



Characterization of glenoid bone remodeling in professional baseball pitchers

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Abstract

Objective To characterize the appearance, location, severity, and prevalence of focal glenoid retroversion on shoulder MRI in professional baseball pitchers versus age-matched controls.

Materials and methods In this retrospective review, two musculoskeletal radiologists evaluated shoulder MRI examinations from 40 professional baseball pitchers and 40 age-matched controls. Images were scored for the presence of a focal posterior glenoid convexity and the clock face positions involved. A consensus interpretation was also performed. A third reader identified the presence of additional shoulder abnormalities.

Results After consensus, 60% (24/40) of pitchers were found to have focal glenoid retroversion versus 20% (8/40) of controls ($p = 0.001$). The most apparent location was posterior or posterior-superior, from 7.75 o'clock to 10.5 o'clock (median, 9.75 o'clock; interquartile range, 9.25–10 o'clock). The median clock angle of involvement was greater in pitchers than in controls (30° vs. 0°; $p < 0.001$). Interreader agreement regarding the presence or absence of focal glenoid retroversion was moderate (Cohen's kappa, 0.49). Focal glenoid retroversion was more prevalent among subjects with additional shoulder abnormalities ($p = 0.014$).

Conclusions Glenoid remodeling occurs in the throwing shoulder of professional baseball pitchers and manifests as focally convex morphology of the posterior or posterior-superior glenoid. This type of remodeling does not appear to be associated with a lower prevalence of injuries related to posterior-superior impingement.

Keywords Glenoid · Retroversion · Shoulder · Baseball · Pitcher · Enchondral ossification

Introduction

High-level overhead-throwing athletes are known to develop osseous changes or adaptations. A well-known example of an adaptation in professional baseball pitchers involves humeral torsion, which is believed to occur as a result of chronic repetitive stress [1, 2] and may serve as a protective adaptation [3]. Another osseous change that has been reported in professional baseball pitchers is glenoid retroversion, which is caused by the enormous amount of stress placed upon the glenoid during pitching [4–6]. The late cocking phase of pitching is the

primary contributor to this force due to contact between the greater tuberosity of the humerus and the glenoid, which can result in posterior-superior impingement in addition to bone stress [7]. This high degree of bone stress has been inferred from computed tomography (CT) bone osteoabsorptiometry as a correlate, with pitchers showing significantly higher stress to the posterior-superior glenoid when compared with control subjects [8].

One of the methods used to measure the degree of glenoid retroversion involves drawing a line along the surface of the glenoid face with respect to the scapular long axis (Fig. 1a) [9]. An alternative method described for use on smaller field-of-view magnetic resonance imaging (MRI) studies defines the scapular long axis using the medial border of the scapular body (Fig. 1b) [5]. There are several key issues to consider when measuring glenoid retroversion with these methods. First, we have noticed anecdotally that professional baseball pitchers tend to have a more focal convexity of the posterior glenoid surface rather than global retroversion (Fig. 2). It can

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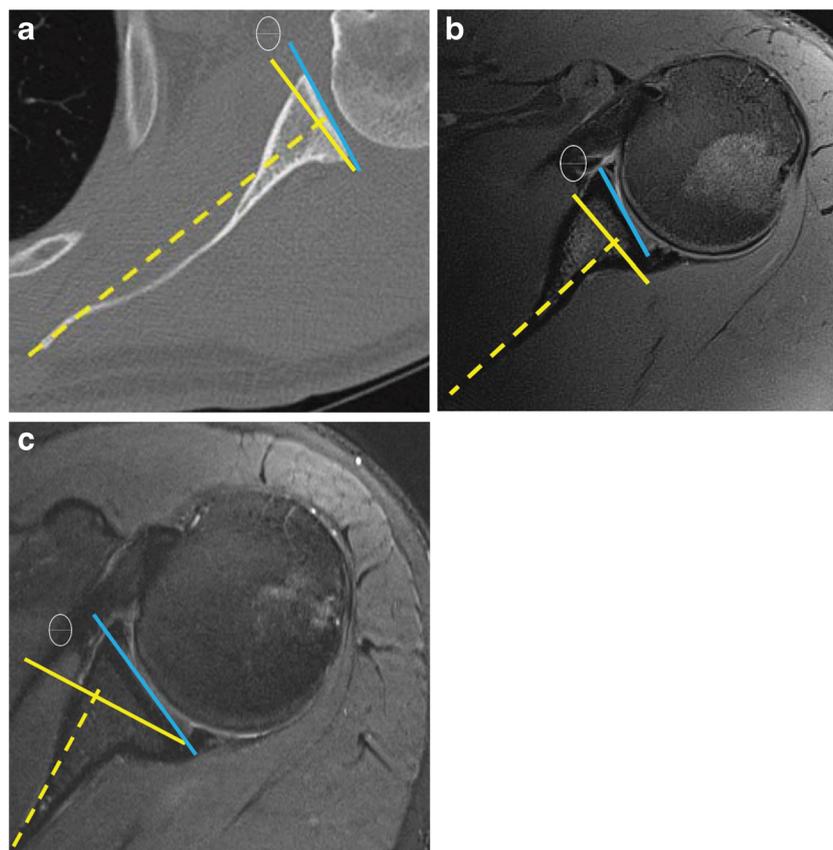


Fig. 1 Methods for measuring the degree of glenoid retroversion. For all figures, the *dashed yellow line* indicates the scapular axis, the *solid yellow line* is orthogonal to the scapular axis, the *solid blue line* indicates the axis of the glenoid surface, and θ indicates measured glenoid retroversion. **a** Glenoid version measured on CT, with the scapular long axis defined along the medial angle of the scapula extending to the center of the glenoid surface (method derived from Hill et al. [9]). **b** Glenoid version measured on MRI in a different subject, with the scapular long axis

defined by the visible medial border of the scapular body (method derived from Drakos et al. [5]). **c** Glenoid version measured on MRI in the same subject shown in (a) using the method derived from Drakos et al. [5]. Note that this scapular axis differs significantly in orientation from the axis described in (a) because the small field of view results in a lack of a medial scapular reference point, resulting in a different measured angle of glenoid retroversion

be difficult to represent these more focal changes with commonly used angle measurements intended to measure the degree of global retroversion. Second, accurate glenoid angle measurements can be challenging to obtain with MRI, as the field of view is often too small to allow for confident identification of the true scapular long axis. This results in high variability in glenoid version measurements (Fig. 1c) [5], making it difficult to identify an absolute measurement threshold against which specific glenoid version measurements can be compared. As a result of these issues, previous descriptions may have incompletely characterized the specific type of glenoid retroversion seen in professional baseball pitchers and may not be practically useful to identify this finding on a case-by-case basis.

The purpose of this study was to characterize the appearance, location, severity, and prevalence of focal posterior glenoid convexity in professional baseball pitchers compared to age-matched controls using shoulder MRI, as opposed to previous studies which evaluated global glenoid retroversion.

A secondary aim involved evaluating for a possible correlation between focal glenoid retroversion and injuries seen in posterior-superior impingement.

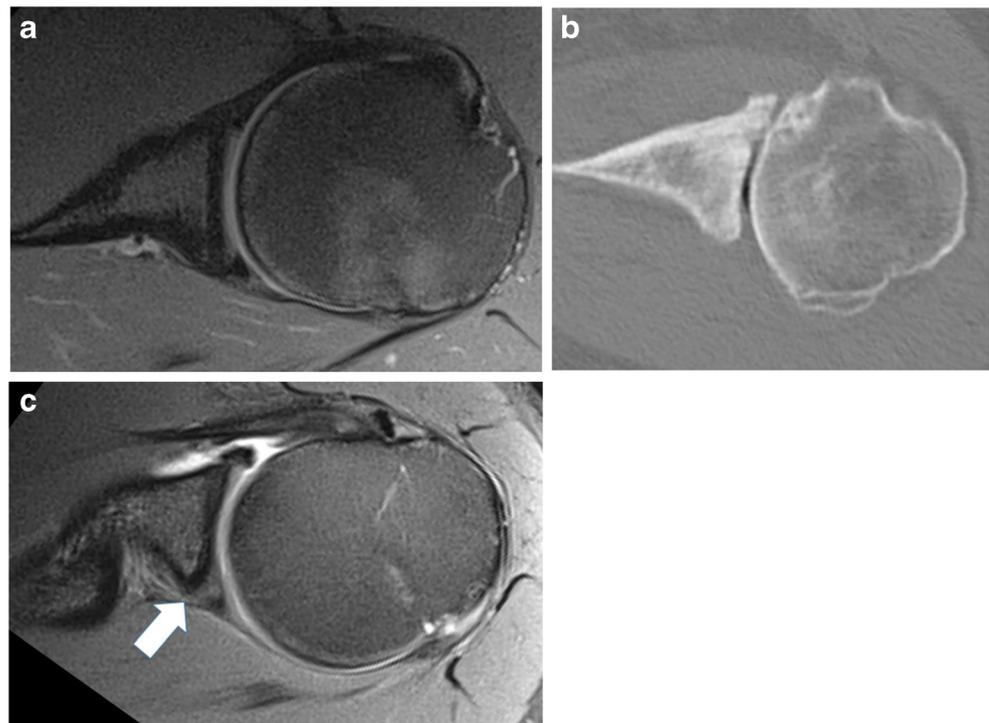
Materials and methods

This study was approved by our institutional review board with a waiver of informed consent and was conducted in compliance with the Health Insurance Portability and Accountability Act.

Study subjects

A total of 40 professional baseball pitchers, including major and minor league athletes, were selected for the study. Professional baseball pitchers who had an MRI examination of the throwing shoulder between 2008 and 2016 were included. Players with prior surgery on the shoulder were excluded.

Fig. 2 Different types of glenoid morphology. **a** Control subject with normal concave morphology of the glenoid on axial proton density MRI of the right shoulder. **b** An example of global retroversion of the glenoid due to severe osteoarthritis manifested by posterior sloping of the entire glenoid surface with respect to the scapular long axis on axial CT of the right shoulder. **c** Right-handed professional baseball pitcher with a focal convexity of the posterior-superior glenoid (*arrow*) on axial proton density MRI of the right shoulder. Note that there is also overlying thickening of the cartilage



A total of 40 age-matched controls were selected for the study using consecutive MRI studies of the dominant shoulder performed as part of routine clinical work. Control subjects with a history of participation in college or higher-level overhead throwing sports were excluded. Patients with a history of heavy weightlifting or participation in football as offensive or defensive linemen were also excluded because of an association of these activities with posterior capsulolabral pathology [10].

Imaging parameters

Nearly all subjects had imaging performed on a 3.0-Tesla MRI scanner (Siemens Verio, Siemens AG, Germany). Two professional pitchers and two control subjects had imaging performed on different MRI scanners (Siemens Aera 1.5-Tesla, Siemens Skyra 3.0-Tesla, or Siemens Symphony 1.5-Tesla). Per routine institutional shoulder MRI protocol, at least axial, sagittal, and coronal single echo intermediate T2-weighted sequences (repetition time ≥ 2000 ms; echo time, 35–70 ms) had been acquired and were used for imaging review.

MRI review

Imaging studies for all subjects were reviewed through a secure, anonymized research database using Aquarius iNtuition (TeraRecon, Foster City, CA, USA) image viewing software. The readers for the evaluation of glenoid retroversion included two board-certified diagnostic radiologists with fellowship

training in musculoskeletal radiology and with 12 and 13 years of musculoskeletal imaging experience. Before data collection, readers reviewed a series of five shoulder MRI training cases exclusive of the study subjects that demonstrated the presence of a glenoid focal posterior marginal convexity (Fig. 2c). Next, each radiologist independently reviewed the shoulder images for each subject; the radiologists were blinded to subject status (professional pitcher vs. control), and the reading order was individually randomized. For each of the subjects, axial MR images were reviewed for the presence or absence of focal glenoid retroversion manifesting as a focal posterior marginal convexity of the glenoid margin. If this convexity was present, each reader correlated the finding to the sagittal MR images using localization lines and documented the most superior and inferior extent of the finding with respect to the traditional glenoid clock face (i.e., with the 9 o'clock position considered posterior and the 12 o'clock position considered superior). Each reader also documented the clock face position at which the finding was most apparent. The clock angle between the most superior and inferior clock face positions (with each clock face position in the circle corresponding to 30°) was used to quantify the extent of focal glenoid retroversion as a marker for severity.

A blinded consensus review was performed when the readers disagreed on the presence or absence of a glenoid focal posterior marginal convexity. Consensus was reached on all cases of initial disagreement, and there was no need for a tie-breaking mechanism. When the two readers initially disagreed on the presence or absence of focal glenoid retroversion,

consensus severity was based on the consensus interpretation between the readers. When the two readers initially agreed on the presence or absence of focal glenoid retroversion, consensus clock angle severity was defined as the average clock angle severity between the two readers.

Evaluation for additional shoulder abnormalities

A third board-certified diagnostic radiologist with fellowship training in musculoskeletal radiology and with 7 years of musculoskeletal imaging experience reviewed each case in a blinded fashion and documented the presence of labral (posterior or posterior-superior), Bennett (osseous or capsular), or chondral abnormalities. In addition, the reader documented the presence of partial- or full-thickness rotator cuff tears.

Statistical methods

A Wilcoxon rank sum test was used to assess the hypothesis that focal glenoid retroversion severity tends to be higher among professional pitchers than among controls. Fisher's exact test was used to test the null hypothesis that there is no association between focal glenoid retroversion and the presence of additional shoulder abnormalities. The consensus interpretation was used for all analyses. A significance level of 0.05 was used for each hypothesis test. Interreader agreement regarding the presence or absence of focal glenoid retroversion was characterized using Cohen's kappa.

Results

Subject demographics

The mean age was 23 years for professional pitchers (\pm 3.9 years; range, 17–31 years) and 23 years for controls (\pm 4.6 years; range, 17–33 years). All subjects were male. Of the professional pitchers, 80% (32/40) were right-throwing; 73% (29/40) of controls were right-handed.

Focal glenoid retroversion

According to the consensus, 60% (24/40) of professional pitchers had focal glenoid retroversion compared to 20% (8/40) of controls ($p = 0.001$). In these 32 subjects with focal glenoid retroversion, the location at which the finding was most apparent was posterior or posterior-superior, ranging from clock face position 7.75 o'clock to 10.5 o'clock (median, 9.75 o'clock; interquartile range: 9.25–10 o'clock) (Fig. 3a). The median clock angle severity was 30° among professional pitchers (range, 0–112.5°) compared to 0 degrees among controls (range, 0–105°) (Fig. 4). The median clock angle severity

of focal glenoid retroversion tended to be more severe among professional pitchers than among controls ($p < 0.001$).

The two readers agreed on the presence or absence of focal glenoid retroversion in 75% (60/80) of subjects. Cohen's kappa was 0.49 (95% confidence interval: 0.31, 0.68), which is considered moderate agreement.

Additional shoulder abnormalities

Additional shoulder abnormalities were identified in 68% (54/80) of subjects (Table 1). Focal glenoid retroversion was more prevalent among subjects with additional abnormalities than among subjects without additional abnormalities (27/54 = 50% vs. 5/26 = 19%; $p = 0.014$). With regard to pitchers, the prevalence of any additional shoulder abnormality excluding Bennett lesions (i.e., labral tear, chondral abnormality, or rotator cuff tear) was not significantly different between subjects with and without focal glenoid retroversion (10/24 = 42% vs. 10/16 = 63%; $p = 0.333$). More specifically, the prevalence of labral tear among pitchers was not significantly different between subjects with and without focal glenoid retroversion (8/24 = 33% vs. 4/16 = 25%; $p = 0.729$). Rotator cuff tears were identified in 14% (11/80) of all subjects. There was no significant difference in the prevalence of focal glenoid retroversion among subjects with rotator cuff tear and those without rotator cuff tear (4/11 = 36% vs. 28/69 = 41%; $p = 0.999$).

Discussion

In this study, we have shown that focal retroversion of the posterior glenoid is more prevalent in professional baseball pitchers than in age-matched controls. The most common location of focal retroversion was in the posterior or posterior-superior glenoid, with most cases falling between the 9.25 o'clock and 10 o'clock positions (Fig. 3a). This location in the glenoid correlates with an area of high bone stress in professional pitchers (Fig. 3b) [8]. The median clock angle severity of focal retroversion in professional baseball pitchers was 30°, which was significantly greater than the severity in age-matched controls.

Our findings are in contrast to the findings of previous studies that have described more global glenoid retroversion in pitchers. For example, one study using a traditional method to measure glenoid tilt demonstrated that the degree of glenoid retroversion was higher in the throwing shoulder than in the contralateral nonthrowing shoulder in pitchers but that there was no significant difference in glenoid retroversion of the dominant arm between the throwing and nonthrowing groups [4]. It is possible that the method used to quantify the degree of glenoid retroversion in this previous study did not account for the more focal nature of the finding we observed in our current work. Another study using a modified method to measure

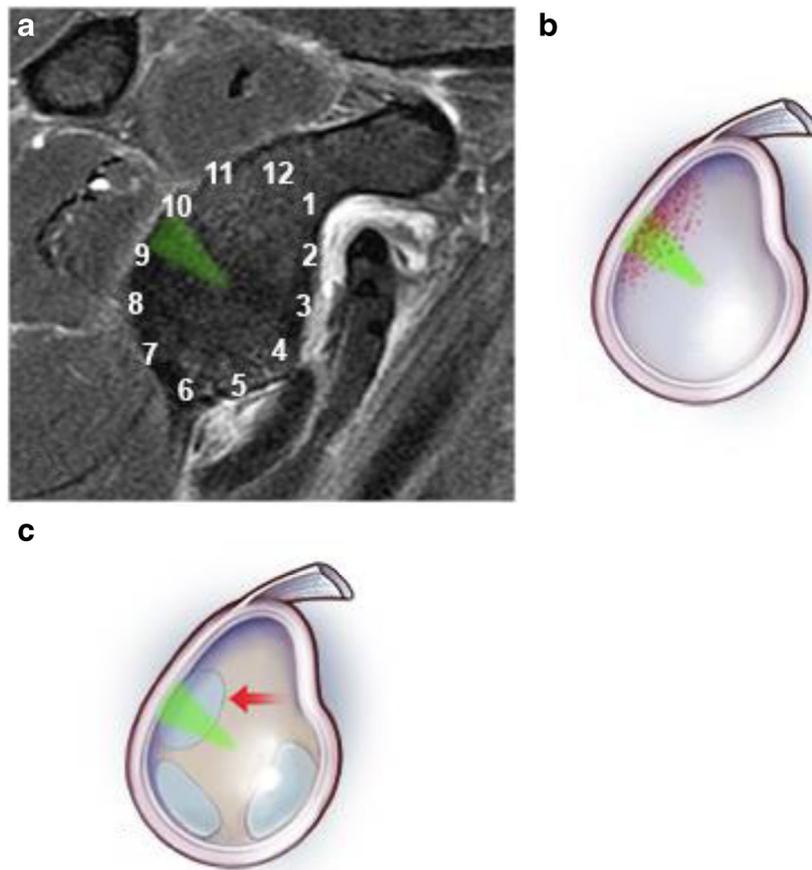


Fig. 3 Sagittal orientation of the glenoid represented by the traditional clock face, with 9 o'clock being considered posterior and 12 o'clock being considered superior. **a** The median location for focal glenoid retroversion in all subjects was 9.75 o'clock, with an interquartile range of 9.25 o'clock to 10 o'clock (*green shaded area*). **b** This location of the glenoid correlates with an area of high bone stress (*red shaded area*) to

the posterior-superior glenoid previously demonstrated in pitchers by Shimizu et al. [8]. **c** The majority of the glenoid articular surface is formed by three secondary ossification centers as described by Kothary et al. [11]. The location of focal glenoid retroversion appears to correlate with the more posterior ossification center, which may be affected due to repetitive stress in professional baseball pitchers

glenoid tilt found that the degree of glenoid retroversion was higher in the throwing shoulder of pitchers than in the

shoulders of nonthrowers at the superior, middle, and inferior glenoid levels, suggesting a more global change [5]. We believe

Fig. 4 Distribution of focal glenoid retroversion findings according to consensus. Remodeling severity was defined as the clock angle between the two clock face positions used to denote the extent of the finding. When no retroversion was noted, the angle was considered zero

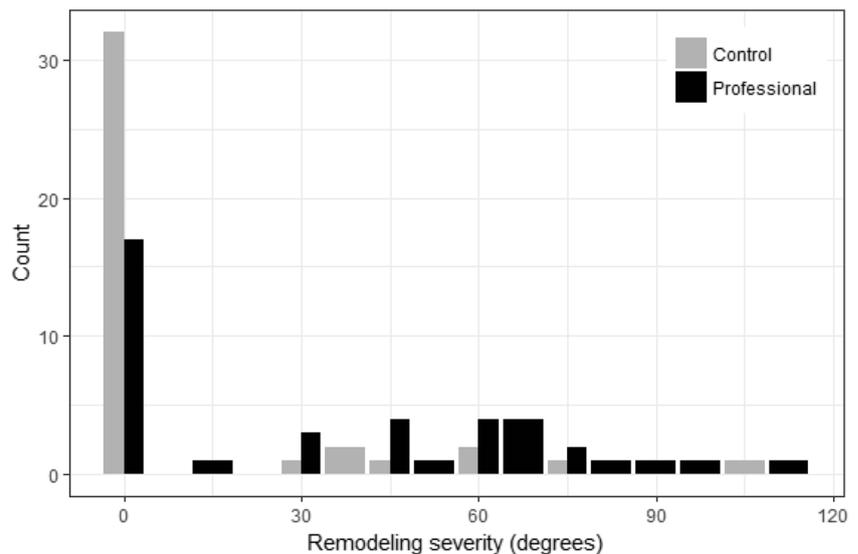


Table 1 Distribution of additional shoulder abnormalities for subjects with and without focal glenoid retroversion

Shoulder abnormality	Without focal retroversion	With focal retroversion
No additional abnormalities	44% (21/48)	16% (5/32)
Posterior/posterior-superior labral tear	15% (7/48)	9% (3/32)
Bennett lesion (bone or capsule)	21% (10/48)	38% (12/32)
Chondral abnormality	4% (2/48)	6% (2/32)
Labral tear and Bennett lesion	8% (4/48)	31% (10/32)
Labral tear and chondral abnormality	6% (3/48)	0% (0/32)
Bennett lesion and chondral abnormality	2% (1/48)	0% (0/32)

that using clock face positions and clock angle severity allowed us to better characterize the more focal nature of glenoid retroversion seen in pitchers in this study, and this technique may provide a more reliable method for quantifying these changes in the future. Given the inaccuracy of measuring global glenoid retroversion when the entire scapula is not included in images and the lack of a reliable threshold value of global glenoid retroversion to distinguish between normal and abnormal glenoid morphology, the focal posterior remodeling described here may be a better means of assessing these changes.

Although this study was not designed for this purpose, we also assessed whether glenoid remodeling potentially protects the throwing shoulder from other injuries. Focal glenoid retroversion was more prevalent among subjects with additional shoulder abnormalities than among those without additional abnormalities. Bennett lesions, the most commonly encountered abnormality, were more common among subjects with retroversion, the majority of whom were professional pitchers. This finding is consistent with the fact that Bennett lesions are more prevalent among overhead throwing athletes [12]. Among pitchers, the prevalence of any additional shoulder abnormality excluding Bennett lesions was not significantly different between subjects with and without focal glenoid retroversion. At the very least, focal glenoid retroversion does not appear to be associated with a lower prevalence of injuries related to posterior-superior impingement. Although it seems that glenoid remodeling is a response to the chronic repetitive stress of throwing, we cannot confidently conclude whether it is a marker of injury seen alongside other structural injuries of the glenohumeral joint or is an adaptive, protective mechanism.

It is important to distinguish between the focal glenoid retroversion described in this study and the type of global retroversion seen in osteoarthritis. Osteoarthritis involves mechanical erosion of the joint with progressive chondral loss and even osseous remodeling. One of the morphologic subtypes of osteoarthritis involves global retroversion of the entire glenoid surface (Fig. 2b) [13]. The type of focal glenoid retroversion we describe in this study does not appear to be due to mechanical or degenerative erosion, as the cartilage overlying the affected bone is preserved or even thickened (Fig. 2c). This preservation of the overlying soft tissues

suggests that alterations in bone development are the cause of this type of focal glenoid retroversion.

Focal glenoid retroversion is also different from what has been described as glenoid dysplasia, hypoplasia, or posterior glenoid rim deficiency. These entities typically involve localized osseous hypoplasia of the posterior inferior glenoid, often with overlying chondral or labral hypertrophy and with an increased incidence of posterior labral tears [14].

The type of focal glenoid retroversion described in this study likely develops in overhead throwing athletes as a response to chronic repetitive stress. Many professional baseball players begin their athletic training during the period of skeletal immaturity, which likely provides an ideal window for this morphologic remodeling similar to what has been described in epiphyseal injuries and humeral torsion [1, 2, 15]. In normal glenoid development, the glenoid ossification margin during the first decade is usually flat or slightly convex; during maturation, this ossification margin becomes concave to match the articular surface and accommodate the humeral head [11, 16]. Secondary ossification centers, which form two-thirds of the glenoid articular surface (Fig. 3c) [11], usually appear between 11 and 14 years of age and fuse between 12 and 16 years of age [11]. These ossification centers, and in particular the more posterior center, may be involved in the development of focal glenoid retroversion during skeletal immaturity in professional pitchers.

The process of enchondral ossification in the glenoid begins centrally and extends peripherally to the glenoid margin [16]. This distribution might suggest that the more peripheral, marginal glenoid may be susceptible to impairment or inhibition of enchondral ossification during skeletal maturation. Enchondral ossification depends on growth cartilage, which is immediately subjacent to the epiphyseal plate and populated by germinal cells that are supported by epiphyseal vessels [17]. These germinal cells both multiply and elaborate cartilage matrix, leading to growth [17]. Longitudinal trauma to this zone of growth can disrupt either the germinal cells or the supporting epiphyseal vessels, leading to impaired or completely inhibited growth; this can result in osseous deformity, in an analogous fashion to Blount disease [17]. Chronic repetitive stress from overhead throwing may serve as a form of longitudinal trauma to the developing glenoid, and stress

loading to the growth cartilage of the posterior or posterior-superior glenoid in professional pitchers may result in impairment or complete inhibition of enchondral ossification, leading to osseous deformity (Fig. 5). This may occur as a result of impaired chondrocyte proliferation at the primary growth plate or impaired ingrowth of epiphyseal vessels that normally lead to the development of secondary ossification centers. This process would also explain why the overlying cartilage and labrum are preserved or even thickened in cases of focal glenoid retroversion. The more posterior center of the glenoid inferior ossification centers may be involved in this process, and this posterior center likely correlates to the most common location of focal glenoid retroversion (Fig. 3c) [11].

Our study had several limitations. First, while we excluded control subjects if they had a history of participation in college or higher-level overhead throwing sports, some of these subjects may have been active overhead throwing athletes during adolescence and thus during skeletal immaturity. As a result, some of the control subjects may have had focal glenoid retroversion that developed from these activities, which would make distinguishing professional pitchers from controls more challenging. However, we were still able to determine that focal glenoid retroversion was more prevalent in professional pitchers than in age-matched controls, and the degree of retroversion was greater in professional pitchers.

Second, there was a difference between the control and professional groups in the mix of asymptomatic and symptomatic subjects. All of the control subjects had initially presented with shoulder symptoms that prompted a shoulder MRI examination. Although some of the pitchers in the study were

symptomatic, some were asymptomatic and underwent MRI examination simply as a baseline study after the baseball draft. As a result, the attempted comparison of the incidence of structural injuries in control subjects versus pitchers did not isolate differences that would be accounted for by throwing activity and associated glenoid retroversion, making our conclusions uncertain. Had we found a lower incidence of structural injury among pitchers relative to controls, this would have left open the possibility that glenoid retroversion may be a protective adaptation. However, subjects with focal glenoid retroversion, the majority of whom were professional pitchers and some of whom were asymptomatic, did not have a lower incidence of additional shoulder abnormalities. Thus, despite the limitation of symptomatic differences between controls and pitchers, we infer that focal glenoid retroversion is unlikely to be a protective adaptation.

Third, although there was moderate inter-reader agreement regarding the presence or absence of focal glenoid retroversion, readers still differed in their perceptions of the findings. These differences were able to be rectified by consensus review, but the use of more explicit criteria for the identification of focal glenoid retroversion and additional training cases could have resulted in greater inter-reader agreement.

In conclusion, our results suggest that focal glenoid retroversion is more common and more extensive in the throwing shoulder of professional baseball pitchers than in controls. The location of retroversion involves the posterior to posterior-superior glenoid; this is consistent with a model of altered bone development related to chronic repetitive stress, as this location correlates with an area of high bone stress in

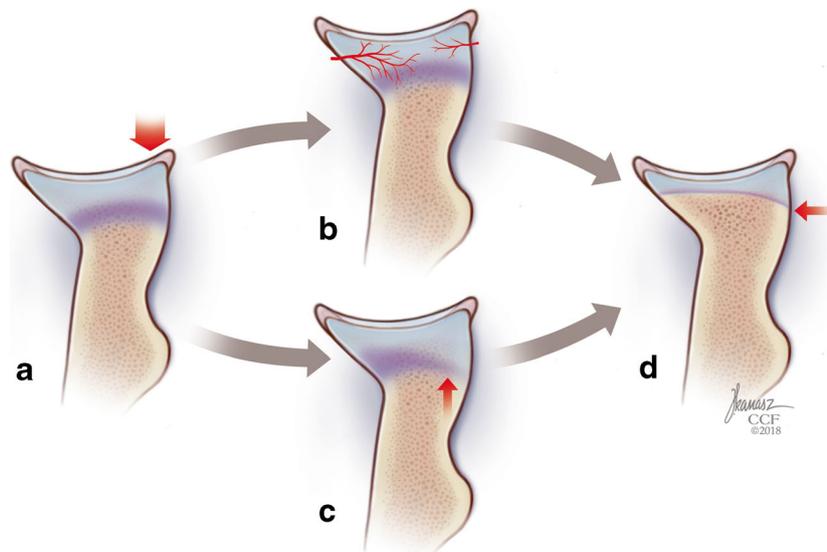


Fig. 5 Schematic of the developing glenoid. Cartilage is represented in light blue. Area of enchondral ossification is represented in light purple. Area of ossification is represented in beige. **a** Repetitive bone stress to the posterior or posterior-superior glenoid in pitchers may be a cause of longitudinal trauma to the developing glenoid (arrow). **b** This repetitive stress may inhibit or irreversibly damage the function of the germinal

cells and supporting epiphyseal vessels, which are vital to the ossification center. **c** This injury to the ossification center may inhibit or cease the process of enchondral ossification in the affected area (arrow). **d** As a result, the affected portion of the glenoid may demonstrate a posterior sloping due to inhibited or failed ossification (arrow)

pitchers and likely involves only the throwing shoulder. The presence of glenoid retroversion does not appear to be protective against additional shoulder pathologies, but further study of this point is needed.

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Compliance with ethical standards

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Conflict of interest The authors declare that they have no conflict of interest.

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References

- 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;33:1716–22.
- Warden SJ, Bogenschutz ED, Smith HD, Gutierrez AR. Throwing induces substantial torsional adaptation within the midshaft humerus of male baseball players. *Bone.* 2009;45:931–41.
- Polster JM, Bullen J, Obuchowski NA, Bryan JA, Soloff L, Schickendantz MS. Relationship between humeral torsion and injury in professional baseball pitchers. *Am J Sports Med.* 2013;41:2015–21.
- Crockett HC, Gross LB, Wilk KE, et al. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *Am J Sports Med.* 2002;30:20–6.
- Drakos MC, Barker JU, Osbahr DC, et al. Effective glenoid version in professional baseball players. *Am J Orthop (Belle Mead NJ).* 2010;39:340–4.
- Wyland DJ, Pill SG, Shanley E, et al. Bony adaptation of the proximal humerus and glenoid correlate within the throwing shoulder of professional baseball pitchers. *Am J Sports Med.* 2012;40:1858–62.
- Chang IY, Polster JM. Pathomechanics and magnetic resonance imaging of the thrower's shoulder. *Radiol Clin N Am.* 2016;54:801–15.
- Shimizu T, Iwasaki N, Nishida K, Minami A, Funakoshi T. Glenoid stress distribution in baseball players using computed tomography osteoabsorptiometry: a pilot study. *Clin Orthop Relat Res.* 2012;470:1534–9.
- Hill JA, Tkach L, Hendrix RW. A study of glenohumeral orientation in patients with anterior recurrent shoulder dislocations using computerized axial tomography. *Orthop Rev.* 1989;18:84–91.
- Mair SD, Zarzour RH, Speer KP. Posterior labral injury in contact athletes. *Am J Sports Med.* 1998;26:753–8.
- Kothary S, Rosenberg ZS, Poncinelli LL, Kwong S. Skeletal development of the glenoid and glenoid-coracoid interface in the pediatric population: MRI features. *Skelet Radiol.* 2014;43:1281–8.
- Wright RW, Paletta GA Jr. Prevalence of the Bennett lesion of the shoulder in major league pitchers. *Am J Sports Med.* 2004;32:121–4.
- Walch G, Badet R, Boulahia A, Khoury A. Morphologic study of the glenoid in primary glenohumeral osteoarthritis. *J Arthroplast.* 1999;14:756–60.
- Harper KW, Helms CA, Haystead CM, Higgins LD. Glenoid dysplasia: incidence and association with posterior labral tears as evaluated on MRI. *AJR Am J Roentgenol.* 2005;184:984–8.
- Mirtz TA, Chandler JP, Eysers CM. The effects of physical activity on the epiphyseal growth plates: a review of the literature on normal physiology and clinical implications. *J Clin Med Res.* 2011;3:1–7.
- Ogden JA, Phillips SB. Radiology of postnatal skeletal development. VII. The scapula. *Skelet Radiol.* 1983;9:157–69.
- Siffert RS. The effect of trauma to the epiphysis and growth plate. *Skelet Radiol.* 1977;2:21–30.