Increased Glenoid Index as a Risk Factor for Pediatric and Adolescent Anterior Glenohumeral Dislocation

An MRI-Based, Case-Control Study

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Background: In adults, anterior glenohumeral instability has been associated with a tall and narrow glenoid morphology, assessed using the glenoid index (GI; glenoid height-to-width ratio) on magnetic resonance imaging (MRI). This morphological association has not been assessed in children and adolescents.

Purpose/Hypothesis: To examine the association of GI and other MRI measurements of interest supported in studies on adults with anterior glenohumeral dislocation in patients aged ≤19 years. We hypothesized that these patients would have a significantly greater GI (relatively taller and narrower glenoid morphology) compared with healthy controls.

Study Design: Case-control study; Level of evidence, 3.

Methods: An institutional radiology database was queried over a 10-year period to identify patients aged ≤19 years who had been diagnosed with radiographically confirmed anterior shoulder dislocation and who underwent glenohumeral magnetic resonance arthrography as well as those without dislocation with normal shoulder arthrogram studies (controls). Patients with bony Bankart lesions were excluded. The following glenohumeral dimensions were measured on shoulder arthrogram: GI, glenoid version, coracohumeral interval, and rotator interval width/depth. Comparative analysis between the 2 groups was performed using the Student *t* test for each variable, followed by receiver operating characteristic (ROC) analysis to determine discriminative ability when statistically significant.

Results: Overall, 55 participants (33 male and 22 female patients; mean age, 15.4 ± 2.1 years) were enrolled; 22 patients were in included in the dislocator group and 33 patients comprised the control group. The mean GI in the dislocator group was significantly greater than the control group (1.55 ± 0.14 vs. 1.38 ± 0.08; $P < .001$). ROC analysis revealed adequate discrimination of GI in predicting glenohumeral dislocation (area under the curve = 0.88). A GI ≥1.45 was 83% sensitive and 79% specific for predicting dislocation in the study cohort.

Conclusion: Patients with anterior glenohumeral dislocation had increased GI (taller and narrower glenoid morphology) than controls. This useful MRI measurement may help identify patients at risk for primary or recurrent anterior glenohumeral instability events and may therefore help with guiding treatment and prevention.

Keywords: glenoid index; shoulder; anterior dislocation; pediatrics

The overall estimated incidence of shoulder dislocation in the United States is 23.9 per 100,000 person-years with 46.8% of all dislocations occurring in patients between 15 and 29 years of age.[17] Approximately 20% of shoulder dislocations occur in patients younger than the age of 20 years. Traumatic anterior instability events, defined as subluxation and dislocation events, account for 80% of instability episodes experienced by young athletes.[12] Moreover, as reported by Wagner and Lyne,[16] the risk of recurrence after an initial event is 80% in the 12- to 16-year age group.

Given the significant morbidity associated with repeated dislocations, early identification of at-risk patients is paramount in the pediatric patient population.[13] Studies[8,10,12,17] in the adult population have examined and

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revealed risk factors for dislocation, including age and activity level. Other nonmodifiable risk factors include physical exam findings of ligamentous laxity as well as anterior apprehension and relocation signs.[1,11]

In a recent prospective study conducted at the US Military Academy, Owens et al[9] examined several anatomic landmarks on magnetic resonance imaging (MRI) and successfully identified 2 such landmarks as risk factors for instability in the adult population, including the glenoid index (GI, glenoid height-to-width ratio) and coracohumeral interval. However, this study included both dislocation and subluxation events. Furthermore, the implications of this in children and adolescents remain unknown. Thus, this retrospective case-control study was designed to examine the association of GI and other MRI measurements of interest supported in studies on adults with anterior glenohumeral dislocation in patients aged $\leq$19 years. We hypothesized that these patients would have a significantly greater GI (relatively taller and narrower glenoid morphology) compared with controls with no history of glenohumeral dislocation.

METHODS

Study Patients

After obtaining institutional review board approval for this study, we searched an institutional radiology database to identify direct magnetic resonance (MR) arthrograms of patients aged $\leq$19 years who were diagnosed with anterior shoulder dislocation (cases) and those as well as healthy shoulders (controls) over a 10-year study period (2005-2015). Because the World Health Organization defines an adolescent as someone from age 10 to 19 years, 19 years of age was chosen as the upper age limit.

Patients were included if there was a confirmed radiographic and clinical history of anterior glenohumeral dislocation, which was reduced in an emergency room or orthopaedic clinical setting. Patients with a documented history of congenital shoulder dislocation, previous shoulder surgery on the affected side, brachial plexopathy/neurologic injury, known connective tissue disorder, and humeral shaft or scapular body fracture, including bony Bankart fractures/glenoid bone loss after any dislocation event, were strictly excluded. Patients included those with first-time and recurrent dislocations. Subluxations and cases of atraumatic or multidirectional dislocation were excluded.

The control group consisted of patients included if they had undergone MR arthrogram without documented radiologic pathology of the affected side (eg, negative study). The majority of patients in the control group underwent MR arthrogram after presenting in the clinic with shoulder pain or shoulder contusion.Control patients were excluded if they had any subjective or objective documented history of an instability event (subluxation or dislocation) on the affected side, a physical examination consistent with glenohumeral instability, a known connective tissue disorder, or a history of previous shoulder surgery on the affected side. Because all available patients in the institutional radiology database were used for the current study, an a priori power calculation could not be performed.

Imaging

All patients underwent shoulder MR arthrograms within 1 hour after direct injection of gadolinium contrast. Contrast was injected via an anterior or posterior approach depending on radiologists' preferences. MRI protocol included fat-saturated T1-weighted images in the axial, coronal oblique, and sagittal oblique planes. The sagittal oblique plane is prescribed perpendicular to the long axis of the scapula, with the glenoid en face. Additional fluid-sensitive sequences were acquired in the axial and oblique coronal planes. In all sequences, the slice thickness was 3-4 mm without interslice gap.

An attending pediatric musculoskeletal radiologist (N.A.C.) and a fellowship-trained attending orthopaedic surgeon (J.T.L) measured the following glenohumeral dimensions on shoulder arthrogram: glenoid height, glenoid width, GI (Figure 1),[5,9] glenoid version, coracohumeral interval,[4] and rotator interval width and depth (Figure 2).[7] The 2 reviewers were blinded to each other's measurements.

Statistical Analysis

Descriptive statistics were used to report characteristic and glenoid morphology variables for the dislocator and control

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Ethical approval for this study was obtained from The Children's Hospital of Philadelphia (study No. IRB 15-011851).

groups. Interrater reliability of the glenoid morphology variables was assessed using the intraclass correlation coefficient ICC (2,k) based on absolute agreement and classified using the Landis and Koch criteria.[6] ICC (2,k) was chosen as the appropriate version of ICC because it is a 2-way analysis that assumes random error, and the mean of the glenoid morphology variables of the 2 raters was calculated for each patient to define a final accepted value for use in comparative analyses. After ensuring data normality, independent-sample Student *t* tests and chi-square analyses were used as appropriate to compare characteristic and glenoid morphology variables between groups. Logistic regression was used to evaluate significant glenoid morphology variables while controlling for characteristic variables (eg, age) with noted significant differences between the dislocator and control groups. Those glenoid morphology variables that were found to be statistically different between groups were loaded into a receiver operating characteristic (ROC) analysis to evaluate discriminative capacity. The threshold for acceptable discriminative capacity was an area under the ROC curve >0.80. All comparative analyses were 2-tailed and used $P < .05$ as the threshold for statistical significance. Because all eligible patients in the institutional database were used in the current study, an a priori power calculation could not be performed.

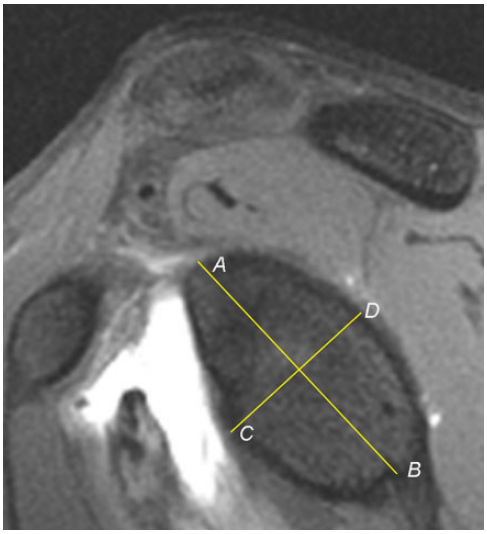

Figure 1. Magnetic resonance arthrogram in the sagittal oblique plane showing measurement of the glenoid index (GI). The glenoid height (*AB*) was measured from the superior glenoid tubercle to the inferior glenoid, and glenoid width (*CD*) was measured from the widest part of the glenoid, perpendicular to the height axis. The GI was calculated as *AB*/*CD*.

RESULTS

In total, 33 male and 22 female patients (mean age, 15.4 ± 2.1 years) met the inclusion and exclusion criteria for this study. The dislocator group was composed of 22 patients, 14 (63.6%) boys and 8 girls (36.4%), and the control group was composed of 33 patients, 19 (57.6%) boys and 14 girls (42.4%). Of note, the dislocator group was statistically significantly older than the control group (16.41 ± 1.33 vs. 14.73 ± 2.29 years; $P = .001$). Table 1 displays a characteristic data comparison between the study groups.

Interrater reliability between the attending pediatric musculoskeletal radiologist and fellowship-trained attending orthopaedic surgeon was acceptable (ICC > 0.7) for all glenoid morphology variables (Table 2). Reliability was substantial for GI and almost perfect for glenoid version,

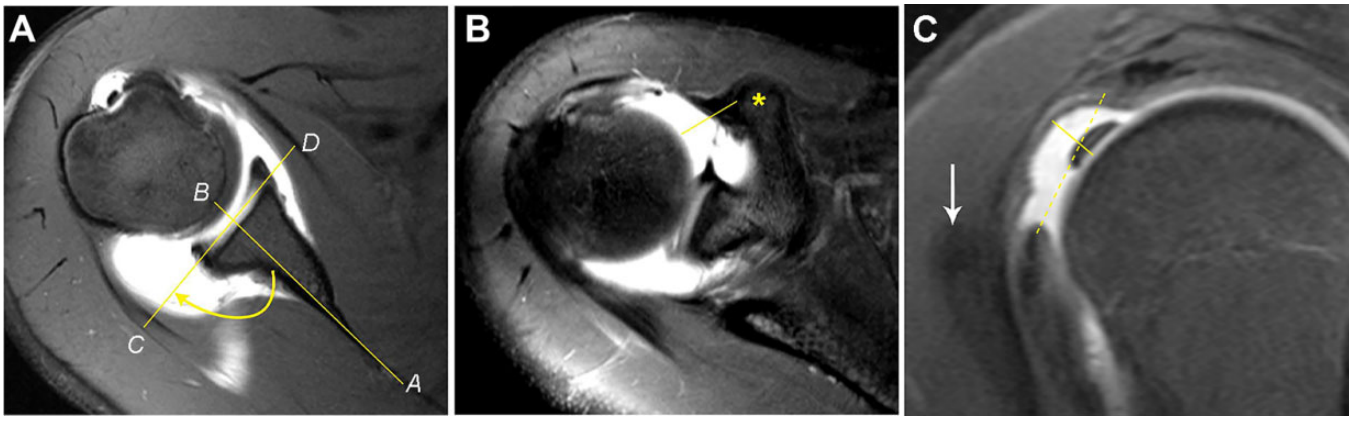

Figure 2. (A) Glenoid version on magnetic resonance (MR) arthrogram in the axial plane through the midglenoid. Line *AB* is from the medial scapular tip to the midpoint of the glenoid. A second line along the glenoid surface is drawn (*CD*). The glenoid version is calculated by $\angle ABC - 90^\circ$. (B) The coracohumeral interval on MR arthrogram in the axial plane is the shortest distance (yellow line) between the outer cortices of the coracoid process (*) and the adjacent humeral head. (C) Rotator interval width and depth on MR arthrogram in the sagittal oblique plane with the most lateral aspect of the coracoid process present (arrow). The rotator interval width is measured from the superior border of the subscapularis tendon to the anterior border of the supraspinatus tendon (dashed line). The rotator interval depth is the longest perpendicular distance from the humeral head to the roof of the rotator interval capsule (solid line).

TABLE 1
Demographic Characteristics of the Dislocator and Control Groups[a]

Variables	Dislocator Group (n = 22)	Control Group (n = 33)	*P* (test)
Age, y, mean ± SD (range)	16.41 ± 1.33 (14-19)	14.73 ± 2.29 (10-19)	**.001** (*t* test)
Body mass index, kg/m^2, mean ± SD)	25.73 ± 6.10	24.00 ± 4.94	.282 (*t* test)
Sex, % male	57.6	63.6	.653 (χ^2 test)

[a]Bolded *P* value indicates statistically significant between-group difference ($P < .05$).

TABLE 2
Interrater Reliability for Radiology Measurements[a]

Glenoid Morphology Variable	ICC (2,k)
Glenoid version	0.827
Coracohumeral interval	0.908
Glenoid index	0.796
Rotator interval width	0.921
Rotator interval depth	0.838

[a]ICC, intraclass correlation coefficient.

TABLE 3
Comparison of Glenoid Morphology Between the Dislocator and Control Groups[a]

Glenoid Morphology Variable	Dislocator Group	Control Group	*P* (*t* test)
Glenoid version (mm)	86.80 ± 4.11	86.03 ± 2.14	.802
Coracohumeral interval (mm)	12.76 ± 2.87	11.93 ± 2.87	.298
Glenoid index	1.55 ± 0.14	1.38 ± 0.08	<**.001**
Rotator interval width (mm)	17.36 ± 3.42	18.63 ± 2.80	.136
Rotator interval depth (mm)	9.27 ± 2.75	9.91 ± 2.61	.389

[a]Bolded *P* value indicates statistically significant between-group difference ($P < .05$).

coracohumeral interval, rotator interval width, and rotator interval depth.[6]

Glenoid morphology and glenohumeral dimensions were evaluated on MR arthrogram and compared between the 2 groups (Table 3). GI was the only variable found to be significantly different, with the dislocator group having a higher GI when compared with the control group (1.55 ± 0.14 vs. 1.38 ± 0.08; $P < .001$). This finding remained statistically significant when controlling for age in a logistic regression analysis ($P = .002$). Furthermore, ROC analysis revealed adequate discrimination of GI in predicting glenohumeral dislocation (Figure 3, area under the curve = 0.88). A GI ≥1.45 was determined to be 83% sensitive and 79% specific for predicting dislocation in the study cohort.

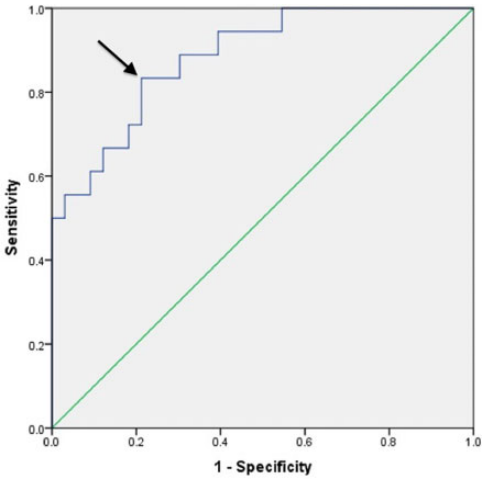

Figure 3. ROC analysis of GI as a predictor of shoulder dislocation. Area under curve = 0.88 (threshold of acceptability was >0.80); Glenoid index ≥1.45 (arrow) was 83% sensitive and 79% specific for predicting dislocation in this cohort.

DISCUSSION

In this case-control study, we demonstrated that patients with anterior glenohumeral dislocation had greater GI measurements when compared with controls. That is to say, patients with a taller and narrower glenoid morphology are at greater risk for anterior glenohumeral dislocation. These findings are consistent with those reported by Owens et al[9] in their adult cohort. In the current study, a GI ≥1.45 was 83% sensitive and 79% specific for predicting glenohumeral dislocation. While on first take, the absolute difference in GI between the dislocator and control groups seems small (1.55 ± 0.14 vs. 1.38 ± 0.08), the high interrater reliability and extremely low variance within each cohort (eg, standard deviation) makes it an excellent predictor of glenohumeral dislocation in this population as evidenced by the results of the ROC analysis.

In addition to differences in GI, Owens et al[9] also reported increasing coracohumeral distance as a risk factor for anterior glenohumeral instability in their prospective study. It was theorized that a greater coracohumeral distance may result in less effective stabilization by both the dynamic and static glenohumeral stabilizers.[9] However, in our retrospective adolescent cohort, while the dislocators had a higher measured coracohumeral interval than controls (12.76 ± 2.87 mm vs. 11.93 ± 2.87 mm), this was not a statistically significant difference. This finding may be age-related or the result of some other factors including sample-size limitations.

This study has several limitations and strengths. A case-control study design is the most appropriate, as a similar prospective study in a pediatric and adolescent cohort would require unfeasible resource utilization including MR arthrography on otherwise healthy children. Aside from the inherent limitations of a retrospective design, both our dislocator and control groups had relatively small sample sizes. Yet, this relates to 1 of the several strengths of the study: stringent inclusion and exclusion criteria. Only true anterior dislocation events documented both via clinical procedural notes and on radiograph and patients who underwent MR arthrogram were included in the dislocator group. Strict exclusion criteria applied for the control arm of the study as well. The authors acknowledge the fact that since the control patients underwent MR arthrogram for various reasons, they may have had unrelated underlying pathology. However, in analyzing the control group, any subjective or objective inclination of joint instability in clinic notes, imaging, or otherwise warranted strict exclusion from our study.

Patients in the dislocator group were evaluated based on the first MRI obtained to evaluate their shoulder. Most, but not all, received this study after their first dislocation, which is another inherent limitation to this study (ie, in a minority of patients, history of dislocation was unclear; thus, the small specific number of recurrent dislocators is unavailable, but is worthy of mention as a study limitation). While it is conceivable that glenoid dimensions may be affected after glenohumeral trauma, thus affecting final glenoid height and width measurements and GI calculations, all patients who sustained a bony Bankart lesion (thus directly affecting glenoid anatomy), humeral shaft, or scapular body fracture were strictly excluded from the study. In the future, perhaps an internal case-control study can be designed to compare the GI of the uninjured shoulder with the injured shoulder, allowing for the examination of these measurements and potential risk factors within the same patient.

While the trauma history of these dislocations and activity level of the patients are certainly important, we did not feel that we could accurately quantify the degree of trauma or level of activity in all of the patients based on the history available in the medical record, so this was not included in the analysis. Similarly, although all office notes and operative reports (where applicable) were reviewed for each patient in an effort to extract standard physical exam findings, because of the heterogeneous nature of these data, we did not feel that reliable and meaningful conclusions could be drawn, and they were therefore not included.

Another potential limitation of the study centers on the mean age difference between the 2 study groups, with the dislocators being clinically slightly, yet statistically significantly, older than the controls (16.41 versus 14.73 years; $P = .001$). We understand that this had the possibility of introducing bias if age confounded the relationship between GI and glenohumeral dislocation. However, to proactively account for this, we utilized logistic regression to control for age, and the relationship between GI and glenohumeral dislocation remained significant, thus excluding it as a potential confounding variable.

Identifying *modifiable* risk factors for shoulder instability, such as glenohumeral strength deficits, may be important for injury prevention. However, while some have suggested that strength deficits may be associated with recurrent instability, a subsequent prospective study failed to identify rotator cuff strength deficits as a risk factor for first-time anterior instability.[2,14] While patients cannot change their glenoid morphology, knowledge of the *nonmodifiable* risk factors identified here can still prove useful in providing guidance to patients and their families. Indices such as the Instability Shoulder Index Score[15] and various morphological measurements such as assessment of the degree of anterior glenoid bone loss[3] have been proposed as tools to help drive clinical decision-making in anterior instability. Knowing the glenoid morphology associated with stability versus instability may therefore also help in clinical and surgical decision-making and even, perhaps, in implementing prevention protocols for recurrent dislocation or contralateral dislocation if certain nonmodifiable risk factors are identified. While GI has been identified as a risk factor for anterior glenohumeral dislocation, it would be interesting to further examine the impact and association of GI in patients with recurrent dislocations or instability events. Furthermore, perhaps the results from this study may influence nonoperative and surgical treatment. For example, if a tall and narrow glenoid is associated with dislocation and/or recurrent dislocation, does a threshold GI value exist for earlier interventions to decrease GI, such as bone block procedures (eg, Latarjet)? Future studies can examine some of these questions in greater detail.

In conclusion, this is the first study to measure and report glenohumeral morphological differences measured on MR arthrogram between patients who sustained anterior shoulder dislocation and controls (patients undergoing MR arthrography for other reasons) in the pediatric and adolescent patient population. From this analysis, a taller and narrower glenoid morphology with a GI >1.45 has been identified as a sensitive and specific marker for predicting pediatric patients at risk for a glenohumeral dislocation. This significant MRI measurement may help identify patients at risk for primary or recurrent anterior glenohumeral instability events and may help guide treatment and anticipatory guidance for those who have already dislocated.

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