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SCIENTIFIC ARTICLE

Maturation-dependent findings in the shoulders of pediatric baseball players on magnetic resonance imaging

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Abstract

Purpose To compare the prevalence and characteristics of shoulder osseous and soft tissue findings on magnetic resonance imaging (MRI) with respect to skeletal maturation in symptomatic pediatric baseball players without a history of acute trauma.

Methods The IRB-approved, HIPAA-compliant retrospective study analyzed 87 consecutive pediatric baseball players (86 boys and 1 girl; mean age, 15.4 ± 2.1 years) with shoulder MRI performed between March 1, 2012 and September 30, 2017. In consensus, two radiologists assessed the MRI studies for findings involving the humerus, the glenoid, the labrum, the rotator cuff, and the acromioclavicular joint. Exact Cochran–Armitage trend and Mantel–Haenszel Chi-square tests were used to investigate the association between these findings and skeletal maturation.

Results The mean ages between players who are skeletally immature (37 shoulders), maturing (26 shoulders), and matured (24 shoulders) were significantly different ($p < 0.001$). Bone marrow edema ($p < 0.001$) and sclerosis ($p < 0.001$) within the proximal humeral metaphysis decreased with skeletal maturation. Glenoid remodeling ($p = 0.038$) was more severe in the skeletally immature players and the prevalence of Bennett lesions ($p = 0.048$) increased with skeletal maturation. The prevalence of labral tears, rotator cuff tendinosis, and acromioclavicular joint separation did not significantly change with skeletal maturation.

Conclusions The change in the prevalence of findings within the proximal humerus and glenoid with skeletal maturation suggest differences in the distribution of stress within the shoulders of pediatric baseball players during development.

Keywords Baseball · Children · MRI · Shoulder · Skeletal maturation

Introduction

Youth participation in organized sports has steadily increased over the past decade with approximately 45 million children involved annually [1]. An increasing incidence of overuse injuries has been attributed to a combination of sport participation at a younger age, increased duration and intensity of training, and improper training of underdeveloped musculature [2–5]. In baseball players, the repetitive abduction and external rotation of the glenohumeral joint can produce pain, instability, and injury [1, 5, 6], which correlate with pitch count, pitch type, and pitch biomechanics [7–9]. In adult players, the pathophysiology for the shoulder pain is postulated to be the result of excessive traction with failure of the scapular-stabilizing mechanisms and adaptive osseous remodeling. Impingement with or without glenohumeral instability and the development of glenohumeral internal rotation deficit (GIRD) can occur [10–12]. Our clinicians have occasionally noted that these symptoms of instability and GIRD can be elicited in the shoulders of our adolescent baseball players, suggesting that the underlying structural remodeling may start during childhood.

Currently, the published literature on youth baseball players has predominately focused on the proximal humerus and the prevalence of proximal humeral epiphysiolysis, also known as the Little Leaguer's shoulder [5, 13]. The peak incidence for Little Leaguer's shoulder occurs at 13 to 14 years [5, 14], just before the onset of skeletal maturation, defined as the transition from skeletally immaturity with open proximal humeral physes, to skeletally mature with completely closed physes, which occurs between 14 to 17 years [15]. It is

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postulated that the progressive decline in the total range of motion of the glenohumeral joint just prior to the onset of skeletal maturity predisposes the proximal humeral physis to injury [16–18].

In recent years, isolated or concurrent injuries to the soft tissues of the glenohumeral joint in children and adolescents are being increasingly recognized, which may be partially due to the increasing use of magnetic resonance imaging (MRI) in the diagnostic and treatment algorithms for shoulder pain. However, these results have been derived from studies that included both athletic and non-athletic children without the exclusion of acute trauma and none of these studies correlated the injury pattern with skeletal maturation [6, 20–24]. Therefore, the purpose of our observational study was to compare the prevalence and characteristics of shoulder osseous and soft tissue findings on MRI with respect to skeletal maturation in symptomatic pediatric baseball players without a history of acute trauma.

Materials and methods

Study group

Our study was performed in compliance with Health Insurance Portability and Accountability Act (HIPAA) regulations, with the approval from our Institutional Review Board (IRB), and a waiver for informed consent.

A retrospective review of the picture archiving and communication system (PACS, Sectra Medical Systems, Linköping, Sweden) for shoulder MRI performed between March 1, 2012 and September 30, 2017 on pediatric patients, defined as 18 years of age and under, initially identified 842 studies. Patients who play baseball were included. Exclusion criteria included a history or MRI findings of prior instrumentation or implanted hardware, infectious or inflammatory arthropathy, malignancy, acute trauma, including traumatic shoulder dislocation. Patients with incomplete medical records, incomplete or severely motion-degraded MRI studies were also excluded. Medical records were reviewed for demographic information, history, and presenting symptoms and, if available, player position, surgical findings, follow-up notes, and treatment rendered.

Skeletal maturation was determined using the appearance of the proximal humeral physis on the oblique coronal three-dimensional, fat-suppressed, spoiled gradient recalled acquisition in steady-state (3D-SPGR) images. An open physis, reflecting skeletal immaturity, was defined as a uniform, well-defined band of hyperintense growth plate cartilage signal. A closing physis, reflecting upcoming skeletal maturity, was defined as narrowing, indistinctness, or complete loss of the hyperintense cartilage signal that involved at least 25% of the growth plate. A closed physis, reflecting skeletal maturity, was defined as complete loss of the hyperintense growth plate cartilage signal. The development of the distal acromion was divided into one of three categories based on its osteochondral composition: completely cartilaginous, partially cartilaginous with single or multiple ossification centers, and predominately osseous with fused ossification centers, which reflect progressive stages of maturation (Fig. 1).

MRI examination

All images were acquired using either a 3.0-Tesla (750w; GE Healthcare, Waukesha, WI, USA) or a 1.5-Tesla magnet (450w; GE Healthcare, Waukesha, WI, USA) at our institution and with a 8-channel shoulder phased-array coil (Precision; Invivo Inc, Gainesville, FL, USA). The patients were placed

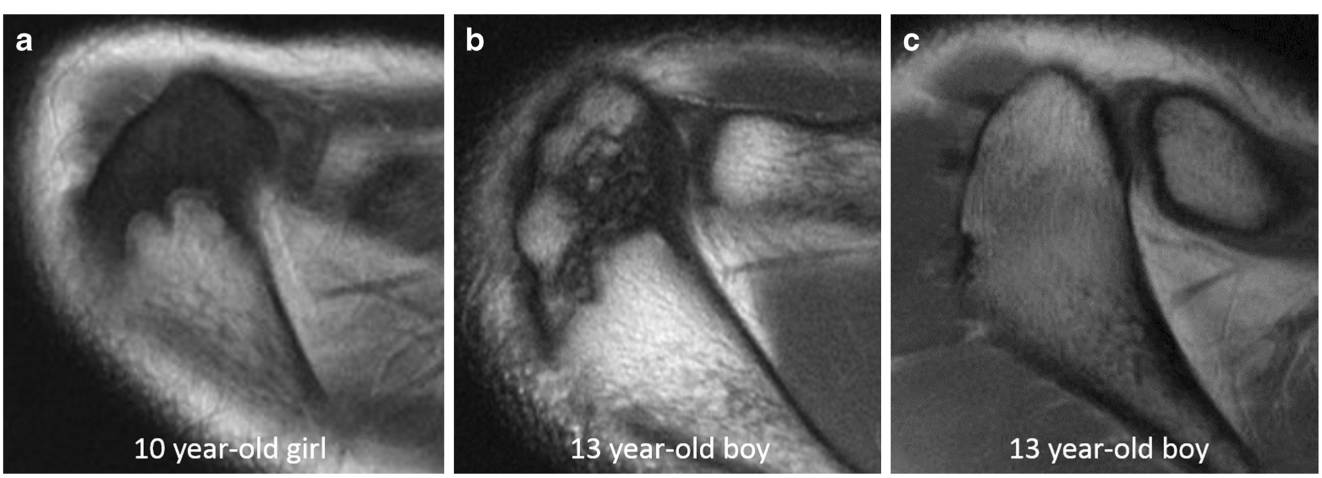

Fig. 1 Maturation of the distal acromion. Axial proton-density weighted (PDW) images through the acromioclavicular joint show different stages of maturation, ranging from immature with a cartilaginous acromion (**a**) to maturing with unfused ossification centers (**b**) to mature with fused ossification centers and closed growth plates (**c**)

supine and the humerus in neutral rotation. MRI pulse sequences and imaging parameters are summarized in Table 1.

MRI review

The MR images of the shoulder of all patients were retrospectively reviewed by two fellowship-trained radiologists in consensus, one in musculoskeletal (H.G.P.) and one in pediatric imaging (J.C.N) with over 25 years and 4 years of clinical experience in the interpretation of pediatric musculoskeletal MRI examinations, respectively, using a PACS workstation. The radiologists were blinded to the clinical history at the time of the image review.

The radiologists evaluated the multi-planar fast spin-echo images to determine the presence or absence of findings that involve the various aspects of the shoulder, which include the proximal humerus, the glenoid, the labrum, the rotator cuff, and the acromioclavicular joint. For the proximal humerus, the presence or absence of metaphyseal bone marrow edema, defined as high signal on the inversion recovery images (Fig. 2a), and metaphyseal sclerosis, defined as a band of low signal that parallels the physis on the proton-density weighted images (Fig. 2b). For the glenoid, the presence of posterosuperior remodeling was defined as irregularity, rounding, or flattening of the glenoid rim and, when present, its severity was graded as mild (involving less than one-third of the posterosuperior glenoid rim), moderate (involving one-third to two-thirds), or severe (involving more than two-thirds) (Fig. 2c). A Bennett lesion was defined as either mineralization (focus of low signal) or new bone formation (focus of high signal reflecting fatty marrow) at the site of capsular attachment onto the posterior glenoid [25, 26] (Fig. 3). The labrum was evaluated for tears, defined as linear intrasubstance signal that extended to the articular surface and, when present, was sub-divided based on its location into anteroinferior, superior, and posteroinferior tears with boundaries set at the anterior and posterior equators, respectively. The presence or absence of an accompanying paralabral cyst was also recorded. The rotator cuff was evaluated for tendinosis and tear and, when present, was sub-divided based on the cuff muscle involved. Cuff tendinosis was defined as thickening and loss of its low signal. Cuff tear was defined as fiber disruption that can be bursal-sided, articular-sided, or involve both. The acromioclavicular joint was evaluated for the presence or absence of recent or remote injury, which was defined as regional bone marrow edema (high signal on the inversion recovery images), joint space widening (>2 mm), and/or malalignment.

Statistical analysis

Statistical analyses were performed with SAS Version 9.4 (SAS Institute, Cary, NC, USA). All statistical hypothesis tests were two-sided. A p value of < 0.05 was considered significant.

The analysis of variance (ANOVA) was used to compare the mean age between players who are skeletally immature, maturing, and matured. The exact Cochran–Armitage trend test was used to compare the presence of proximal humeral metaphyseal bone marrow edema, proximal humeral metaphyseal sclerosis, Bennett lesion, labral tear, paralabral cyst, acromioclavicular joint separation, and rotator cuff tendinosis with the different stages of skeletal maturation. The Mantel–Haenszel Chi-square test was used to investigate the association between the glenoid remodeling and distal acromion osteochondral composition categories with the different stages of skeletal maturation.

Table 1 MRI parameters for the shoulder

Parameters	Axial PDW FSE	Coronal PDW FSE	Sagittal PDW FSE	Coronal IR	Coronal FS 3D SPGR
Repetition time (ms)	3500–6000	3500–6000	3500–6500	4000–6000	Minimal
Echo time (ms)	28–34	28–34	28–34	40–50	2.5
Flip angle (degrees)	90	90	90	–	20 (10)
Matrix size	512 × 256	512 × 256	512 × 384	256 × 224	256 × 256
Field of view (cm)	15–16	14	14	14	14
Slice thickness (mm)	3.5	3.5	3.5	4	1.5
Bandwidth (kHz)	62.5 (31.25)	62.5 (31.25)	62.5 (31.25)	20.8	20.8
Echo train length	10–14	10–14	10–14	14	
Signals averages	2	2	2	2	2

MRI magnetic resonance imaging, *FS* fat-suppressed, *FSE* fast spin-echo, *IR* inversion recovery, *PDW* proton-density weighted, *T* Tesla, *3D SPGR* three-dimensional, spoiled gradient recalled acquisition in steady state

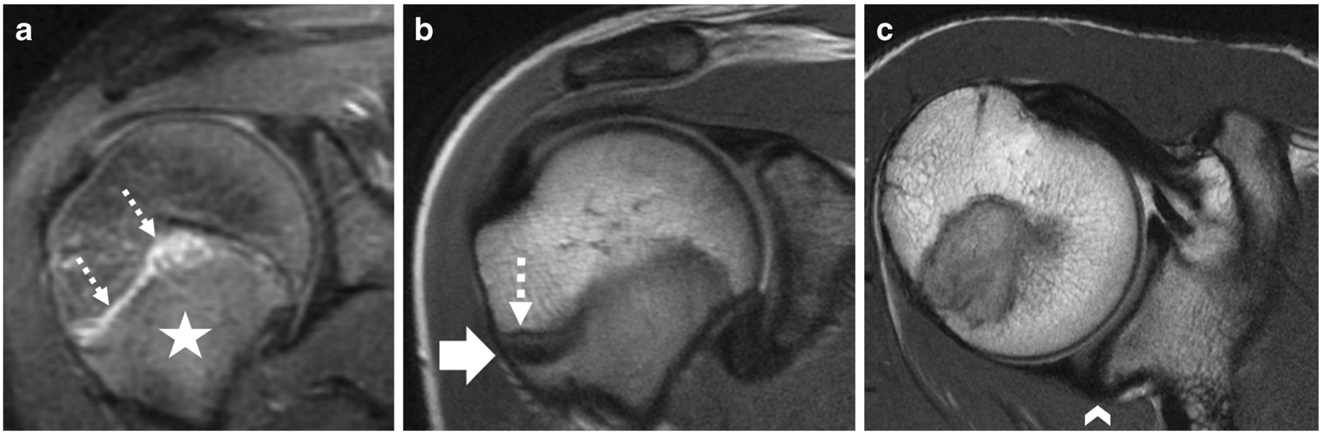

Fig. 2 Osseous findings of the shoulder joint. Coronal inversion recovery image (**a**) from a 13-year-old male pitcher shows a widened and irregular proximal humeral physis (*dashed arrows*) with metaphyseal edema (*star*). Coronal PDW image (**b**) from a 14-year-old male player shows a band of low-signal within the juxta-physeal metaphysis (*block arrow*), adjacent to the lateral physis that has not yet closed (*dashed arrow*). Axial PDW image (**c**) from a 15-year-old male catcher shows medial sloping of the posterior glenoid reflecting chronic bony remodeling from internal impingement (*chevron*)

Results

The study group consisted of 87 pediatric baseball players between 8 years and 18 years of age (86 boys and one girl; mean age, 15.4 $\pm$ 2.1 years) who underwent a total of 87 MRI examinations of their dominant throwing shoulder. Thirty-seven shoulders had open proximal humeral physes (mean age, 13.6 $\pm$ 1.8 years), 26 shoulders had closing physes (mean age, 16.2 $\pm$ 0.9 years), and 24 shoulders had closed physes (mean age, 17.3 $\pm$ 0.8 years). The mean ages among those three groups were statistically significant ($p < 0.001$). Additional demographic information is listed in Table 2.

Player position was recorded for 45 patients (52%), which included pitcher ($n = 36$), multiple positions ($n = 4$), catcher ($n = 3$) and outfielder ($n = 2$). The indications for the MRI examinations were pain with overhead activity ($n = 38$), non-specified pain ($n = 33$), pain with limited range of motion ($n = 12$), and pain with the subjective sensation of instability ($n = 4$). Thirteen patients underwent arthroscopic evaluation at a median of 3 months (range, 0–12 months) following the MRI examinations, which documented a torn superior labrum ($n = 7$), labral degeneration with fraying ($n = 3$), biceps tendinosis ($n = 1$), and adhesive capsulitis ($n = 1$).

Fig. 3 Bennett lesion. Axial PDW imaging from a 12-year-old male player shows new bone formation (*arrow*) at the site of the capsular attachment onto the posterosuperior glenoid

Table 2 Demographics

	All $n = 87$	Skeletal maturation		
		Immature $n = 37$	Maturing $n = 26$	Mature $n = 24$
Mean age (SD)[a]	15.4 (2.1)	13.6 (1.8)	16.2 (0.9)	17.3 (0.8)
Sex				
Boys	86 (99)	36 (97)	26	24
Girls	1 (1)	1 (3)	0	0
Laterality				
Left	15 (17)	6 (16)	3 (12)	6 (25)
Right	72 (83)	31 (84)	23 (88)	18 (75)

Unless otherwise specified, data are numbers of patients with percentages in *parentheses*

[a] Data are means with standard deviation (SD) in *parentheses*. Analysis of variance (ANOVA), $p < 0.001$

Osseous findings with respect to skeletal maturation

The findings of proximal humeral metaphyseal bone marrow edema ($p < 0.001$) and sclerosis ($p < 0.001$) decreased with progressive skeletal maturation (Fig. 2) (Table 3). More severe glenoid remodeling ($p = 0.038$) was found in the skeletally immature. The prevalence of Bennett lesions ($p = 0.048$) increased with progressive skeletal maturation.

Soft tissue findings with respect to skeletal maturation

Tears of the superior labrum were more common than tears of the anteroinferior and posteroinferior labrum. The prevalence of these tears did not correlate with skeletal maturation ($p = 0.999$ for all three locations). Paralabral cysts were only identified in shoulders with underlying labral tears and its prevalence did not correlate with skeletal maturation ($p = 0.660$) (Table 3). No rotator cuff tears were identified within our patient cohort. Rotator cuff tendinosis preferentially involved the supraspinatus and the infraspinatus tendons, but their prevalence did not correlate with skeletal maturation ($p = 0.204$ for supraspinatus tendinosis; $p = 0.894$ for infraspinatus tendinosis).

Table 3 Shoulder pathology

	All $n = 87$	Skeletal maturation			p values
		Immature $n = 37$	Maturing $n = 26$	Mature $n = 24$	
Humerus					
Edema	19 (22)	14 (38)	5 (19)	0	< 0.001
Low signal band	60 (69)	35 (95)	20 (77)	5 (21)	< 0.001
Glenoid remodeling					0.038
Mild	38 (44)	14 (38)	8 (31)	16 (67)	
Moderate	32 (37)	15 (41)	12 (46)	5 (21)	
Severe	11 (13)	6 (16)	4 (15)	1 (4)	
Bennett lesion	66 (76)	25 (68)	19 (73)	22 (92)	0.048
Labral tear					
Anteroinferior	1 (1)	0	1 (4)	0	0.999
Superior	64 (74)	27 (73)	20 (77)	17 (71)	0.999
Posteroinferior	2 (2)	0	2 (8)	0	0.999
Paralabral cyst	8 (9)	2 (5)	4 (15)	2 (8)	0.660
Cuff tear	0	0	0	0	NA
Cuff tendinosis					
Supraspinatus	78 (90)	34 (92)	25 (96)	19 (79)	0.204
Infraspinatus	54 (62)	23 (62)	17 (65)	14 (58)	0.894
Subscapularis	0	0	0	0	NA
Teres minor	0	0	0	0	NA
AC joint injury	8 (9)	4 (11)	3 (12)	1 (4)	0.510

Unless otherwise specified, data are numbers of patients with percentages in *parentheses*

AC acromioclavicular, *NA* not applicable

Acromioclavicular joint

Acromioclavicular injury was uncommon (9%) and its prevalence did not correlate with skeletal maturation ($p = 0.510$). None of the players had bone marrow edema within either or both the distal acromion and the distal clavicle. Progressive ossification of the distal acromion was observed with skeletal maturation ($p < 0.001$) (Table 4).

Discussion

Our study investigated the maturation-related differences in the osseous and soft tissue changes of the shoulder in symptomatic pediatric baseball players. The information gained from our study serves as a first step toward a better understanding of the changes in the pattern of injury during development and skeletal maturation. Our study identified significant associations between skeletal maturation and the prevalence of proximal humeral metaphyseal changes, glenoid remodeling, and Bennett lesions. Our study also discovered an overall high prevalence of superior labral tears and rotator cuff tendinosis that had no significant association with skeletal maturation.

Adolescent pitchers with a higher number of pitches and higher pitch velocity have been linked to higher incidences of injury [8, 9]. For skeletally immature players, the cartilaginous physes are two to five times weaker than the surrounding soft tissues and hence more vulnerable and prone to injure [17]. Biomechanical analyses have shown that the shear stress generated from the higher torque in the late arm-cocking phase of a throw can deform the proximal humeral epiphyseal cartilage [27]. The decrease in the total range of motion at the onset of skeletal maturation [16], in addition to the progressive ability to generate more force with progressive muscle growth, coincides with the peak incidence of Little Leaguer's shoulder [5]. However, Little Leaguer's shoulders are occasionally diagnosed in older children [5, 14] but prior MRI reports on the Little Leaguer's shoulders have been limited to the skeletally immature, between 11 and 15 years of age [13, 28, 29]. By including children between 8 and 18 years of age, our study found a significant negative association between the reactive changes within the proximal humerus and skeletal maturation and these findings are not limited to only those players who are skeletally immature.

In our study, the reactive changes within the proximal humeral metaphysis included both bone marrow edema and sclerosis. While metaphyseal bone marrow edema can only be identified in players who are skeletally

Table 4 Distal acromion morphology

Distal acromion	Proximal humeral physis		
	Immature ($n = 37$)	Maturing ($n = 26$)	Mature ($n = 24$)
Cartilaginous	16 (43)	0	0
Ossification centers (≥ 1)	21 (57)	17 (65)	0
Osseous	0	9 (35)	24 (100)

Unless otherwise specified, data are numbers of patients with percentages in *parentheses*

Mantel–Haenszel Chi-square, $p < 0.001$

immature and skeletally maturing, metaphyseal sclerosis can be identified in players at all stages of skeletal maturation. Although metaphyseal bone marrow edema has been described, metaphyseal sclerosis, in the context of Little Leaguer's shoulder, has not been previously described. The linear morphology of the sclerosis differs from the poorly defined regional sclerosis observed on radiography [14] and thus, its exact etiology remains unknown. However, its pattern of decreasing prevalence with skeletal maturation, paralleling and just lagging behind that for the bone marrow edema, suggests it may represent a healing response, analogous to fracture healing. In fracture healing, regional high signal on fluid-sensitive sequences represent an active stress response [13, 28–30] reflecting an increase in the concentration of unbound water molecules due to regional inflammatory vasodilatation and permeability [31]. This bone marrow edema pattern decreases with time due to the introduction of reparative and inflammatory macromolecules, altering the regional signal characteristics [31].

Our study also found an overall high prevalence of glenoid remodeling, which was more severe in the skeletally immature. Analogous to the relatively weaker proximal humeral physis (predisposing the child to the development of the Little Leaguer's shoulder), the glenoid physes may also be vulnerable to repetitive stress. The glenoid forms from several secondary ossification centers, including the subcoracoid ossification center superiorly and anterosuperiorly (which appears at 8–10 years of age and fuses by 16–17 years of age), and multiple inferior ossification centers (which appear at 11–15 years of age and fuse by 17–18 years of age) [32]. In adult professional baseball pitchers, asymmetric glenoid retroversion ($p < 0.01$) in the dominant shoulder is common [33], but whether this remodeling occurred before, during, or after skeletal maturation is unknown. Our study suggests that this remodeling starts early during development but its long-term effect and its reversibility remain unknown and likely depend on a combination of duration of the repetitive stress and severity of the insult [17].

Our study found an increasing prevalence of Bennett lesions with skeletal maturation. A Bennett lesion describes a posteriorly located extra-articular focus of mineralization or ossification, which was initially used to describe a group of adult baseball players [25, 34]. In children, although these lesions have been previously described within the arthroscopic literature [21], they have not been described within the imaging literature. Histologic analysis reveals reactive new bone formation from excessive traction at the capsular insertion onto the posterior glenoid. Thus, this represents a late subacute or chronic reparative response to repetitive stress [12, 25], which explains why these lesions were more prevalent in the older, skeletally mature shoulders in our study cohort.

Bennett lesions may coexist with rotator cuff injury that preferentially involves supraspinatus and infraspinatus and labral tears that preferentially involves the superior and posterosuperior labrum. This constellation of findings is a feature of internal impingement [25, 35]. Internal impingement can occur during overhead movements when the extreme abduction and external rotation result in the entrapment of the articular-sided fibers of the rotator cuff tendons and the labrum between the humeral head and the posterior glenoid [36]. In children, there are rare reports of rotator cuff tendon tears, often precipitated by trauma or collision [6, 20, 24] and less commonly in athletes without antecedent trauma [23, 30]. None of the players in our study cohort had cuff tendon tears, although many did have tendinosis of the supraspinatus and infraspinatus tendons, reflecting low-grade strain, possibly from repetitive submaximal insults.

Tear of the superior labrum was common in our study cohort, but we found no association between the prevalence of these tears and skeletal maturation. This preferential superior location is consistent with prior studies on overhead athletes [10, 30, 36], although its prevalence is slightly higher than those that were previously reported [30, 37]. The lack of association with skeletal maturation differs from a previously published study that showed a significantly higher ($p < 0.01$) prevalence of labral tear in high school and collegiate players compared to junior high players [22]. This discrepancy may reflect the imperfect correlation between grade level and skeletal maturity as well as regional differences in patient selection, practice schedules, and regulatory guidelines.

An overall low incidence of acromioclavicular joint injury was found in our study cohort and none of our patients demonstrated features of acromial apophysiolysis, defined as incomplete fusion and edema within the acromial apophysis and is postulated to be a risk factor for the future development an os acromiale [19]. In our study cohort, the skeletal maturation of distal acromion paralleled the maturation of the proximal humeral physis, such that at skeletal maturation, none of the shoulders had completely cartilaginous or unfused distal acromion ossification centers.

Our study has several limitations, including the retrospective nature of the study design, which used preexisting clinical information and available imaging. Player field position was recorded for only 52% of the study subjects and additional details regarding training routine and play duration were not often available, which may potentially yield a heterogeneous group of youth athletes ranging from amateurs to near-professional level players. The field of view for the routine MRI examination does not include the entire scapula or imaging through the distal humerus to allow for the calculation of glenoid version and humeral version, respectively [27, 33]. The routine MRI examination also does not include the contralateral non-symptomatic shoulder [12], which may create bias in the absolute clinical significance of these findings, but would not influence the investigation of maturation dependent differences. Although MR arthrogram may improve diagnostic sensitivity for low-grade injury [10, 35], the intra-articular injection of contrast is not without risk and, in a child, may also require sedation, and thus is not part of our routine MRI protocol. However, we have previously demonstrated an overall high diagnostic accuracy using non-contrast techniques with arthroscopy as the gold standard [38]. Finally, although our overall sample size is not small, for each stage of skeletal maturation, the sample size is small, and many of the players had incomplete clinical history, including player position, practice routines and duration, and limited surgical confirmation; however, the latter is not dissimilar to other published reports which have shown that most of the patients improve on conservative management, obviating the need for arthroscopic confirmation and treatment [20, 23], and most are lost to follow-up as symptoms improve or resolve [23].

In conclusion, our study found that the prevalence of proximal humeral metaphyseal bone marrow edema and sclerosis decreased and the prevalence of Bennett lesions increased with skeletal maturation. Glenoid remodeling was more severe in the skeletally immature, while the prevalence of rotator cuff tendinosis and labral tears did not correlate with skeletal maturation. Our study serves as a first step toward a better understanding on how skeletal maturation may influence the prevalence and severity of shoulder findings. Additional prospective longitudinal studies are needed to delineate the underlying pathophysiology and to establish the reversibility of these findings.

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Compliance with ethical standards

Informed consent was waived by the Institutional Review Board for this HIPAA-compliant retrospective study.

Disclosures The authors have no relevant disclosures.

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