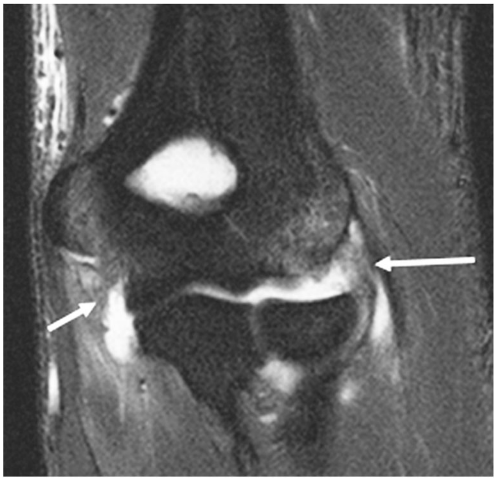

Fig. 18 Elbow dislocation in a 17-year-old boy, a football player who sustained elbow dislocation after a tackle. Status post closed reduction. Coronal T2-weighted fat-suppressed MR image demonstrates marrow edema within the capitellum and medial epicondyle. There are tears of the both the anterior band of the ulnar collateral ligament (*short arrow*) and radial collateral ligament (*long arrow*). Extravasated joint fluid is seen along the medial and lateral soft tissues of the elbow

Fig. 20 Fishtail deformity of the distal humerus in a 15-year-old boy, a swimmer with elbow pain and stiffness. Anteroposterior radiograph of the elbow demonstrates a chevron-like appearance of the distal humerus (*solid arrows*). There is abnormal development of the trochlea with an elongated appearance (akin to a fishtail) from prior avascular necrosis of the lateral trochlea (*dashed arrow*). An osteochondral lesion is seen within the capitellum (*arrowhead*). The boy had a history of supracondylar fracture at age 6

is dependent upon symptoms. For more complicated cases, debridement with loose body retrieval, capsulotomy, epiphysiodesis, osteotomy or ulnar nerve transposition is required [35].

Conclusion

Understanding physeal and apophyseal development is of paramount importance in interpreting elbow injuries in the young athlete. In children, the weakest part of the musculoskeletal system is the physeal cartilage. The stage of skeletal maturity and sports-specific mechanism of overuse might help predict the pattern of injury. MRI plays a substantial role in troubleshooting elbow pain and can depict marrow edema as well as chondral and soft-tissue injuries.

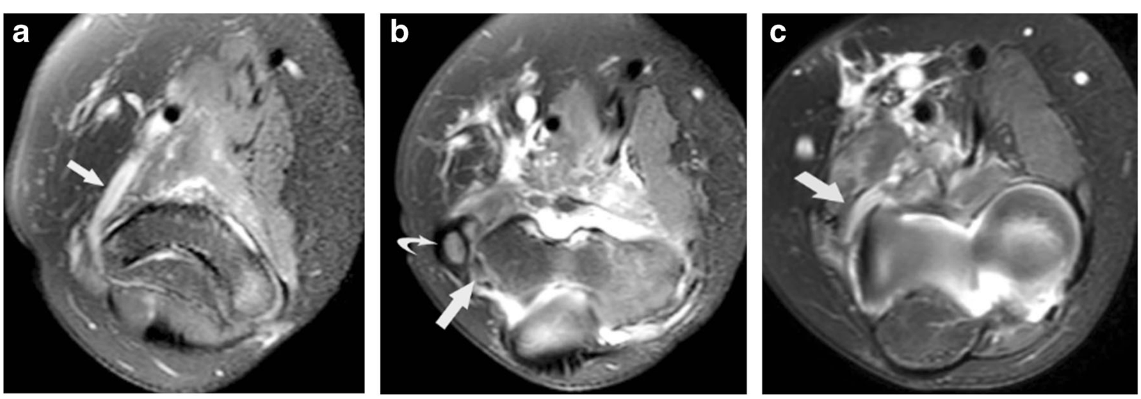

Fig. 19 Elbow dislocation with entrapment of the median nerve in a 7-year-old boy who sustained a traumatic elbow dislocation with medial epicondyle apophyseal avulsion fracture. Post reduction and casting, he had persistent median nerve palsy. Follow-up MRI obtained 8 weeks after injury demonstrated entrapment of the median nerve within the reduced medial epicondyle apophyseal fracture. Three axial T2-weighted fat-suppressed MR images of the elbow are provided, superior to inferior. **a** At the level of the distal humerus, the median nerve is enlarged and edematous (*arrow*). **b** Medial epicondylar apophyseal avulsion with the apophysis located anteriorly and slightly medial to the distal humerus (*curved arrow*). The median nerve (*straight arrow*) is posteriorly displaced behind the avulsed medial epicondylar apophysis. **c** At the level of the radial head, the median nerve courses anteriorly, toward the region of its expected location. Images courtesy of Dr. Jerry Dwek

Fig. 21 Fishtail deformity of the distal humerus in an 11-year-old boy with elbow pain and history of supracondylar fracture 5 years prior. **a** Coronal T1-weighted MR image of the elbow shows an abnormal configuration of the distal humerus with irregularity and fragmentation of the trochlea and a concave defect extending along the physis (*arrow*). **b** Sagittal T1-weighted fat-saturated post-contrast MR image of the elbow demonstrates an elbow joint effusion with diffuse synovitis (*short arrows*). The radial head is anteriorly subluxated and demonstrates mild overgrowth. An osteochondral lesion of the capitellum is noted (*long arrow*), with a loose body within the posterior aspect of the joint

Compliance with ethical standards

Conflicts of interest None

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