J Shoulder Elbow Surg (2021) 30, 756–762

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Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Glenoid vault and humeral head alignment in relation to the scapular blade axis in young patients with pre-osteoarthritic static posterior subluxation of the humeral head

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Background: Static posterior subluxation of the humeral head is a pre-osteoarthritic deformity preceding posterior erosion in young patients. Its etiology remains unknown. The aim of this study was to analyze the differences in scapular morphology between young patients with pre-osteoarthritic static posterior subluxation of the humeral head and healthy controls with a centered humeral head.
Methods: We performed a retrospective analysis of all patients with pre-osteoarthritic static posterior subluxation of the humeral head who were treated in our institution between January 2018 and November 2019. Fourteen shoulders in 12 patients were included in this study and then matched according their age, sex, and affected side with controls. Computed tomography images of both groups were compared in the standardized axial imaging plane for differences in scapular morphology. The following parameters were measured: glenoid version relative to the Friedman line and scapular blade axis, scapulohumeral and glenohumeral subluxation index, and neck angle, as well as glenoid and humeral offset.
Results: The patients in the subluxation group showed significantly higher scapulohumeral and glenohumeral subluxation indexes than controls (0.76 vs. 0.55 [$P < .0001$] and 0.58 vs. 0.51 [$P = .016$], respectively). The mean measurements of glenoid version according to the Friedman line and relative to the scapular blade axis were significantly higher in the subluxation group than in controls (19° vs. 4° [$P < .0001$]and 14° vs. 2° [$P = .0002$], respectively). The glenoid vault was significantly more anteriorly positioned with respect to the scapular blade axis in the subluxation group than in controls (neck angle, 166° vs. 173° [$P = .0003$]; glenoid offset, 9.2 mm vs. 4.6 mm [$P = .0005$]). The midpoint of the humeral head showed a posterior offset with respect to the scapular blade axis in the subluxation group, whereas controls had an anteriorly placed midpoint of the humeral head (–2 mm vs. 3.1 mm, $P = .01$). A higher scapulohumeral subluxation index showed significant correlations with an increased anterior offset of the glenoid vault (increased glenoid offset: $r = 0.493$, $P = .008$ and decreased neck angle: $r = –0.554$, $P = .002$), a posterior humeral offset ($r = –0.775$, $P < .0001$), and excessive glenoid retroversion measured by both methods (Friedman line: $r = 0.852$, $P < .0001$; scapular blade axis: $r = 0.803$, $P < .0001$). A higher glenohumeral subluxation index also correlated significantly with an increased anterior offset of the glenoid vault (increased glenoid offset: $r = 0.403$, $P = .034$; decreased neck angle: $r = –0.406$, $P = .032$) and posterior humeral offset ($r = –0.502$, $P = .006$).

The study protocol (application no. EA2/076/18) was reviewed and approved by the institutional review board (Charité Universitätsmedizin). Approval from the institutional ethics committee was obtained prior to the onset of this investigation.

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https://doi.org/10.1016/j.jse.2020.08.004

Conclusion: Young patients with pre-osteoarthritic static posterior subluxation of the humeral head have significant constitutional differences in scapular morphology in terms of an increased anterior glenoid offset, excessive glenoid retroversion, and increased posterior humeral offset in relation to the scapular blade compared with healthy matched controls.
Level of evidence: Anatomy Study; Imaging

Keywords: Glenoid retroversion; static posterior subluxation; anterior glenoid offset; posterior humeral offset; scapular blade axis; scapular morphology

The ABC classification separates posterior shoulder instability into acute (type A), dynamic (type B), and static (type C) and further distinguishes static posterior shoulder instability into constitutional posterior decentering (type C1) and acquired posterior decentering (type C2).[13] Although the cause of acquired static posterior shoulder instability (type C2) is clearly linked to traumatic posterior instability events, for example, due to macrotrauma or seizures, the etiology of constitutional static posterior shoulder instability remains controversial.[4,7] Because static posterior humeral subluxation has been recognized as a pre-osteoarthritic deformity that might lead to early-onset posterior decentering osteoarthritis,[17] it is of interest and importance to identify structural risk factors contributing to this development.

Increased retroversion of the glenoid is recognized by some authors as the only possible cause of the humeral static subluxation, whereas others have questioned this.[6-8,15] Corrective glenoid osteotomy, while effective in restoring glenoid version, does not necessarily correct posterior humeral subluxation, meaning that excessive glenoid version may not be the primary cause of the humeral head subluxation.[9] Hoenecke et al[7] and Landau and Hoenecke[9] have lately highlighted the modular development of the scapular body and the glenoid vault controlled by independent genes and environmental factors, resulting in diverse morphologic scapular body–vault combinations. This variable relationship between the scapular body and glenoid vault may alter the relationship with the line of action of the rotator cuff and result in posterior subluxation of the humeral head.[4] Therefore, the aim of this study was to analyze the glenoid vault morphology and its position in relation to the presumed line of action of the anteroposterior force couple of the rotator cuff in young patients with pre-osteoarthritic static posterior subluxation of the humeral head compared with healthy controls with a centered humeral head.

Materials and methods

Study population

This was a retrospective case-control study analyzing patients with pre-osteoarthritic static posterior subluxation of the humeral head (type C) who were treated in our institution between January 2018 and November 2019. Patients with a known cause of the static posterior instability (eg, trauma or seizure) (type C2) were excluded. Thus, 14 shoulders in 12 patients with type C1 pathology were identified and included in this study. All patients had received preoperative computed tomography (CT) scans of the affected shoulder in the supine position with the arms at the side and elbows resting on the examination table with complete depiction of the scapula and humeral head. These patients were then matched according their age (within 5 years), sex, and affected side with patients from our institutional radiology database who had received positron emission tomography–CT scans meeting the following inclusion criteria: (1) supine position with the arms at the side and elbows resting on the examination table, (2) complete depiction of the scapula and humeral head, and

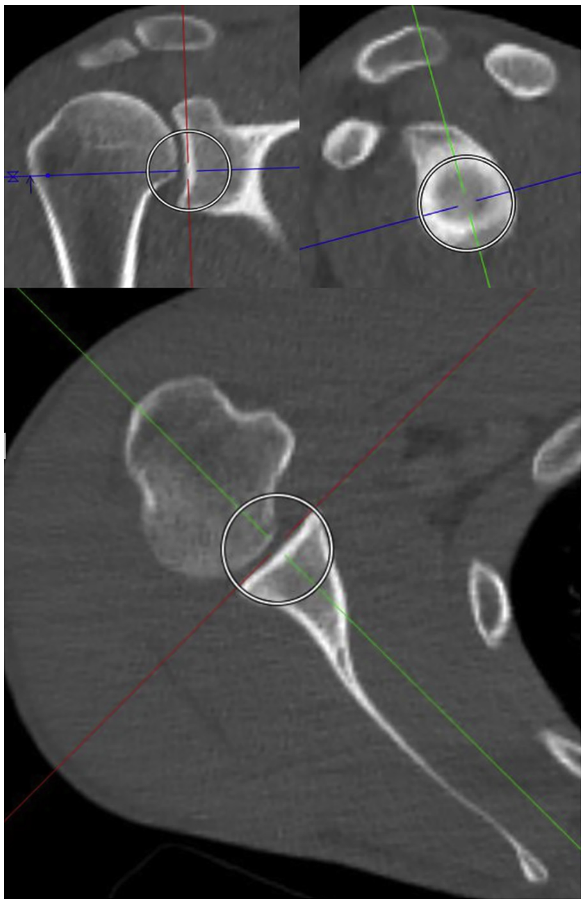

Figure 1 Multiplanar reconstruction to define the standardized axial imaging plane (———), which is perpendicular to the long axis of the glenoid (———) and passes through the center of the best-fit circle *(white)* drawn on the en face view of the glenoid. The ——— represent the glenoid axis.

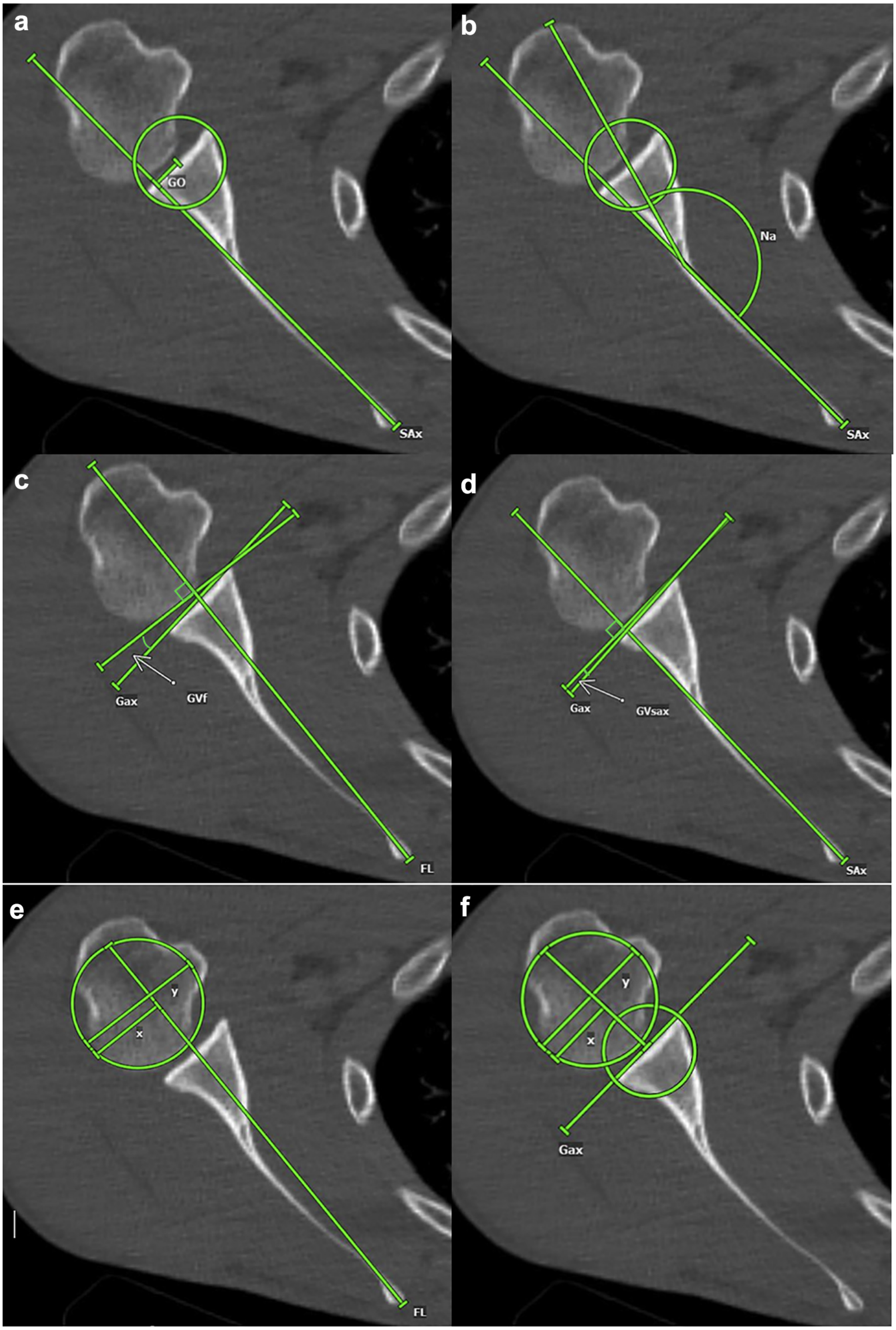

Figure 2 Measurements of glenoid offset *(GO)* (**a**), neck angle *(Na)* (**b**), glenoid version according to Friedman line *(GVf)* (**c**), glenoid version relative to scapular blade axis *(GVsax)* (**d**), scapulohumeral subluxation index *(x/y)* (**e**), and glenohumeral subluxation index *(x/y)* (**f**). *SAx*, scapular blade axis; *Gax*, glenoid axis; *FL*, Friedman line.

(3) centered humeral head with no signs of glenohumeral osteoarthritis. Patients with visual pathologies of the upper extremities (eg, fractures, prostheses, or dysplasia) were excluded. A total of 14 healthy shoulders in 11 control patients were identified and included in the study.

Image selection for measurements

A standardized axial imaging plane for all measurements was created using a multiplanar reconstruction as previously described.[12] The standardized axial imaging plane was defined as the perpendicular imaging plane to the long axis of the glenoid that passes through the center of the best-fit circle drawn on the en face view of the glenoid (Fig. 1).[11]

Image measurements

For all measurements, CT scan data were used. All measurements were performed with Visage software (version 7.1; Visage Imaging, Berlin, Germany). The glenoid axis was defined as the tangent between the anterior and posterior rims of the glenoid. The scapular blade axis was defined as the line of best fit between the medial border of the scapula and the beginning of the glenoid vault.[7] Glenoid version was measured according to the method of Friedman et al[5] and relative to the scapular blade axis as described by Hoenecke et al.[7] Humeral head subluxation was calculated using the glenohumeral and scapulohumeral subluxation indexes.[4] The glenohumeral subluxation index uses a line drawn as a perpendicular line to the glenoid joint surface passing its middle. The percentage of the humeral head posterior to this line is measured at the longest anteroposterior diameter. The scapulohumeral subluxation index uses the Friedman line as a reference, and the percentage of the humeral head posterior to the Friedman line is assessed at the longest anteroposterior diameter of the humeral head on a line perpendicular to the Friedman line. Furthermore, the neck angle and glenoid offset were used to measure the displacement of the glenoid vault in relation to the scapular blade. The neck angle was defined as the angle between the scapular blade axis and a line between the beginning of the glenoid vault and the midpoint of the glenoid surface. Glenoid offset was defined as the perpendicular distance between the scapular blade axis and the midpoint of the glenoid surface. All measurements are shown in Figure 2.

In addition, glenoid vault tapering from lateral to medial was determined similarly to previously published methods.[11] The vault extent was measured from lateral to medial as the perpendicular distance to the scapular blade axis from the anterior and posterior edges of the glenoid and then in 5-mm steps for a total of 13 measurements. In addition, humeral offset was measured as the perpendicular distance to the scapular blade axis from the midpoint of the humeral head (Fig. 3).

Statistical analysis

Two raters (P.S. and D.A.) conducted the measurements independently at different time points. The intraclass correlation coefficient (ICC) with the 95% confidence interval was calculated for all measurements. As recommended by Landis and Koch,[10] an ICC $\leq$ 0.20 indicates slight agreement; 0.21-0.40, fair agreement; 0.41-0.60, moderate agreement; 0.61-0.80, substantial agreement; and $\geq$0.81, almost perfect agreement. After reliability assessment, the values of both raters were averaged for further analysis. The Kolmogorov-Smirnov test was used to test for normal distribution. The 2-sample t test (for parametric distributions) or Mann-Whitney U test (for nonparametric distributions) was used to compare continuous variables between groups. Correlation analyses were performed using the Pearson correlation coefficient. The results were given as the mean and standard deviation or as the number and percentage. For statistical analyses, IBM SPSS Statistics software (version 25.0; IBM, Armonk, NY, USA) was used. $P < .05$ was considered statistically significant.

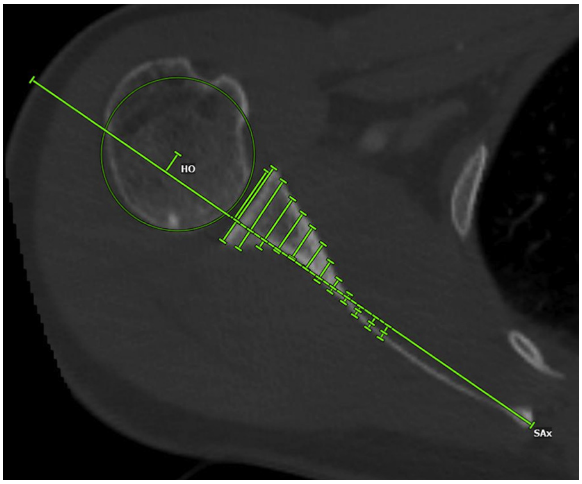

Figure 3 Example of measurements performed to determine the tapering of the glenoid vault from lateral to medial and the humeral offset *(HO)*. The vault extent was measured from lateral to medial as the perpendicular distance to the scapular blade axis (*SAx*) from the anterior and posterior edges of the glenoid and then in 5-mm steps toward medial for a total of 13 measurements.

Results

No significant difference was found between the subluxation group and the matched control group in terms of age, sex, affected side, weight, and height (Table I). All measurements showed almost perfect agreement between the 2 raters. ICCs are summarized in Table II.

Measurements

The results of the measurements and comparisons between groups are summarized in Table III. Glenoid vault morphology in both groups is depicted in Figure 4. Major differences in the tapering of the vault and scapular blade from lateral to medial were detected between the 2 groups, with more anterior positioning of the vault in the subluxation group. The midpoint of the humeral head showed a posterior offset with respect to the scapular blade axis in the subluxation group, whereas controls had an anteriorly placed midpoint of the humeral head (–2 mm vs. 3.1 mm, $P = .01$).

Table I General characteristics of subluxation and matched control groups

	Subluxation group (n = 14)	Control group (n = 14)	*P* value
Age, yr	30.3 ± 11.8	30.2 ± 11.2	>.999
Sex	12 M	11 M	>.999
Side	10 R/4 L	10 R/4 L	>.999
Height, cm	182.5 ± 10.6	180.2 ± 10.6	.6
Weight, kg	84.5 ± 23.9	76.3 ± 17.6	.4

M, male; *R*, right; *L*, left.
Data are given as mean ± standard deviation or number of shoulders.

Table II Calculated ICCs for all measurements

	ICC	95% CI		Agreement
		Lower bound	Upper bound	
Glenoid offset	0.887	0.743	0.949	Almost perfect
Neck angle	0.916	0.819	0.961	Almost perfect
Glenoid version				
Friedman method	0.989	0.977	0.995	Almost perfect
Relative to scapular blade axis	0.982	0.956	0.992	Almost perfect
Glenohumeral subluxation index	0.931	0.851	0.968	Almost perfect
Scapulohumeral subluxation index	0.983	0.963	0.992	Almost perfect
Humeral offset	0.993	0.989	0.995	Almost perfect
Tapering	0.989	0.987	0.990	Almost perfect

ICC, intraclass correlation coefficient; *CI*, confidence interval.

Table III Measurement comparison between subluxation and matched control groups

	Subluxation group (n = 14)	Control group (n = 14)	*P* value
Scapulohumeral subluxation index	0.76 ± 0.1	0.54 ± 0.03	<.0001
Glenohumeral subluxation index	0.58 ± 0.1	0.51 ± 0.02	.016
Glenoid version, °			
Friedman method	19 ± 10	4 ± 3	<.0001
Relative to scapular blade axis	14 ± 10	2 ± 3	.0002
Glenoid offset, mm	9.2 ± 3.7	4.6 ± 2.1	.0005
Neck angle, °	166 ± 6	173 ± 3	.0003
Humeral offset, mm	−2 ± 6.5	3.1 ± 2.9	.01

Data are given as mean ± standard deviation.

A higher scapulohumeral subluxation index showed a significant correlation with an increased anterior offset of the glenoid vault (increased glenoid offset and decreased neck angle) (increased glenoid offset: $r = 0.493$, $P = .008$; decreased neck angle: $r = –0.554$, $P = .002$), a posterior humeral offset ($r = –0.775$, $P < .0001$), and excessive glenoid retroversion measured by both methods (Friedman line: $r = 0.852$, $P < .0001$; scapular blade axis: $r = 0.803$, $P < .0001$). A higher glenohumeral subluxation index also correlated significantly with an increased anterior offset of the glenoid vault (increased glenoid offset: $r = 0.403$, $P = .034$; decreased neck angle: $r = –0.406$, $P = .032$) and posterior humeral offset ($r = –0.502$, $P = .006$) but not with glenoid retroversion measured by both methods (Friedman line: $r = 0.146$, $P = .46$; scapular blade axis: $r = 0.076$, $P = .70$).

Discussion

According to the results of this study, patients with preosteoarthritic static posterior subluxation of the humeral head inherently differ from healthy controls in terms of an anteriorly displaced glenoid vault in relation to the scapular blade and excessive glenoid retroversion (Fig. 5). In addition to these bony differences, the subluxation group showed a posterior translation of humeral head with respect to the scapular blade axis, whereas the controls had an anteriorly translated humeral head. Significant correlations were also found between the scapulohumeral subluxation index and increased anterior offset of the glenoid vault, excessive retroversion, and posterior humeral offset, as well as between the glenohumeral subluxation index and

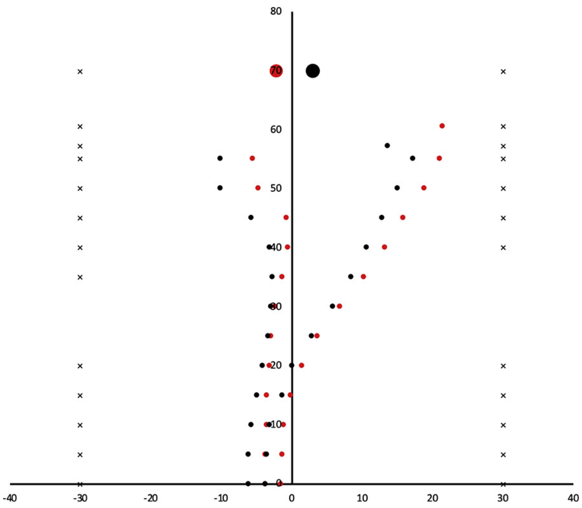

Figure 4 Scatter plot with millimeter scale showing the average tapering of the glenoid vault and scapular blade from lateral to medial in the standardized axial imaging plane in the subluxation group (•) and control group (•). The ● and ● represent the humeral head midpoint. The *y-axis* represents the scapular blade axis. Statistically significant differences are marked (*x*).

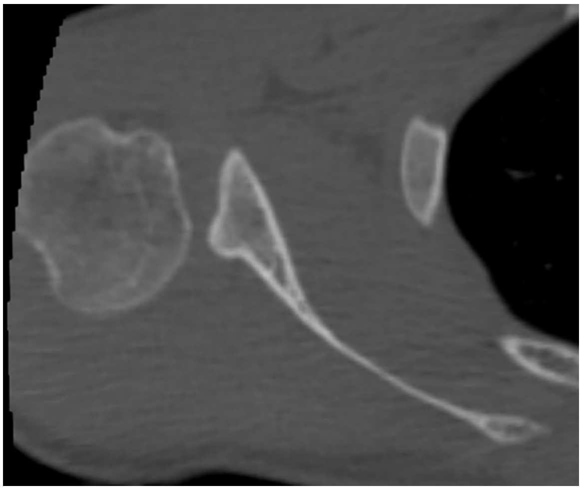

Figure 5 Static posterior subluxation of the humeral head in combination with increased anterior glenoid offset and excessive glenoid retroversion without any signs of osteoarthritis.

increased anterior offset of the glenoid vault and posterior humeral offset.

The strong association between increasing posterior humeral head subluxation and an anteriorly displaced glenoid vault in relation to the scapular blade has not been previously described, to our knowledge. On the basis of our results, it is likely that the posterior subluxation of the humeral head may be associated not only with rotator cuff asymmetries[1] but also with constitutional bony abnormalities, such as an increased anterior glenoid offset. Although it seems logical that the anterior glenoid offset could alter the relationship with the line of action of the rotator cuff and result in posterior subluxation of the humeral head, the occurring order of events remains unclear. Landau and Hoenecke[9] have recently emphasized the modular development of the glenoid vault and scapular blade governed by independent factors. Although the development of the scapular body is dependent on the surrounding thoracic shape, muscular imbalances can significantly alter the bony development of the glenoid. Literature studying glenoid changes seen in brachial plexus birth palsy clearly shows the direct association between the severity of the muscular imbalance and the severity of glenoid abnormality, especially excessive glenoid retroversion.[2,3,14] Given that the unaffected shoulder undergoes normal growth in patients with brachial plexus birth palsy, the surrounding muscles must be capable of producing forces that contribute to shoulder deformity, and genetic influences do not seem to be the only possible cause.[2] Nonetheless, there are also rare cases with glenoid dysplasia or hypoplasia, which often occurs bilaterally and can be associated with further abnormalities of the scapula and humeral head.[18] These cases may be caused by pathologic gene regulations, especially the *HOXC6* gene, which is integral for glenoid development.[9] In our study, the subluxation group showed a clear difference in scapular morphology compared with the controls in terms of an anterior glenoid offset, excessive glenoid retroversion, and posterior humeral offset. The causes leading to these differences between the 2 groups, however, remain unclear.

Currently, no consensus exists in the literature regarding the relationship between glenoid retroversion and humeral head subluxation. Whereas Walch et al[17] identified increased retroversion as the main risk factor for posterior humeral head subluxation in young patients, other studies did not support this finding.[6,7] Recently, Terrier et al[16] were able to find a strong correlation between glenoid version and scapulohumeral subluxation, showing an association of each degree of glenoid version with a percentage of subluxation in the same orientation. However, it is important to underline that the glenohumeral subluxation index may not be the optimal reference for evaluating subluxation.[4] Indeed, the humeral head can perfectly align with the glenoid fossa but may still be misaligned with the scapula and, most important, with the rotator cuff action lines, especially in patients with dysplastic glenoids. This was also confirmed by our findings. The glenohumeral subluxation index was significantly lower than the scapulohumeral subluxation index in the subluxation group (0.58 vs. 0.76, $P < .0001$), and no correlation was found between the glenohumeral subluxation index and retroversion.

This study has some limitations. Although the standardized axial imaging plane for all measurements was created using a multiplanar reconstruction, small variations in coronal and sagittal alignment can significantly affect the chosen axial reconstruction plane and the performed measurements. To reduce the effects of this limitation, 2 raters conducted the measurements independently; they showed almost perfect agreement in all measurements. The measurements performed in this study were obtained with the patients in the supine position with their arms at the side without any standardized arm rotation, which could have altered our results, owing to different translation of the humeral head depending on the arm rotation. Finally, the patients analyzed in this study were retrospectively analyzed, and the different clinical indications applied for positron emission tomography–CT scans can lead to a potential selection bias.

Conclusion

Young patients with pre-osteoarthritic static posterior subluxation of the humeral head have significant constitutional differences in scapular morphology in terms of an increased anterior glenoid offset, excessive glenoid retroversion, and increased posterior humeral offset in relation to the scapular blade compared with healthy matched controls.

Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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