Clinical Imaging 57 (2019) 99–109

Contents lists available at ScienceDirect

Clinical Imaging

journal homepage: www.elsevier.com/locate/clinimag

Pediatric Radiology

MR imaging of the shoulder in youth baseball players: Anatomy, pathophysiology, and treatment☆,☆☆

Julien T. Aoyama[a], Pia Maier[b], Sabah Servaes[b], Suraj D. Serai[b], Theodore J. Ganley[a], Hollis G. Potter[c], Jie C. Nguyen[b,*]

[a] Department of Orthopedic Surgery, Children's Hospital of Philadelphia, 3401 Civic Center Blvd, Philadelphia, PA 19104, United States of America
[b] Department of Radiology, Children's Hospital of Philadelphia, 3401 Civic Center Blvd, Philadelphia, PA 19104, United States of America
[c] Department of Radiology, Hospital for Special Surgery, 535 E. 70th St, New York, NY 10021, United States of America

ARTICLE INFO

Keywords:
Adolescent
Overuse
MRI
Baseball
Shoulder
Sports

ABSTRACT

With an increasing participation in youth sports and a growing popularity of overhead sports, shoulder pain and injuries are common in pediatric baseball players. In contrast to traumatic and collision injuries, which are more frequent with high-impact sports, many of the shoulder injuries are the result of repetitive overuse. Undiagnosed and untreated injury to the growth plates of skeletally immature athletes can lead to remodeling, which can negatively impact the biomechanics of the shoulder and produce long-term morbidity. Recently, there is an increasing emphasis on the association between skeletal maturation and injury patterns. The increasing use of magnetic resonance (MR) imaging has led to a better characterization of the traditionally radiographically-diagnosed growth plate injuries and awareness of other soft tissue and cartilaginous injuries that were previously thought to predominately occur in adult baseball players. The goal of this review is to: 1) highlight the normal anatomic changes that occur in the shoulder girdle during development and maturation; 2) discuss the biomechanical forces that are applied to the shoulder during a pitch; and 3) highlight the various injury patterns and adaptive remodeling that can occur in the shoulders of youth baseball athletes along with the current treatment options. These topics include growth plate injury, osteochondral injury, labral tear, capsular remodeling and rotator cuff tendinopathy.

1. Introduction

With increasing participation in youth sports, shoulder pain and injuries have become more common among children and adolescents. According to the National Council of Youth Sports, 60 million youth in the U.S. between 6 and 18 years of age participate in organized athletics with nearly half in a team-based sport such as baseball, football or volleyball [1]. Overhead sports like baseball remain one of the most injurious due to the high rates of participation and the altered shoulder biomechanics. In the U.S., 2 million children participate in Little League Baseball, and an additional half a million participate at the high school level [2]. Across all levels, baseball accounts for 50,000 new injuries every year with an injury rate of at least 2 out of every 100 players for Little League Baseball and 58 out of every 100 players for Major League Baseball [2].

In contrast to traumatic and collision injuries, which are frequent in high-impact sports such as football, many of the shoulder injuries in overhead athletes are the result of repetitive overuse, and are increasingly more common with single-sport specialization [3]. Although soft tissue injuries predominate in adult (skeletally mature) athletes, in youth athletes the injury pattern varies dependent on the athlete's skeletal maturity. In particular, undiagnosed and untreated injury to the growth plates (physes) of skeletally immature athletes can lead to adaptive remodeling, which can negatively impact the biomechanics of the shoulder and produce long-term complications. Therefore, a basic understanding of the normal developmental anatomy and physiology in children and adolescents is fundamental. The goal of this review is to: 1) highlight the normative anatomic changes that occur in the shoulder girdle during development and maturation; 2) discuss the biomechanical forces that are applied to the shoulder during a pitch; and 3) review the various injury patterns and adaptive remodeling that can occur in the shoulders of youth baseball athletes along with the current

☆ No grant funding or other financial support.
☆☆ No relevant disclosures.
* Corresponding author at: the Children's Hospital of Philadelphia, 3401 Civic Center Blvd, Philadelphia, PA 19104, United States of America.
E-mail address: nguyenj6@chop.edu (J.C. Nguyen).

https://doi.org/10.1016/j.clinimag.2019.05.005
Received 28 March 2019; Received in revised form 1 May 2019; Accepted 13 May 2019
0899-7071/

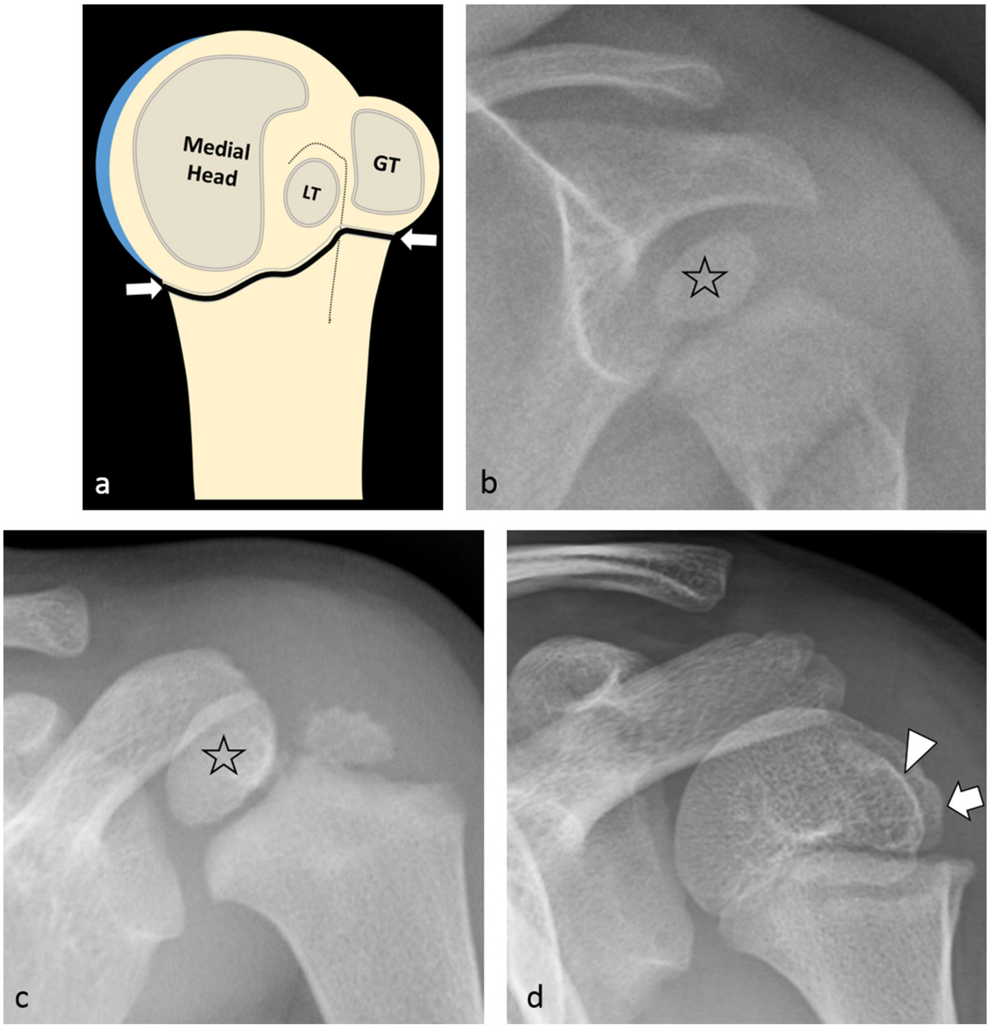

Fig. 1. Development of the proximal humerus. (a) Illustration of the proximal humerus showing the articular cartilage (blue), primary growth plate (arrows), and secondary ossification centers (tan color) that contain peripherally-located secondary growth plates. LT = lesser tuberosity, GT = greater tuberosity. Anteroposterior (AP) radiographs of the shoulder from a 12 month-old boy (b), 24 month-old girl (c), and 7 year-old boy (d) demonstrate age-dependent ossification, enlargement, and coalescence of the humeral head ossification centers, starting with the medial head ossification (stars) and ending with a near adult-like morphology with better defined lesser (arrowhead) and greater tuberosities (arrow). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

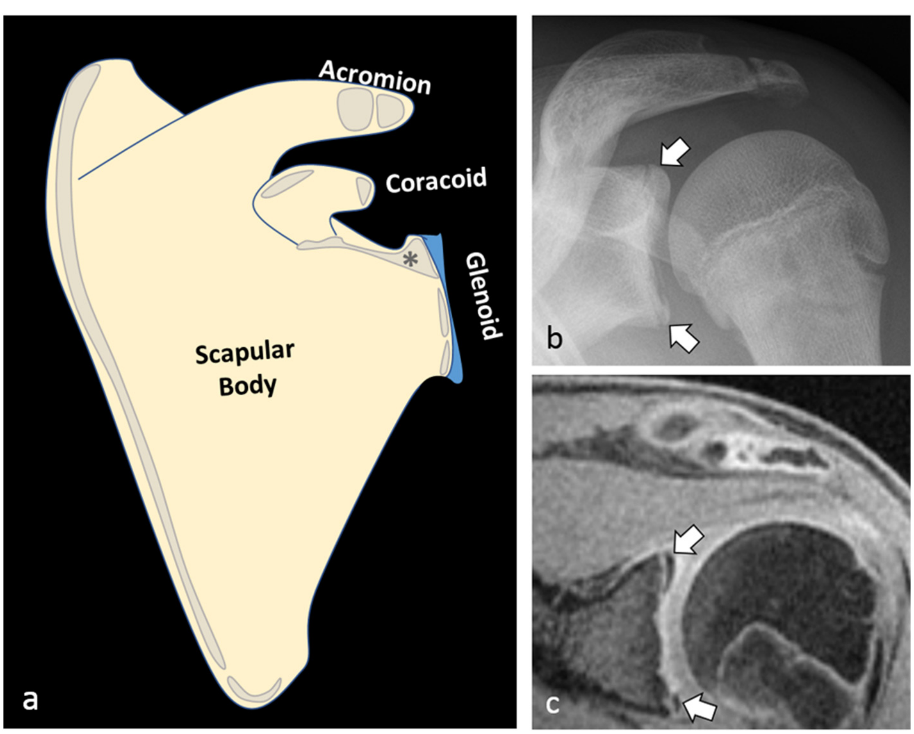

Fig. 2. Development of the scapula. (a) Illustration of the scapula showing the glenoid articular cartilage (blue color) and multiple secondary ossification centers (tan color). Grashey radiographic view (b) and coronal 3-dimensional spoiled gradient echo (SPGR) image (c) from a 13 year-old boy demonstrates glenoid ring ossification centers (arrows). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

treatment options.

2. Anatomy of the shoulder girdle

The osseous structures in the shoulder girdle include the proximal humerus, clavicle and scapula. The proximal humerus undergoes endochondral growth at its primary physis, which is responsible for 80% of the longitudinal growth of the humeral shaft [4] (Fig. 1). In girls, closure of this physis occurs between 14 and 17 years of age, while in boys it occurs slightly later between 16 and 18 years of age [4,5]. In addition to the proximal humeral primary physis, the ossification centers in the medial humeral head and in the greater tuberosity grow via their peripherally-located secondary physes. These ossification centers remain separate until 5–7 years of age, at which time they start to coalesce to form the epiphysis, containing the humeral head, greater tuberosity and lesser tuberosity [4,6]. The existence of a third ossification center in the lesser tuberosity is currently debated with some arguing that it can be seen [7,8], and others arguing instead that the lesser tuberosity merely forms from anterior growth of the medial humeral head [9,10].

The clavicle lengthens through endochondral ossification, occurring at its medially- and laterally-located primary physes [11]. The medial physis is the primary contributor of length in the clavicle, accounting for 80% of its longitudinal growth. The late closure of the medial physis around 22–25 years of age makes it the last physis to close in the human body, while the lateral physis usually closes around 18 years of age [12].

The scapula undergoes both intramembranous ossification (e.g., body of the scapula) and endochondral ossification (e.g., glenoid cavity, coracoid process, and acromion) [4,13,14] (Fig. 2). The glenoid cavity is formed by multiple ossification centers, each containing their own secondary physis, and are classified based on their location into superior one-third and inferior two-thirds of the fossa [15–18]. The superior one-third of the fossa is formed by a single ossification center named subcoracoid or infracoracoid ossification, which appears around 8–10 years of age and fuses with the scapula around 15–17 years of age [7,16,18]. The inferior two-thirds of the fossa is formed by multiple smaller ossifications that appear around puberty and coalesce around 17–18 years of age to produce the horseshoe-shaped portion of the epiphysis [7,18]. Occasionally, additional secondary ossification sites of the glenoid are noted at the superior angles, considered to represent normal developmental variants [17]. The orientation of the glenoid is characterized by its version, defined by the degree with which it faces anteriorly or posteriorly with respect to the plane of the scapular body, and tilt, defined by the degree with which it faces superiorly or inferiorly with respect to the vertical axis [19]. The coracoid process contains two to three secondary ossification centers that appear around 1 year of age and do not fuse with the scapula until 15–16 years of age [4]. The acromion contains a variable number of ossification sites ranging from two to five (Fig. 3). These secondary ossifications appear around 14–16 years of age and close around 18–25 years of age [7]. The lack of displacement and bone marrow edema within these unfused ossifications distinguish them from a fracture. However, localized pain and edema involving the unfused ossification center and within the adjacent scapula is termed acromial apophysiolysis, and is a risk factor for the future development an os acromiale. Os acromiale, diagnosed after 25 years of age, can be the cause of chronic superior shoulder pain and subacromial impingement [20].

3. Normal shoulder function

The wide range of movements achievable in the shoulder requires a delicate balance between stability and mobility across the glenohumeral joint, which involves both static and dynamic stabilizers [21]. Static stabilizers are the glenoid labrum, joint capsule, and glenohumeral ligaments, which function primarily at the extremes of motion to prevent translation of the humeral head out of the relatively shallow glenoid cavity [22]. The glenoid labrum deepens the glenoid cavity and also serves as an intra-articular attachment site for the long head of the biceps brachii tendon [22]. The three glenohumeral ligaments (superior, middle, and inferior) represent focal thickening of the joint capsule and are commonly recognized, but their precise location, thickness, and presence can be variable among individuals. At maximum external rotation and abduction, the inferior glenohumeral ligament becomes taught and prevents anteroposterior and inferior translation, while in adduction, internal rotation and flexion, the posterior capsule prevents posterior translation of the humeral head [5].

In contrast to the extremes of motion, at the midranges of motion, the dynamic stabilizers provide the concavity-compression required to maintain the humeral head within the glenoid cavity. These dynamic stabilizers are the long head of the biceps brachii, rotator cuff, deltoid, and scapulothoracic muscles. The long head of the biceps brachii attaches to the superior glenoid labrum and prevents superior and anterior humeral head translation. The rotator cuff consists of four muscles: the subscapularis, supraspinatus, infraspinatus and teres minor. These muscles near completely envelop the glenohumeral joint and allow the internal-external rotation and abduction-adduction of the humerus against the glenoid. The deltoid muscle also contributes to the external rotation, internal rotation, flexion, and extension of the arm. The remaining scapulothoracic muscles, which include the rhomboids, levator scapulae, serratus anterior, and trapezius, help the scapula maintain its optimal position and indirectly impact glenohumeral joint stability.

4. Biomechanics of overhead throws

In order to produce both the velocity and precision needed for baseball pitching, overhead throwers go through six common phases [23,24]. The windup and stride prepare the thrower for the ensuing phases using the thrower's legs and trunk to act as a stable base while separating the arms into position, 180° apart. The cocking, acceleration, deceleration, and follow-through are the most common culprits for inducing shoulder injury [25]. The late cocking phase is distinctive, characterized by forward-facing shoulders, maximum external rotation of the shoulder, and 90° abduction of the humerus. The flow of motion

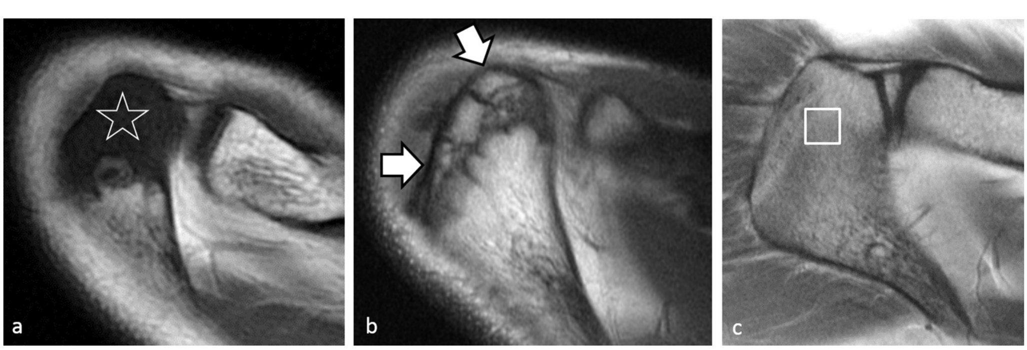

Fig. 3. Maturation of the distal acromion. Axial intermediate-weighted MR images from 3 different children are shown: (a) 12 year-old boy with a skeletally immature distal acromion (star: completely cartilaginous), (b) 15 year-old girl with a maturing distal acromion (arrows: multiple unfused ossification centers), and (c) 16 year-old boy with a skeletally mature distal acromion (square: completely ossified with closed growth plates).

allows the transfer of kinetic forces from the pitcher's body to the ball [25,26]. Within the shoulder, the humeral head experiences an anterior translational force from the extreme external rotation, which is restrained by both static and dynamic stabilizers [12,27]. This transition peaks between the late cocking and the acceleration phases, where the subscapularis, pectoralis major, and latissimus dorsi muscles begin to internally rotate the maximally externally rotated humerus. This sudden change from external to internal rotation leads to high angular velocities (upwards of 7000°/sec in some competitive throwers) and requires considerable force, and thus creates adaptive changes as well as ample opportunity for shoulder injury [24,25,27].

Following the acceleration phase, the deceleration phase acts to resolve most of the extreme force and torsion created moments. The teres minor, infraspinatus, and posterior deltoid all work together to dissipate the acceleration forces, while the posterior capsule and rotator cuff contract to prevent anterior translation of the humeral head [23,28]. While injuries can occur during any of the six phases when improper throwing techniques are practiced or excessive training behaviors are followed, the tremendous forces generated during the cocking and acceleration phases make these particularly liable to induce shoulder injuries in the overhead-throwing athlete, regardless of age [25,29,30].

5. Imaging considerations

Conventional radiography is the least expensive and readily available initial imaging modality routinely used to evaluate for the presence of osseous pathology, including fractures and findings to suggest Little League Shoulder. Three views of the shoulder are often acquired but the exact views differ slightly depending on the institution's preference and patient's ability to cooperate. For patients with suspected Little League Shoulder, an external rotation view is recommended as it best profiles the anterolateral aspect of the physis, which is the most common site of involvement [25].

Computer tomography (CT) is often reserved for pre-operative surgical planning. The abundance of cartilage in children, the limited ability to detect bone marrow edema, and potential harmful effects of ionizing radiation on growing tissue have limited the routine use of CT. CT arthrography, however, is accurate in detecting certain non-osseous injuries like labral tears and can be considered as an alternative whenever MR is not possible or contraindicated [31]. Such instances can include the presence of certain implants like some pacemakers or reduced accessibility to MR scanners in other geographic locations.

Magnetic resonance (MR) imaging is the preferred imaging modality for the evaluation of shoulder pain and suspected internal joint derangement in youth athletes. Continued technologic improvements in MR imaging allow faster acquisition times and higher spatial resolution, providing exquisite anatomic detail on cartilage, soft tissues and bone. Higher magnetic field strengths of 1.5 and 3.0-Tesla are preferred over lower Tesla scanners as they provides higher signal-to-noise ratios that permit higher resolution scanning, which can improve the detection of often subtle pathology, such as focal chondral lesions [32,33]. Patients are imaged supine with the arm placed in neutral or rotation (with the biceps tendon at 12:00 on the axial localizer), using a dedicated multichannel shoulder coil or flexible phased-array coil.

The exact MR imaging protocol varies among institutions and can be tailored based on the suspected pathology. Routine non-contrast MR of the shoulder typically relies on a combination of intermediate-weighted and fluid-sensitive sequences that are acquired in straight axial, oblique coronal, and oblique sagittal (with respect to the glenoid) imaging planes. Intermediate-weighted sequences are the main workhorse imaging sequences, which can be acquired with and without fat-suppression. While non-fat suppressed images provide more robust signal, thus permitting higher spatial resolution, fat-suppressed images provide more tissue contrast by highlighting sites of increased fluid, whether physiologic (e.g., cartilage and joint fluid) or pathologic (e.g., bone marrow edema, tendinopathy). Slice thickness can range from 1 to 3.5 mm, and matrix size from 256 × 256 to 512 × 512. For non-fat suppressed sequences, it is recommended to oversample in the frequency direction (at a matrix size of 512). However, in contrast to adults who have relatively larger shoulders and are often more compliant with instructions, at our institution we routinely image our adolescent shoulders using a slice thickness of 3 mm with no gap and a matrix size around 512 × 320 to provide a good balance between clinically-feasible acquisition time, adequate spatial resolution and acceptable signal-to-noise ratio.

Direct MR arthrogram involves the intraarticular injection of gadolinium chelates and the reliance on predominately T1-weighted sequences. The injected contrast material distends the joint and can extend into (or outline) sites of pathology within and in continuity with the joint space. The sensitivity and specificity for the detection of partial thickness articular surface supraspinatus tears and anterior labral tears range between 85% and 100% [34,35]. However, the routine use MR arthrograms is institution-, expertise-, and resource-dependent with some authors arguing that high diagnostic accuracy can be achieved with high-resolution non-contrast MR examinations, while avoiding the risk and discomfort associated with injection [36].

Several studies have recommended the use of an additional sequence with the patient's arm abducted and externally rotated (i.e., the so-called “ABER view”) that can improve the sensitivity and specificity for the detection of low-grade and non-displaced anterior labral tear and articular-sided partial-thickness rotator cuff tears [37,38]. The ABER view approximates the late cocking-early acceleration phase of a throw and can offer the visualization of the posterior portion of the supraspinatus tendon insertion onto the greater tubercle and anterior-inferior glenoid labrum. Its added diagnostic value has not been thoroughly assessed in children where patient re-positioning can be cumbersome and images are often degraded by motion. Both MR arthrogram and ABER can help distinguish between stable and unstable labral tears [39].

6. Pathologies and treatments

The unique anatomy of the glenohumeral joint predisposes it to a spectrum of injuries, ranging from acute insult to chronic overuse. In baseball players, overuse injury from repetitive overhead activity predominates. Injuries and anatomic adaptions acquired during childhood can produce long-term chronic shoulder pain and instability that can persist into adulthood. Although the precise injury patterns and adaptive changes within the shoulder are best studied in adults, recent studies show that early signs of these changes can be observed in children [40,41].

In children, the pattern of injury is dependent on the skeletal maturity. Younger children with open physes are most prone to sustain physeal-related injuries [4], such as Little League Shoulder. Older adolescents with closed physes are more prone to sustain injuries to the soft tissue structures, and their injury patterns are similar to those observed in adult athletes [4]. The following section will review the spectrum of common injuries that can occur in an adolescent athlete, which includes acute physeal injuries, Little League Shoulder from subacute repetitive overuse, osteochondral injuries, labral tears, capsular remodeling and rotator cuff injuries.

6.1. Growth plate injuries

The fragile, predominately avascular cartilaginous columns of the physis are two to five times weaker than the surrounding soft-tissue structures [42–44], making it the “weak link” and prone to injury. Physes are involved in 18% of all pediatric fractures with an incidence that peaks between 13 and 17 years and corresponds to the adolescent growth spurt [43–45] (Fig. 4). This overlap in time is believed to be the result of a combination of factors, including temporary bone fragility

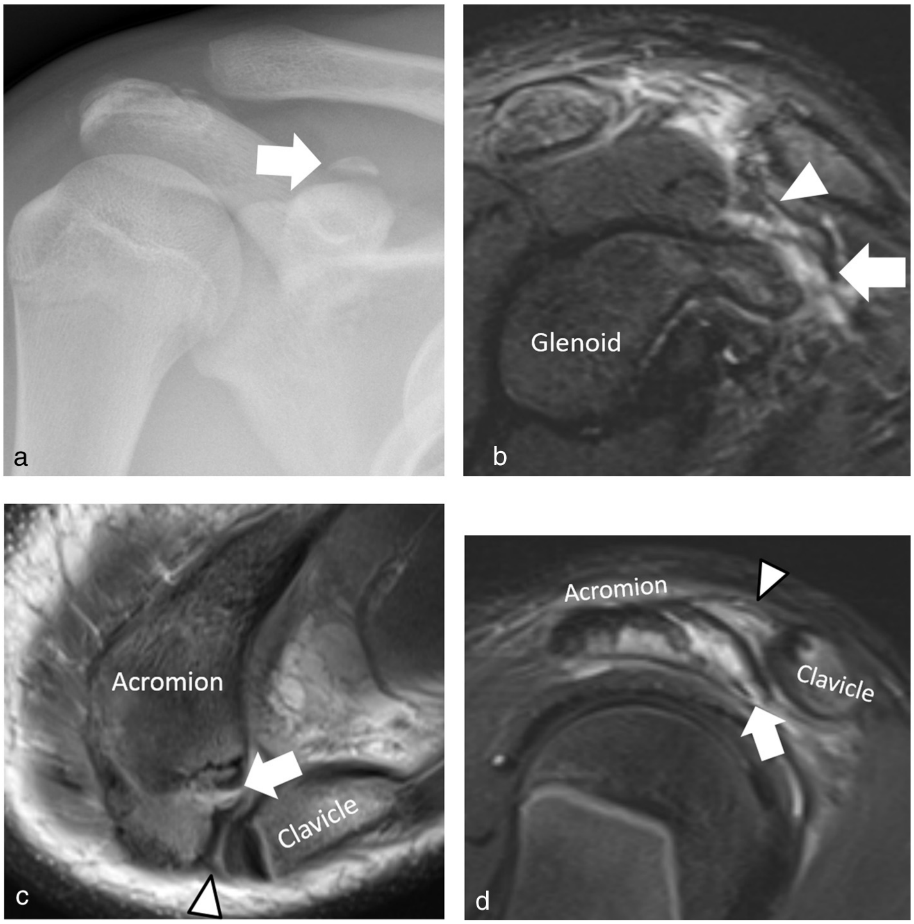

Fig. 4. Avulsion fractures. AP radiography (a) and oblique coronal fluid-sensitive MR image (b) from a 14 year-old boy demonstrate a mildly-displaced coracoid avulsion fracture fragment (arrows). Note the intact coraco-clavicular ligament (arrowhead) is attached to the fractured fragment. Axial intermediate-weighted (c) and oblique coronal fluid-sensitive (d) MR images from a different 14 year-old boy show a fracture (arrows) through distal acromion physis. Note the adjacent acromioclavicular joint capsule (arrowheads) is maintained.

where longitudinal growth outpaces bone mineralization [46], the ability to generate greater force, and the involution of the perichondral sleeve that destabilizes the peripheral margin of the primary physis and the osteochondral interface between the growth plate and the ossified epiphysis and metaphysis [47].

Injury to the physis can be acute or the result of subacute repetitive overuse. Acute injuries are often classified according to the Salter-Harris fracture system using radiography [48]. While the Salter-Harris classification is useful for fracture characterization, prognosis is more dependent on location and physeal contour [43]. For example, fractures through the uniplanar and relatively smooth physis of the distal radius are common but rarely cause delayed complications, while fractures through the multiplanar undulating physis of the proximal humerus can produce growth arrest through premature physeal closure [45,49]. Nondisplaced to minimally displaced acute physeal injuries are often treated conservatively, consisting of immobilization and activity restriction (Fig. 4). However, if the fracture is displaced or unstable, surgical reduction (closed or open) is often required to restore anatomic alignment. Additional reasons for surgical intervention are instances of soft-tissue interposition that resist satisfactory closed reduction in the acute setting, and the presence of transphyseal bridge formation that develops at the site of prior injury in the chronic setting [43,50].

6.2. Little League Shoulder

First described in 1953, Little League Shoulder has been given multiple names, such as proximal humeral epiphysiolysis and osteochondrosis [51,52]. During the late cocking phase of the pitch, a high level external rotational torque is placed on the proximal humeral physis as the distal humerus is held in maximal external rotation and the internal rotators act on the proximal humerus [53]. This repetitive micro-traumatic sheer, torque, or traction on the proximal humeral physis is postulated to damage the most susceptible vertically oriented collagen fibers within the hypertrophic zone of the physis [12,52,54]. Suboptimal throwing technique, excessive throwing volume, high throwing speeds, and playing breaking pitches (e.g., curveballs) can all predispose the proximal humeral physis to injury. One study demonstrated that athletes who can generate throw speeds or distances that are more than three standard deviations above their peers are at a higher risk for the development of Little League Shoulder [55]. Therefore, to prevent the growing epidemic of overuse injuries in youth baseball players, both Little League Baseball and the American Sports Medicine Institute have recently published age-specific practice and pitch count guidelines [56].

Children with Little League Shoulder present with pain during overhead activities that worsen during throws [4,52]. Weakness in the shoulder and pain in the elbow can also occur. On physical examination, typical findings are tenderness over the proximal humerus and, in some patients, glenohumeral internal rotation deficit (GIRD) can be detected [52]. Imaging evaluation starts with radiography, which shows physeal widening, diffusely or only involving the lateral physis. There is often subtle juxta-physeal metaphyseal sclerosis (reflecting chronicity), demineralization/lucency at the metaphyseal boarder (reflecting ongoing insult with absent or incomplete zone of provisional calcification), and metaphyseal calcification (reflecting subacute healing response) in some rare cases [40,43,52,57]. External rotation views are most helpful, as anterolateral physeal widening is most commonly involved. Since physiologic physeal closure starts centrally and progresses in a centripetal fashion toward the periphery, slight delay in the closure of the otherwise normal lateral physis should not be mistaken as pathology [25]. In equivocal cases, radiographs of the contralateral asymptomatic shoulder can be obtained for comparison.

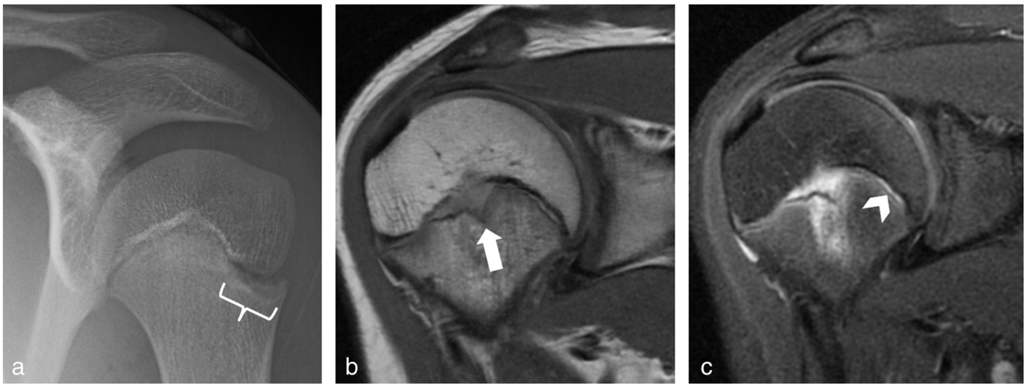

Fig. 5. Little league shoulder. AP radiography (a) from a 12 year-old boy pitcher demonstrates asymmetric widening of the lateral proximal humeral physis (arrowhead). Oblique coronal intermediate-weighted (b) and fluid-sensitive (c) MR images from a 13 year-old boy pitcher demonstrate asymmetric widening of the primary humeral physis centrally (arrow) with relatively normal width of the physis peripherally (chevron).

For children with diffuse or atypical shoulder pain, or with clinical concerns for co-existing soft tissue injuries, MR imaging is the preferred cross-sectional modality of choice. MR imaging not only allows the detection of physeal widening and edema but is also highly sensitive for the identification of juxta-physeal bone marrow edema, which may be accompanied by periosteal elevation and subperiosteal edema [58]. Physeal widening is best delineated on non-fat saturated intermediate-weighted and T1-weighted images, while edema pattern is best appreciated on fluid-sensitive images [58,59] (Fig. 5). A recent study performed on asymptomatic Little League Baseball players found abnormalities in 100% of these players, which brought to light the critical importance of clinical correlation in the imaging diagnosis of truly symptomatic “pathology” [41]. Treatment for Little League Shoulder is conservative, consisting of two to three months of activity restriction and physical therapy [22]. Nonsteroidal anti-inflammatory medication may be used in conjunction, and return to sport should be a gradual progression. In some practices and for children with more severe cases, follow-up assessment is performed until skeletal maturity to ensure normalization of the proximal humeral physis, and to detect signs of growth disturbance.

6.3. Osteochondral injuries

Osteochondral injuries in the shoulder are uncommon [60] but have been observed in youth overhead athletes and on both sides of the joint (Fig. 6). It is theorized that repetitive shearing and compressive microtrauma that result from posterior humeral head translation relative to the glenoid during throwing can injure the secondary growth plate [25], producing osteochondral damage and occasionally fragmentation [61–64]. Additional factors postulated to contribute to the development of osteochondral injuries are joint instability [63,65], a thickened anterior band of the inferior glenohumeral ligament which pushes the humeral head posteriorly [66], and a tight posterior capsule causing posterior translation of the humeral head in the late cocking phase of pitching [63,67]. In many cases, osteochondral findings are incidental but if intraarticular fragments are present, these fragments can produce pain and limit range of motion [63].

Due to the small and often subtle osseous changes, MR imaging is preferred over radiography. On MR imaging the most frequent imaging findings are subchondral cystic lesions, which are more common over the glenoid fossa but can be found over the humeral head [68] (Fig. 7). An osteochondral defect requires a thorough search for any displaced, possibly fragmented, intra-articular bodies, which can be lodged within the tendon sheath of the long head of the biceps brachii, as it communicates with the joint. A combination of intermediate-weighted and fluid-sensitive images are utilized to scrutinize the integrity of the overlying articular cartilage [68]. As these injuries are often focal and small in size, high-resolution images with less than 10% (or no) interslice gap are preferred to reduce partial volume averaging. Although some authors prefer intra-articular contrast (e.g., MR arthrogram) [63,69,70], it is not often not necessary to detect and characterize an osteochondral injury [36], and indeed, intra-articular contrast may obscure some loose bodies.

Treatment for osteochondral injuries of the glenohumeral joint in adolescents have not been well studied compared to those that are found in other joints (e.g., the knee joint), with limited published data and even fewer studies with long-term follow-up data [60]. Both conservative and surgical treatments have been described. Conservative treatment consists of activity restriction and physical therapy, while surgical treatment, reserved for larger and unstable lesions, can consist of debridement, loose body removal, fixation, microfracture, cell-based cartilage repair, and both allograft and autograft transfers [60,71,72].

6.4. Labral tears

In the overhead athlete, injury to the superior labrum is common, with the most common lesion being the SLAP (superior labrum anteroposterior) tear [40,41,69,73] (Fig. 8). The mechanism relates to the

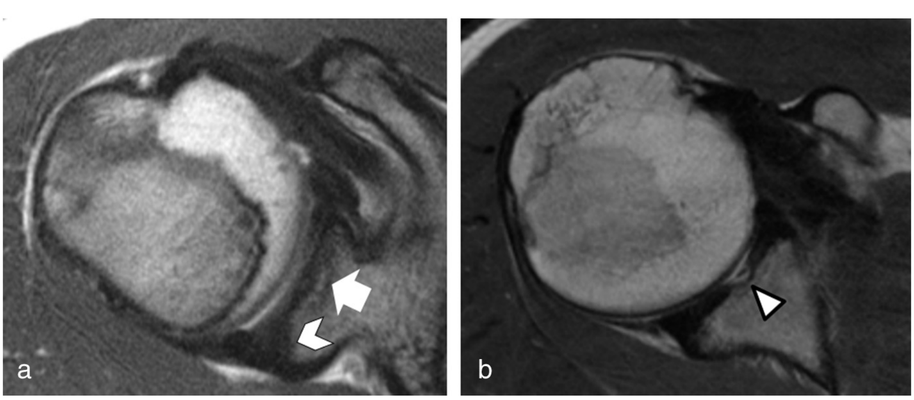

Fig. 6. Osteochondral lesion of the glenoid. Axial intermediate-weighted MR image from a 16 year-old boy pitcher (a) demonstrates abnormal cortical irregularity and subcortical low signal centered at the central glenoid (arrow), suggesting the early formation of an osteochondritis dissecans (OCD). Note the blunting of the posterior glenoid rim (chevron), which reflects biomechanics induced regional remodeling from repetitive overhead activity. OCD should be distinguished from normal bare spot of the central glenoid which contains smooth margins (b: arrowhead) as shown on this axial intermediate-weighted MR image.

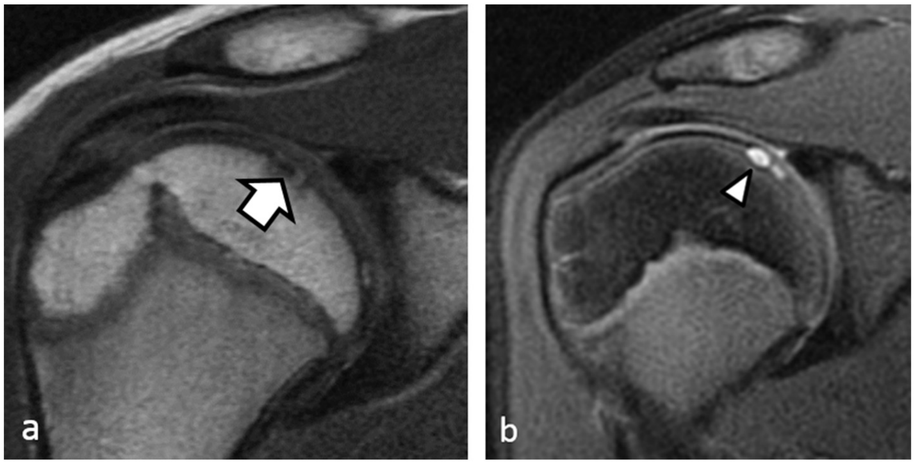

Fig. 7. Osteochondral separation. Oblique coronal intermediate-weighted MR image (a) from a 8 year-old boy pitcher shows focal osteochondral injury of the humeral head (arrow), which appeared more cystic with local subchondral remodeling 7 months later (arrowheads) on fluid-sensitive weighted MR image (b).

biomechanics of the throw, where posteriorly directed strain and twisting of the labral-bicipital anchor in the late cocking phase (with the arm held at maximum external rotation) induces a peel-back tear of the superior labrum from the glenoid [25,74]. Multiple classification systems for SLAP tears have been proposed and Types I to IV are most common. Type I SLAP tears are those with fraying of the labrum and biceps, where the biceps tendon anchor is intact. Type II is labral fraying with detachment of the biceps anchor. Type III is a bucket handle tear, where the biceps separates but leaves an intact biceps tendon anchor. Type IV depicts a bucket handle tear with separation of the biceps anchor [75]. The adaptive changes associated with internal impingement and glenohumeral internal rotation deficit (GIRD) can further alter the biomechanics and predispose the labrum to injury [76]; internal impingement and GIRD are described in detail within the following Capsular remodeling section.

Although MR imaging is highly specific for the detection of labral tears, its sensitivity can be variable [36,77,78], leading some authors to advocate for the use of MR arthrogram and the addition of ABER positioned imaging, both of which are described in more detail within the Imaging considerations section [77,79]. Occasionally, paralabral cysts containing mucinous fluid can be associated with labral tears. When present, these cysts are often more conspicuous than the underlying tear, requiring the underlying labrum to be carefully evaluated. When describing labral tears, the presence of labral detachment and tear extension into the long head of the biceps brachii tendon are important reportable details that impact treatment decision and pre-operative planning [25].

While conservative management is typically attempted initially for chronic labral tears, tears that are unresponsive to conservative management usually require surgical fixation. Conservative treatment consists of activity restriction focusing on reducing inflammation, and physical therapy aimed at improving glenohumeral movement and strength [80]. Exercises can include sleeper stretches, cross-body adduction stretches, peri-scapular strengthening, rotator cuff strengthening, and core strengthening for improving the entire kinetic chain of throwing [81]. Both nonsteroidal anti-inflammatory medication and cortisone injections can also be used in supplement to manage inflammation, which is more routinely used in adults and less commonly used in children. The precise surgical approach depends on the tear and may involve a combination of debridement (for degenerative labrum) and stabilization (for displaced labrum and biceps anchor). For example, treatment of SLAP tears involves debridement for Type I, resection for Type III, and repair for Type II and Type IV. Regardless of the exact treatment selection, the presence of symptomatic labral tears in overhead athletes have consistently shown to negatively impact their return to sport in comparison to non-overhead athletes [81–85].

6.5. Capsular remodeling

Repetitive, non-physiologic forces placed on the glenohumeral joint capsule during overhead throwing can produce capsular remodeling and adaptions, which include GIRD and Bennett lesions. Although better recognized in adult athletes, these findings can be found in children as well [40].

Glenohumeral Internal Rotation Deficit (GIRD) is diagnosed clinically, and is better studied in adults. It is characterized by at least a 25%

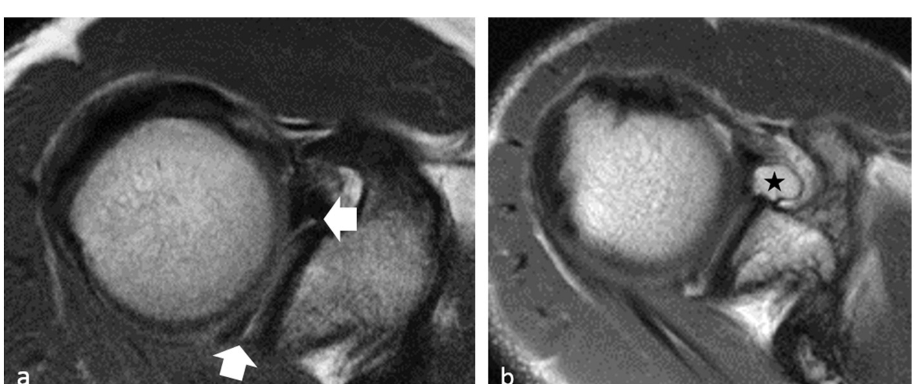

Fig. 8. Labral tear. Axial intermediate-weighted MR images from a 15 year-old boy baseball player (a) demonstrates a superior labral tear (arrows) and from a 16 year-old boy baseball player (b) demonstrates a paralabral cyst (star).

loss in internal rotation involving the throwing arm when compared to the asymptomatic non-throwing side [25,29]. The pathophysiology is postulated to involve microtrauma to the posterior capsule from repetitive overhead activity that subsequently scars and produces contracture of the posterior capsule. The resulting shift of the humerus posterosuperiorly decreases the contact point of the anteroinferior capsule with the humerus, and produces a greater arc of external rotation [86]. This decrease in internal rotation and increase in external rotation can predispose posterosuperior soft tissue structures to injury and further aggregate the torsion failure [87]. During development, humeral retro-torsion and GIRD normally increases with age. Thus, in youth baseball players, the exact impact of GIRD is less clear, and measurable differences in internal rotation are difficult to elicit. On MR imaging, the presence of posterior capsular thickening is best demonstrated on axial, fluid-sensitive images [88]. The lack of clear evidence linking GIRD with increased risk for injury in adolescence has led some authors to propose the use of conservative management in these patients [87].

A Bennett lesion describes a focus of calcification or ossification that is located at the attachment site of the joint capsule onto the posterior glenoid [89] (Fig. 9). It has been postulated that these lesions are the result of subclinical injury from excessive traction placed on the posterior capsule during repetitive throws [90]. Although Bennett lesions were first described in adult baseball players [89,91], they can occur in youth athletes [40,92]. Bennett lesions can cause pain and weakness, hindering the generation of high velocity pitches [91,93]. Physical examination findings can include slight tenderness over the posterior glenoid and discomfort when the arm is placed in extreme abduction and external rotation [91]. On MR imaging, findings can range from subtle minimal posterior glenoid marginal mineralization to bulky ossification at the posterior capsular attachment. The larger ossified lesions may be visible on radiography performed using the axillary view or the Bennett's view (obtained by angling the X-ray beam tube 5° cephalad and placing the arm in 45° abduction) [94–97]. Treatment of Bennett lesions has not been well-studied in either adults or in children. As these lesions are often asymptomatic or minimally symptomatic, conservative management is generally preferred, which consists of activity restriction, physical therapy, and nonsteroidal anti-inflammatory medication. For symptomatic and bulky lesions, studies have found surgical debridement using either open or arthroscopic techniques to yield favorable results [25,89,93].

6.6. Rotator cuff injuries

Rotator cuff muscles work in concert to help stabilize the glenohumeral joint during the throwing motion and are therefore exposed to repetitive high-energy forces and susceptible to overuse injuries, including cuff tendinosis and tears. Tears of the rotator cuff from repetitive overuse are rare in children but articular-sided partial thickness tears located at the junction between supraspinatus and infraspinatus tendons should raise suspicion for internal impingement [69,98–102]. Cuff tendinopathy and internal impingement will be discussed in the following section.

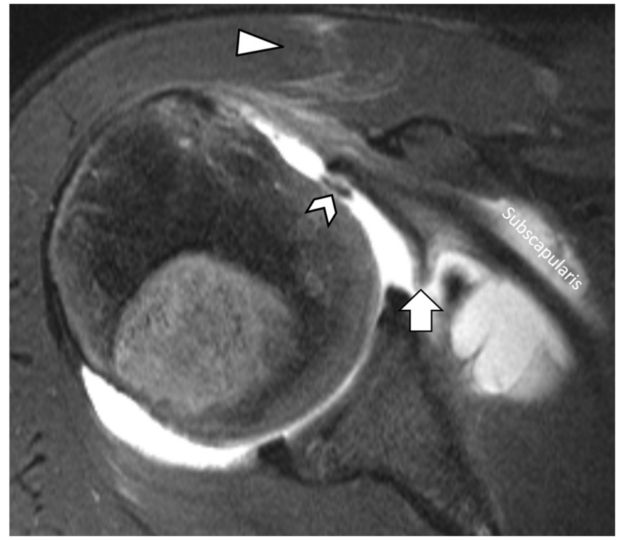

Fig. 10. Humeral avulsion fracture at the attachment of the subscapularis. Axial intermediate-weighted fat-suppressed MR arthrogram image from a 13 year-old boy following collision injury with another player shows a crescentic band of low signal that represents a thin avulsed fragment (arrow), which is displaced medially and remains attached to the intact subscapularis tendon. Note the medially dislocated long-head of the biceps tendon (chevron), which is interposed between the avulsed fragment and the humeral head. Minimal linear edema (arrowhead) within the anterior fibers of the deltoid muscle is due the local anesthetic used during the injection for the arthrogram.

Cuff tendinopathy can result from repetitive overhead throwing and improper throwing technique. In the absence of acute injury, complete cuff tears (or avulsion fractures at the cuff tendon insertion site) are uncommon in children (Fig. 10). Athletes may report chronic discomfort, pain, or throwing impairment with decreased velocity or early fatigue [99,102]. Physical examination may reveal tenderness or pain with decreased muscle strength of the rotator cuff compared to the asymptomatic side [102]. MR imaging is preferred for patients with persistent and atypical symptoms and provides excellent soft tissue detail. Tendinosis (without tendon tear) preferentially involves the supraspinatus and the infraspinatus [40], and produces a thickened, high-signal tendon with decreased definition of its normally fibular internal pattern (Fig. 11). On imaging, tears are suspected when there is increased signal within the tendon that is isointense to joint fluid on fluid-sensitive sequences [25,88]. Focal partial-thickness articular-sided and delaminating tears can be subtle and easily overlooked on MR imaging due to volume averaging, thicker image slices, larger interslice gap, and suboptimal images from patient motion. Thus, some authors advocate for the use of fluid-sensitive sequences [103], the use of ABER positioning [104–106], and the use of external rotation of the humerus to allow more in-plane visualization of the supraspinatus tendon [107].

Internal impingement describes the impingement of the rotator cuff

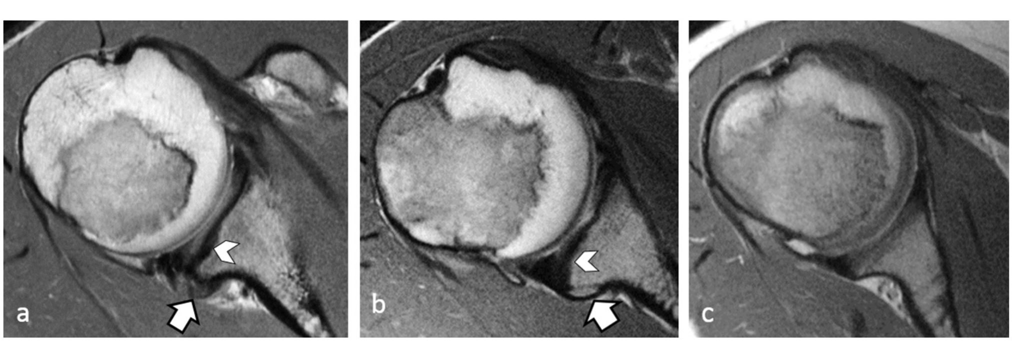

Fig. 9. Bennett lesions. Axial intermediate-weighted MR images are obtained from 2 different patients: (a) 12 year-old boy pitcher with linear low signal (arrow) at the attachment of the posterior joint capsule and (b) 13 year-old boy pitcher with bony proliferation along the posterior margin of the glenoid (arrow). Note the osseous remodeling of the posterior glenoid rim (chevrons). (c) Normal morphology of the posterior glenoid from a 12 year-old boy is provided for comparison.

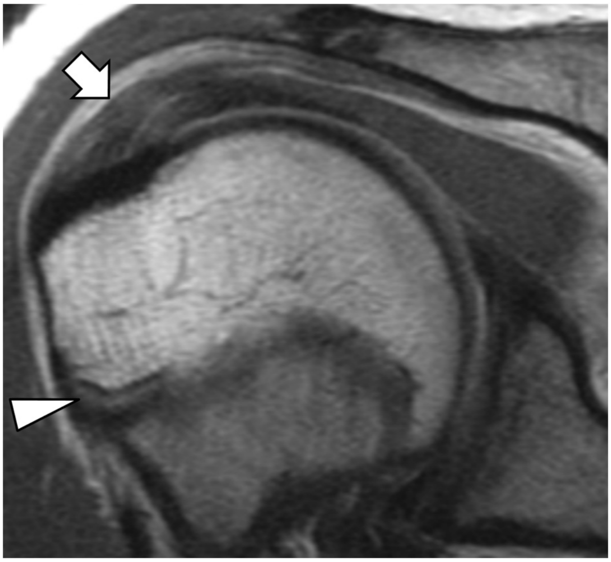

Fig. 11. Cuff tendinosis. Oblique coronal intermediate-weighted MR image from a 12 year-old boy pitcher demonstrates thickening and indistinctness of the normal fibular internal organization of the supraspinatus tendon, reflecting tendinosis (arrow), but is not torn. Note the partial closure of the primary proximal humeral physis, which remains open laterally (arrowhead).

tendon between the greater tuberosity and the posterosuperior glenoid and labrum [69,108,109] during the late cocking phase of a throw, which produces chronic pain and leads to focal remodeling of the posterior glenoid rim [40,69,110]. On physical examination, pain may be elicited within the posterosuperior shoulder when the arm is externally rotated and abducted to 90°–150° [69]. On MR imaging, findings that suggest internal impingement include: articular-sided low-grade partial-thickness tears of the rotator cuff centered at the junction between the supraspinatus and infraspinatus, cystic changes in the posterosuperior humeral head, remodeling of the posterosuperior glenoid above the equator and an abnormal posterosuperior labrum [73].

Conservative management is the primary initial treatment method for most low-grade rotator cuff injuries as they are often asymptomatic or minimally symptomatic. Surgical intervention has not consistently produced favorable results, particularly for competitive overhead athletes with lower rates of return to baseline level of play [102,111–113]. Conservative management can include nonsteroidal anti-inflammatory medication, physical therapy, and corticosteroid injections in some cases [113]. Failed conservative management may progress to surgery. The ultimate decision depends on a variety of factors including age, gender, symptom duration, present functionality, comorbidities, and severity of tear [102]. Surgical options include debridement (for small tears), repair (for large tears) and acromioplasty [25,101,113].

7. Conclusion

The adolescent overhead throwing athlete presents with unique shoulder pathology that requires a basic understanding of the normal musculoskeletal developmental anatomy, biomechanics of overhead throwing, and imaging findings to arrive at the appropriate course of treatment. The tremendous forces created in the process of overhead throwing can lead to osseous and soft-tissue adaptive changes that predispose adolescents to injury. The exact pattern of injury often depends on the skeletal maturity. Prompt diagnosis can help prevent chronic pain, shoulder instability and long-term morbidity.

References

[1] Sports NCoY. Report on trends and participation in organized youth sports. NCYS; 2008.

[2] Conte S, Requa RK, Garrick JG. Disability days in major league baseball. Am J Sports Med 2001;29(4):431–6.

[3] Robinson TW, Corlette J, Collins CL, Comstock RD. Shoulder injuries among US high school athletes, 2005/2006–2011/2012. Pediatrics 2014;133(2):272–9. [peds. 2013-279].

[4] Leonard J, Hutchinson MR. Shoulder injuries in skeletally immature throwers: review and current thoughts. Br J Sports Med 2010;44(5):306–10.

[5] O'Brien SJ, Neves MC, Arnoczky SP, Rozbruck SR, Dicarlo EF, Warren RF, et al. The anatomy and histology of the inferior glenohumeral ligament complex of the shoulder. Am J Sports Med 1990;18(5):449–56.

[6] Long F, Ornitz DM. Development of the endochondral skeleton. Cold Spring Harb Perspect Biol 2013;5(1):a008334.

[7] Zember JS, Rosenberg ZS, Kwong S, Kothary SP, Bedoya MA. Normal skeletal maturation and imaging pitfalls in the pediatric shoulder. Radiographics 2015;35(4):1108–22.

[8] Matsen F. Rockwood CA, Matsen FA, Wirth MA, Lippit SB, editors. Glenohumeral instability. The shoulder. fourt ed.Elsevier; 2009.

[9] Flecker H. Roentgenographic observations of the times of appearance of epiphyses and their fusion with the diaphyses. J Anat 1932;67:118–64.3. Pt 1.

[10] Kwong S, Kothary S, Poncinelli LL. Skeletal development of the proximal humerus in the pediatric population: MRI features. AJR Am J Roentgenol 2014;202(2):418–25.

[11] Gardner E. The embryology of the clavicle. Clin Orthop Relat Res 1968;58:9–16.

[12] Moyer JE, Brey JM. Shoulder injuries in pediatric athletes. Orthop Clin North Am 2016;47(4):749–62.

[13] Kocher MS, Waters PM, Micheli LJ. Upper extremity injuries in the paediatric athlete. Sports Med 2000;30(2):117–35.

[14] Ogden JA, Phillips SB. Radiology of postnatal skeletal development. VII. The scapula. Skeletal Radiol 1983;9(3):157–69.

[15] Boyle S, Haag M, Limb D, Lafosse L. Shoulder arthroscopy, anatomy and variants - part 2. Orthopaedics and Trauma 2009;23(5):365–76.

[16] Munshi M, Davidson JM. Unilateral glenoid hypoplasia: unusual findings on MR arthrography. AJR Am J Roentgenol 2000;175(3):646–8.

[17] Owen R. Bilateral glenoid hypoplasia; report of five cases. J Bone Joint Surg Br 1953;35-b(2):262–7.

[18] Kothary S, Rosenberg ZS, Poncinelli LL, Kwong S. Skeletal development of the glenoid and glenoid-coracoid interface in the pediatric population: MRI features. Skeletal Radiol 2014;43(9):1281–8.

[19] Monk AP, Berry E, Limb D, Soames RW. Laser morphometric analysis of the glenoid fossa of the scapula. Clin Anat 2001;14(5):320–3.

[20] Roedl JB, Morrison WB, Ciccotti MG, Zoga AC. Acromial apophysiolysis: superior shoulder pain and acromial nonfusion in the young throwing athlete. Radiology 2015;274(1):201–9.

[21] Jones KJ, Kahlenberg CA, Dodson CC, Nam D, Williams RJ, Altchek DW. Arthroscopic capsular plication for microtraumatic anterior shoulder instability in overhead athletes. Am J Sports Med 2012;40(9):2009–14.

[22] Chen FS, Diaz VA, Loebenberg M, Rosen JE. Shoulder and elbow injuries in the skeletally immature athlete. J Am Acad Orthop Surg 2005;13(3):172–85.

[23] Weber AE, Kontaxis A, O'Brien SJ, Bedi A. The biomechanics of throwing: simplified and cogent. Sports Med Arthrosc Rev 2014;22(2):72–9.

[24] Dillman CJ, Fleisig GS, Andrews JR. Biomechanics of pitching with emphasis upon shoulder kinematics. J Orthop Sports Phys Ther 1993;18(2):402–8.

[25] Lin DJ, Wong TT, Kazam JK. Shoulder injuries in the overhead-throwing athlete: epidemiology, mechanisms of injury, and imaging findings. Radiology 2018;286(2):370–87.

[26] Lintner D, Noonan TJ, Kibler WB. Injury patterns and biomechanics of the athlete's shoulder. Clin Sports Med 2008;27(4):527–51.

[27] Zaremski JL, Krabak BJ. Shoulder injuries in the skeletally immature baseball pitcher and recommendations for the prevention of injury. PM R 2012;4(7):509–16.

[28] Seroyer ST, Nho SJ, Bach BR, Bush-Joseph CA, Nicholson GP, Romeo AA. Shoulder pain in the overhead throwing athlete. Sports Health 2009;1(2):108–20.

[29] Braun S, Kokmeyer D, Millett PJ. Shoulder injuries in the throwing athlete. J Bone Joint Surg Am 2009;91(4):966–78.

[30] Kuhn JE, Lindholm SR, Huston LJ, Soslowsky LJ, Blasier RB. Failure of the biceps superior labral complex: a cadaveric biomechanical investigation comparing the late cocking and early deceleration positions of throwing. Arthroscopy 2003;19(4):373–9.

[31] Nishii T, Tanaka H, Sugano N, Miki H, Takao M, Yoshikawa H. Disorders of acetabular labrum and articular cartilage in hip dysplasia: evaluation using isotropic high-resolutional CT arthrography with sequential radial reformation. Osteoarthr Cartil 2007;15(3):251–7.

[32] Mosher TJ. Musculoskeletal imaging at 3T: current techniques and future applications. Magn Reson Imaging Clin N Am 2006;14(1):63–76.

[33] Kuo R, Panchal M, Tanenbaum L, Crues JV, 3rd. 3.0 Tesla imaging of the musculoskeletal system. Journal of magnetic resonance imaging : JMRI 2007;25(2):245–61.

[34] Magee T. 3-T MRI of the shoulder: is MR arthrography necessary? AJR Am J Roentgenol 2009;192(1):86–92.

[35] de Jesus JO, Parker L, Frangos AJ, Nazarian LN. Accuracy of MRI, MR arthrography, and ultrasound in the diagnosis of rotator cuff tears: a meta-analysis. AJR Am J Roentgenol 2009;192(6):1701–7.

[36] Connell DA, Potter HG, Wickiewicz TL, Altchek DW, Warren RF. Noncontrast magnetic resonance imaging of superior labral lesions. 102 cases confirmed at arthroscopic surgery. Am J Sports Med 1999;27(2):208–13.

[37] Cochet H, Couderc S, Pele E, Amoretti N, Moreau-Durieux MH, Hauger O. Rotator cuff tears: should abduction and external rotation (ABER) positioning be performed before image acquisition? A CT arthrography study. Eur Radiol 2010;20(5):1234–41.
[38] Jung JY, Jee WH, Chun HJ, Ahn MI, Kim YS. Magnetic resonance arthrography including ABER view in diagnosing partial-thickness tears of the rotator cuff: accuracy, and inter- and intra-observer agreements. Acta Radiol 2010;51(2):194–201.
[39] Magee T. Usefulness of unenhanced MRI and MR arthrography of the shoulder in detection of unstable labral tears. AJR Am J Roentgenol 2015;205(5):1056–60.
[40] Nguyen JC, Lin B, Potter HG. Maturation-dependent findings in the shoulders of pediatric baseball players on magnetic resonance imaging. Skeletal Radiol 2019. https://doi.org/10.1007/s00256-018-3130-2. [Epub ahead of print].
[41] Pennock AT, Dwek J, Levy E, Stearns P, Manning J, Dennis MM, et al. Shoulder MRI abnormalities in asymptomatic little league baseball players. Orthop J Sports Med 2018;6(2):2325967118756825.
[42] Carter SR, Aldridge MJ, Fitzgerald R, Davies AM. Stress changes of the wrist in adolescent gymnasts. Br J Radiol 1988;61(722):109–12.
[43] Nguyen JC, Markhardt BK, Merrow AC, Dwek JR. Imaging of pediatric growth plate disturbances. Radiographics 2017;37(6):1791–812.
[44] Wu M, Fallon R, Heyworth BEM. Overuse injuries in the pediatric population. Sports Medicine & Arthroscopy Review 2016;24(4):150–8.
[45] Mizuta T, Benson WM, Foster BK, Paterson DC, Morris LL. Statistical analysis of the incidence of physeal injuries. J Pediatr Orthop 1987;7(5):518–23.
[46] Caine D, DiFiori J, Maffulli N. Physeal injuries in children's and youth sports: reasons for concern? Br J Sports Med 2006;40(9):749–60.
[47] Shapiro F. Epiphyseal growth plate fracture-separations: a pathophysiologic approach. Orthopedics 1982;5(6):720–36.
[48] Salter RB, Harris WR. Injuries involving the epiphyseal plate. JBJS 1963;45(3):587–622.
[49] Ecklund K, Jaramillo D. Patterns of premature physeal arrest: MR imaging of 111 children. AJR Am J Roentgenol 2002;178(4):967–72.
[50] Khoshhal KI, Kiefer GN. Physeal bridge resection. J Am Acad Orthop Surg 2005;13(1):47–58.
[51] Dotter WE. Little leaguer's shoulder: a fracture of the proximal epiphysial cartilage of the humerus due to baseball pitching. Guthrie Clin Bull 1953;23(1):68–72.
[52] Heyworth BE, Kramer DE, Martin DJ, Micheli LJ, Kocher MS, Bae DS. Trends in the presentation, management, and outcomes of little league shoulder. Am J Sports Med 2016;44(6):1431–8.
[53] Sabick MB, Kim YK, Torry MR, Keirns MA, Hawkins RJ. Biomechanics of the shoulder in youth baseball pitchers: implications for the development of proximal humeral epiphysiolysis and humeral retrotorsion. Am J Sports Med 2005;33(11):1716–22.
[54] Osbahr DC, Kim HJ, Dugas JR. Little league shoulder. Curr Opin Pediatr 2010;22(1):35–40.
[55] Axe M, Hurd W, Snyder-Mackler L. Data-based interval throwing programs for baseball players. Sports health 2009;1(2):145–53.
[56] Committee UBMSA. Youth baseball pitching injuries. http://mlb.mlb.com/usa_baseball/article.jsp?story=medsafety11;; 2018, Accessed date: 23 January 2019.
[57] Patel DR, Breisach S. Evaluation and management of shoulder pain in skeletally immature athletes. Transl Pediatr 2017;6(3):181–9.
[58] Hatem SF, Recht MP, Profitt B. MRI of Little Leaguer's shoulder. Skeletal Radiol 2006;35(2):103–6.
[59] Song JC, Lazarus ML, Song AP. MRI findings in Little Leaguer's shoulder. Skeletal Radiol 2006;35(2):107–9.
[60] Seidl AJ, Kraeutler MJ. Management of articular cartilage defects in the glenohumeral joint. J Am Acad Orthop Surg 2018;26(11):e230–7.
[61] Chu PJ, Shih JT, Hou YT, Hung ST, Chen JK, Lee HM. Osteochondritis dissecans of the glenoid: a rare injury secondary to repetitive microtrauma. J Trauma 2009;67(3):E62–4.
[62] Fujisawa M, Hara M, Ogimoto S, Araki G. Osteochondritis dissecans of the glenoid in two school baseball players. Katakansetsu 2009;37(3):1335–8.
[63] Koike Y, Komatsuda T, Sato K. Osteochondritis dissecans of the glenoid associated with the nontraumatic, painful throwing shoulder in a professional baseball player: a case report. J Shoulder Elbow Surg 2008;17(5):e9–12.
[64] Rossi F, Dragoni S. Osteochondrosis dissecans of the shoulder glenoid fossa diagnosed in four throwing athletes. J Sports Med Phys Fitness 2006;46(1):111–5.
[65] Nishinaka N, Tsutsui H, Mihara K, Hokari S. A case report: painful throwing shoulder accompanied by a peculiar glenoid osteochondral injury. Shoulder Joint 2002;26(3):419–22.
[66] Suzuki K, Hiroaki T, Kenichi M, Shigeru H, Tomoyoshi U, Katsuhiro O, et al. Painful throwing shoulder of a baseball player accompanied by an osteochondritis dissecans of the glenoid fossa: a case report. Shoulder Joint 2003;27:295–9.
[67] Grossman MG, Tibone JE, McGarry MH, Schneider DJ, Veneziani S, Lee TQ. A cadaveric model of the throwing shoulder: a possible etiology of superior labrum anterior-to-posterior lesions. J Bone Joint Surg Am 2005;87(4):824–31.
[68] Yu JS, Greenway G, Resnick D. Osteochondral defect of the glenoid fossa: cross-sectional imaging features. Radiology 1998;206(1):35–40.
[69] Walch G, Boileau P, Noel E, Donell ST. Impingement of the deep surface of the supraspinatus tendon on the posterosuperior glenoid rim: an arthroscopic study. J Shoulder Elbow Surg 1992;1(5):238–45.
[70] Tirman PF, Bost FW, Garvin GJ, Peterfy CG, Mall JC, Steinbach LS, et al. Posterosuperior glenoid impingement of the shoulder: findings at MR imaging and MR arthrography with arthroscopic correlation. Radiology 1994;193(2):431–6.
[71] Pham TT, Kany J, Lakhal W, Sales de Gauzy J, Accadbled F. Arthroscopic osteochondral autograft transfer for juvenile osteochondritis dissecans of the humeral head: a case report. JBJS Case Connect 2017;7(3):e63.
[72] Pydisetty RV, Prasad SS, Kaye JC. Osteochondritis dissecans of the humeral head in an amateur boxer. J Shoulder Elbow Surg 2002;11(6):630–2.
[73] Giaroli EL, Major NM, Higgins LD. MRI of internal impingement of the shoulder. AJR Am J Roentgenol 2005;185(4):925–9.
[74] Burkhart SS, Morgan CD. The peel-back mechanism: its role in producing and extending posterior type II SLAP lesions and its effect on SLAP repair rehabilitation. Arthroscopy 1998;14(6):637–40.
[75] Snyder SJ, Karzel RP, Del Pizzo W, Ferkel RD, Friedman MJ. SLAP lesions of the shoulder. Arthroscopy 1990;6(4):274–9.
[76] Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology part I: pathoanatomy and biomechanics. Arthroscopy 2003;19(4):404–20.
[77] Connolly KP, Schwartzberg RS, Reuss B, Crumbie D, Homan BM. Sensitivity and specificity of noncontrast magnetic resonance imaging reports in the diagnosis of type-II superior labral anterior-posterior lesions in the community setting. J Bone Joint Surg Am 2013;95(4):308–13.
[78] Gusmer PB, Potter HG, Schatz JA, Wickiewicz TL, Altchek DW, O'Brien SJ, et al. Labral injuries: accuracy of detection with unenhanced MR imaging of the shoulder. Radiology 1996;200(2):519–24.
[79] Dinauer PA, Flemming DJ, Murphy KP, Doukas WC. Diagnosis of superior labral lesions: comparison of noncontrast MRI with indirect MR arthrography in unexercised shoulders. Skeletal Radiol 2007;36(3):195–202.
[80] Trofa DP. C.S. A. The management of superior labrum anterior-posterior tears in the throwers' shoulder. Oper Tech Sports med 2016;24(3):181–8.
[81] Edwards SL, Lee JA, Bell JE, Packer JD, Ahmad CS, Levine WN, et al. Nonoperative treatment of superior labrum anterior posterior tears: improvements in pain, function, and quality of life. Am J Sports Med 2010;38(7):1456–61.
[82] Sayde WM, Cohen SB, Ciccotti MG, Dodson CC. Return to play after type II superior labral anterior-posterior lesion repairs in athletes: a systematic review. Clin Orthop Relat Res 2012;470(6):1595–600.
[83] Brockmeier SF, Voos JE, Williams RJ, Altchek DW, Cordasco FA, Allen AA, et al. Outcomes after arthroscopic repair of type-II SLAP lesions. J Bone Joint Surg Am 2009;91(7):1595–603.
[84] Galano GJ, Ahmad CS, Bigliani L, Levine W. Percutaneous SLAP lesion repair technique is an effective alternative to portal of Wilmington. Orthopedics 2010;33(11):803.
[85] Park JY, Chung SW, Jeon SH, Lee JG, Oh KS. Clinical and radiological outcomes of type 2 superior labral anterior posterior repairs in elite overhead athletes. Am J Sports Med 2013;41(6):1372–9.
[86] Sethi PM, Tibone JE, Lee TQ. Quantitative assessment of glenohumeral translation in baseball players: a comparison of pitchers versus nonpitching athletes. Am J Sports Med 2004;32(7):1711–5.
[87] Hibberd EE, Oyama S, Myers JB. Increase in humeral retrotorsion accounts for age-related increase in glenohumeral internal rotation deficit in youth and adolescent baseball players. Am J Sports Med 2014;42(4):851–8.
[88] Major N, Morrison WB, Coker D. The shoulder. Top Magn Reson Imaging 2015;24(2):83–92.
[89] Ferrari JD, Ferrari DA, Coumas J, Pappas AM. Posterior ossification of the shoulder: the Bennett lesion. Etiology, diagnosis, and treatment. Am J Sports Med 1994;22(2):171–5. [discussion 5-6].
[90] Miniaci A, Mascia AT, Salonen DC, Becker EJ. Magnetic resonance imaging of the shoulder in asymptomatic professional baseball pitchers. Am J Sports Med 2002;30(1):66–73.
[91] Lombardo SJ, Jobe FW, Kerlan RK, Carter VS, Shields CL, Jr. Posterior shoulder lesions in throwing athletes. Am J Sports Med 1977;5(3):106–10.
[92] Edmonds EW, Eisner EA, Kruk PG, Roocroft JH, Dwek JD. Diagnostic shortcomings of magnetic resonance arthrography to evaluate partial rotator cuff tears in adolescents. J Pediatr Orthop 2015;35(4):407–11.
[93] Yoneda M, Nakagawa S, Hayashida K, Fukushima S, Wakitani S. Arthroscopic removal of symptomatic Bennett lesions in the shoulders of baseball players: arthroscopic Bennett-plasty. Am J Sports Med 2002;30(5):728–36.
[94] BENNETT GE. Elbow and shoulder lesions of baseball players. Am J Surg 1959;98:484–92.
[95] Bennett GE. Shoulder and elbow lesions distinctive of baseball players. 1947. Clin Orthop Relat Res 2012;470(6):1531–3.
[96] Wright RW, Paletta GA. Prevalence of the Bennett lesion of the shoulder in major league pitchers. Am J Sports Med 2004;32(1):121–4.
[97] Bennett GE. Shoulder and elbow lesions of the professional baseball pitcher. JAMA 1941;117(7):510–4.
[98] Connor PM, Banks DM, Tyson AB, Coumas JS, D'Alessandro DF. Magnetic resonance imaging of the asymptomatic shoulder of overhead athletes: a 5-year follow-up study. Am J Sports Med 2003;31(5):724–7.
[99] Mazoue CG, Andrews JR. Repair of full-thickness rotator cuff tears in professional baseball players. Am J Sports Med 2006;34(2):182–9.
[100] Conway JE. Arthroscopic repair of partial-thickness rotator cuff tears and SLAP lesions in professional baseball players. Orthop Clin North Am 2001;32(3):443–56.
[101] Matava MJ, Purcell DB, Rudzki JR. Partial-thickness rotator cuff tears. Am J Sports Med 2005;33(9):1405–17.
[102] Shaffer B, Huttman D. Rotator cuff tears in the throwing athlete. Sports Med Arthrosc Rev 2014;22(2):101–9.
[103] Reinus WR, Shady KL, Mirowitz SA, Totty WG. MR diagnosis of rotator cuff tears of the shoulder: value of using T2-weighted fat-saturated images. AJR Am J Roentgenol 1995;164(6):1451–5.
[104] Herold T, Bachthaler M, Hamer OW, Hente R, Feuerbach S, Fellner C, et al.

Indirect MR arthrography of the shoulder: use of abduction and external rotation to detect full- and partial-thickness tears of the supraspinatus tendon. Radiology 2006;240(1):152–60.
[105] Lee SY, Lee JK. Horizontal component of partial-thickness tears of rotator cuff: imaging characteristics and comparison of ABER view with oblique coronal view at MR arthrography initial results. Radiology 2002;224(2):470–6.
[106] Tirman PF, Bost FW, Steinbach LS, Mall JC, Peterfy CG, Sampson TG, et al. MR arthrographic depiction of tears of the rotator cuff: benefit of abduction and external rotation of the arm. Radiology 1994;192(3):851–6.
[107] Polster JM, Schickendantz MS. Shoulder MRI: what do we miss? AJR Am J Roentgenol 2010;195(3):577–84.
[108] Edelson G, Teitz C. Internal impingement in the shoulder. J Shoulder Elbow Surg 2000;9(4):308–15.
[109] Paley KJ, Jobe FW, Pink MM, Kvitne RS, ElAttrache NS. Arthroscopic findings in the overhand throwing athlete: evidence for posterior internal impingement of the rotator cuff. Arthroscopy 2000;16(1):35–40.
[110] Perry J. Anatomy and biomechanics of the shoulder in throwing, swimming, gymnastics, and tennis. Clin Sports Med 1983;2(2):247–70.
[111] Klouche S, Lefevre N, Herman S, Gerometta A, Bohu Y. Return to sport after rotator cuff tear repair: a systematic review and meta-analysis. Am J Sports Med 2016;44(7):1877–87.
[112] Azzam MG, Dugas JR, Andrews JR, Goldstein SR, Emblom BA, Cain EL, Jr. Rotator cuff repair in adolescent athletes. Am J Sports Med 2018;46(5):1084–90.
[113] Oliva F, Piccirilli E, Bossa M, Via AG, Colombo A, Chillemi C, et al. I.S.Mu.L.T - rotator cuff tears guidelines. Muscles Ligaments Tendons J 2015;5(4):227–63.