J Shoulder Elbow Surg (2021) 30, 324–330

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Journal of Shoulder and Elbow Surgery

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Natural history of glenoid bone loss in primary glenohumeral osteoarthritis: how does bone loss progress over a decade?

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Introduction: Progressive glenoid bone loss and humeral head subluxation occur in primary glenohumeral osteoarthritis (GHOA), but less is known about the rate and pattern by which this occurs. The purpose of this study was to determine how glenohumeral subluxation and glenoid bone loss changed over time in shoulders that underwent arthroplasty and had been evaluated with radiographs at 1 or more time points over the 5-15 years before arthroplasty.

Methods: We retrospectively identified 48 shoulders that had been evaluated with high-quality radiographs both before arthroplasty and at least once 5-15 years earlier. Axillary radiographs were used to classify glenoid morphology using the modified Walch classification on the oldest, most recent, and all intervening radiographs. The mean interval time between the oldest and most recent radiographs was 8.9 years (range 5-15 years). Nineteen patients had a single intervening radiograph (mean, 6.7 years from most recent radiograph; range 4.4-8.9 years), 6 patients had 2 (mean, 5.6 years; range 0.2-13.9 years), 3 had 3 (mean, 5 years; range 2.4-8.3 years), 2 had 5 (mean, 3.4 years; range 1.1-5.7 years), and 1 had 6 (0.5 years).

Results: Glenoid morphology on the earliest radiograph was classified as A1 in 22, A2 in 13, B1 in 1, B2 in 9, B3 in 1, and D in 2 shoulders. Walch A patterns identified on early radiographs most commonly maintained an A pattern over time, but 20% developed eccentric wear with 5 of 35 becoming B type and 2 of 35 becoming a D type before arthroplasty. All B-type glenoids remained B type. Classic progression of bone loss along the same concentric or eccentric "track" occurred 41% of the time, with 9 of 22 A1 glenoids becoming A2 glenoids, the only B1 glenoid becoming a B2 glenoid, and 56% (5/9) of B2 glenoids becoming B3 glenoids before arthroplasty. Only 15% (2/13) of A2 glenoids developed eccentric wear compared with 32% (7/22) of A1 glenoids.

Conclusion: In primary GHOA, humeral head subluxation and glenoid bone loss do progress over time, but not universally and not always through the same pathway. Shoulders presenting with posterior subluxation (B types) remained posteriorly subluxed. Shoulders presenting with concentric arthritis developed an eccentric pattern 20% of the time. For concentric arthritis, progression of bone loss from A1 to A2 occurred 41% of the time. For eccentric arthritis, progression of bone loss from B2 to B3 occurred 56% of the time.

Level of Evidence: Level IV; Case Series; Prognosis Study

Keywords: Glenoid morphology; glenohumeral osteoarthritis; humeral head subluxation; anatomic total shoulder arthroplasty; x-ray; Walch classification

Institutional Review Board approval was received from Mayo Clinic (17-004591).

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Primary glenohumeral osteoarthritis (GHOA) is known to be associated with various morphologic patterns. Currently, the classification scheme proposed by Walch is most commonly used to characterize primary GHOA regarding the glenoid in the axial plane. The initial Walch

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https://doi.org/10.1016/j.jse.2020.05.021

classification was later modified and includes several combinations that consider the position of the humeral head in reference to the glenoid as well as the presence or absence of bone loss (A1, A2, B1, B2, B3, C, and D).[2] Humeral head subluxation and bone loss are important when planning anatomic and reverse shoulder arthroplasty. Progressive subluxation and bone loss may need special reconstructive techniques.

When patients are evaluated for painful GHOA but the severity of their symptoms does not justify replacement surgery yet, patients need to be counseled about the possibility of progressive subluxation and bone loss. However, at the present time there is very limited information about how subluxation and bone loss occur. The assumption by many surgeons is that concentric patterns remain concentric and eccentric patterns remain eccentric. A major difficulty when trying to understand the natural history of subluxation and bone loss in primary GHOA relates to how difficult it is to procure high-quality radiographs of the same shoulders over time.

The purpose of this study was to determine how glenohumeral subluxation and glenoid bone loss in the axial plane changed over time in shoulders that underwent arthroplasty and had been evaluated with radiographs of the same shoulder at 1 or more time points over the 5-15 years before arthroplasty. We aimed to determine whether the natural history of primary glenohumeral arthritis could be described along "tracks" of pathologic progression (eg, B1 to B2 to B3) or if the evolution of arthritis over time was more fluid (eg, A2 to B2).

Methods

Patients

After institutional review board approval, we retrospectively identified all patients that had undergone a primary anatomic (n = 41, 85%) or reverse shoulder arthroplasty (n = 7, 15%) for primary GHOA between 2006 and 2016 to perform a cohort study. At our institution, all patients undergoing arthroplasty are evaluated with high-quality radiographs (anteroposterior views in internal and external rotation as well as axillary radiographs) and computed tomography (CT). Our Institutional Image Viewing Software Database was then queried to determine for how many of these shoulders we also had access to high-quality anteroposterior and axillary radiographs obtained from the same shoulder a minimum of 5 years before arthroplasty. If more than one set of radiographs were available from greater than 5 years before surgery, these were also included.

The final study sample consisted of 48 shoulders with primary GHOA, with radiographs available immediately before arthroplasty and 5-15 years prior. These shoulders were from 30 male and 18 female patients, with the right shoulder being affected 45% of the time. Patient age was an average of 62 years (range 40.9-83.1, standard deviation [SD] 11.0) at the time of the oldest (initial) radiograph and 70.9 years (range 48.5-88.6, SD 10.3) at the time of replacement surgery. The mean body mass index (BMI) was 32.8 (SD 7.0). Of all shoulders, 85% ended up receiving an anatomic shoulder arthroplasty, with the remaining receiving a reverse shoulder arthroplasty.

The mean interval time between the oldest and most recent radiographs for each shoulder was 8.9 years (range 5-15 years). Nineteen patients had a single intervening set of radiographs (mean, 6.7 years from most recent radiographs; range 4.4-8.9 years), 6 patients had 2 (mean, 5.6 years; range 0.2-13.9 years), 3 had 3 (mean, 5.0 years; range 2.4-8.3 years), 2 had 5 (mean, 3.4 years; range 1.1-5.7 years), and 1 had 6 (mean, 0.5 years) radiographs between the oldest and most recent radiograph. The remaining 17 patients had only 2 radiographs.

Evaluation of radiographs

All radiographs were qualitatively classified according to the modified Walch classification (Fig. 1).[8] Two observers (A.L.L. and J.S.S.) evaluated all radiographs in random order and independently. When disagreement occurred, the 2 observers discussed the images further until consensus was reached without a limitation on time. Additionally, humeral head subluxation was measured on all axillary radiographs at every individual time point. Because the os trigonum is not easily visualized in the majority of axillary radiographs, Friedman line could not be used to compare subluxation over time. As such, for the purposes of this study, we measured the humeral head subluxation index in reference to the face of the glenoid according to the methods used in the original Walch classification publication (Fig. 2).[1]

Statistical analysis

Data were extracted and standardized to arithmetic means and standard deviations as a measure of variance, taking sample size into account. Continuous variables were reported as mean with standard deviation, with the mean weighted for sample size. Categorical variables were reported as frequencies with percentages. Differences between continuous variables were evaluated using a 2-sample, 2-tailed, Mann-Whitney *U* test. Differences between categorical variables were evaluated using a χ^2 analysis or a Fisher exact test to account for small sample bias. All data were analyzed using JMP software, version 14.0.0 (SAS Institute Inc, Cary, NC, USA).

Results

Progression of humeral head subluxation and glenoid bone loss over time for all 48 shoulders included in this study is summarized in the flow diagram depicted in Fig. 3. On the earliest radiographs obtained, glenoids were classified as A1 in 22 (46%), A2 in 13 (27%), B1 in 1 (2%), B2 in 9 (19%), B3 in 1 (2%), and D in 2 (4%) shoulders. In this sample of 48 shoulders, no dysplastic joints (C type) were identified. The mean humeral head subluxation index for each subtype were 0.46 for A1, 0.48 for A2, 0.55 for B1, 0.58 for B2, 0.47 for B3, and 0.38 for D.

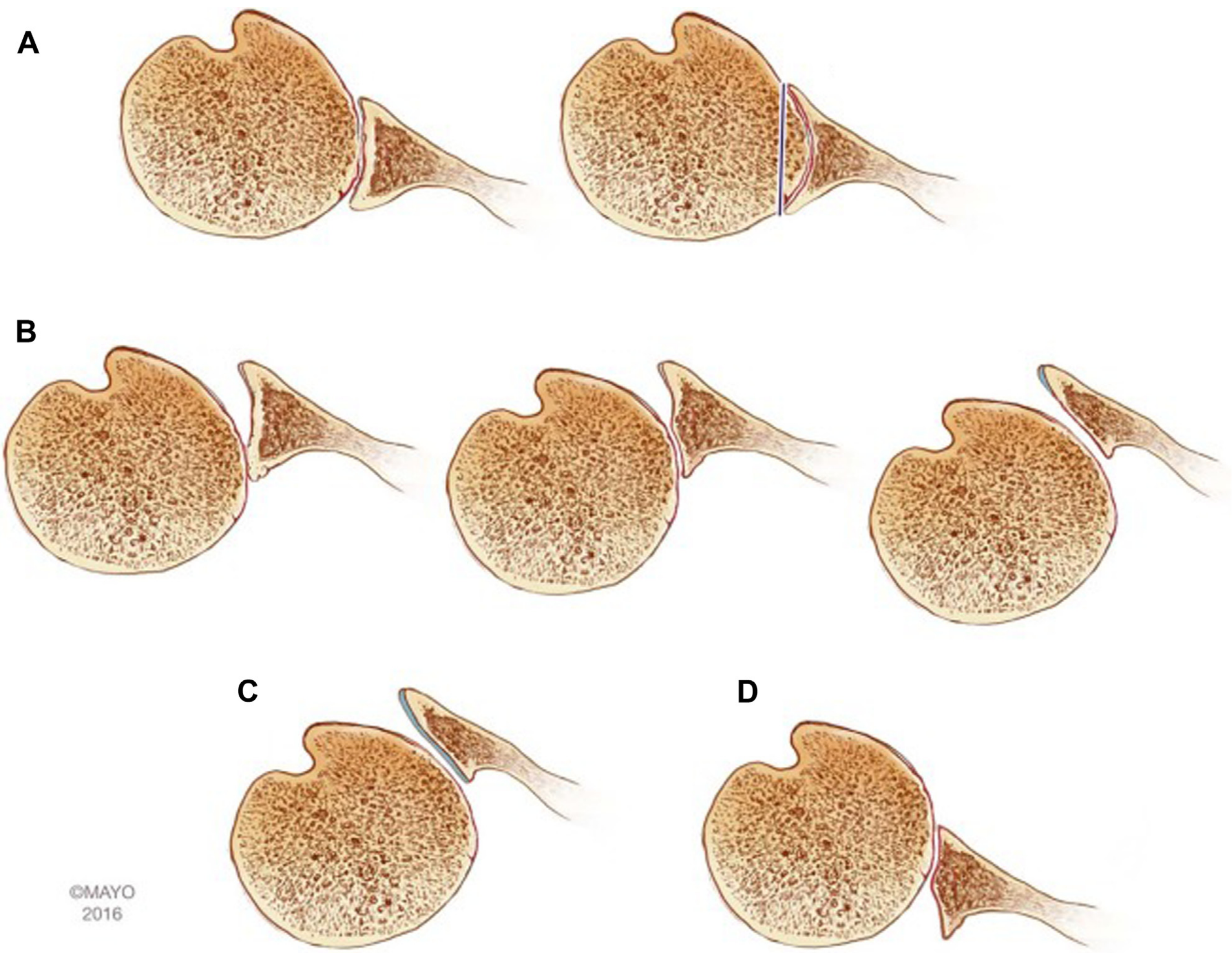

Figure 1 **(A-D)** Walch classification of glenoid morphology including contemporary modifications. (Used with permission of Mayo Foundation for Medical Education and Research. All rights reserved.)

Initial age at the time of the first radiograph was 60.2, 67.1, and 63.8 for A, B, and D Walch types, respectively ($P > .1$ for all comparisons). At the time of the preoperative radiograph, the age was 71.1, 70.5, and 71.3 years for the respective Walch types ($P > .9$ for all comparisons). In addition, there was no difference in mean BMI (A = 34.9, B = 30.5, D = 27.3; $P > .1$ for all comparisons) or gender ($P = .1$) between Walch glenoid types.

Forty-one percent (9/22) of the glenoids that were classified in the early time point as A1 were classified as A2 just before shoulder arthroplasty, whereas 32% (7/22) remained A1 glenoids. Among shoulders with an A2 glenoid at the early time point, 85% (11/13) remained A2 whereas 15% (2/13) transitioned to B3. Overall, 20% (7/35) of all A glenoids developed eccentric wear over time and became either a Walch B or Walch D type before surgery (Fig. 4). This was approximately twice as common for A1 glenoids (32%, 7/22) compared with A2 glenoids (15%, 2/13). The only B1 glenoid in this cohort transitioned to B2 morphology, and the only B3 glenoid remained B3 at the time of arthroplasty. Of all the B2 glenoids, 56% (5/9) transitioned to B3 whereas 44% (4/9) remained B2 before surgery. Both D glenoids within this cohort transitioned to a different morphology, with one transitioning to A1 and one transitioning to A2.

When assessed collectively as an A type, B type, or D type, 77% (27/35) of the A glenoids remained A and 100% (11/11) of the B glenoids remained B at the time of surgery, whereas no D-type glenoids remained the same. Classic progression of bone loss along the same concentric or eccentric "track" occurred 41% of the time, with 9/22 A1 glenoids becoming A2 glenoids, the only B1 glenoid becoming a B2 glenoid, and 56% (5/9) of B2 glenoids becoming B3 glenoids before arthroplasty.

Discussion

Primary GHOA may present with various degrees of humeral head subluxation and patterns of glenoid bone loss. Currently, the modified Walch classification is the most common system used to categorize various morphologic

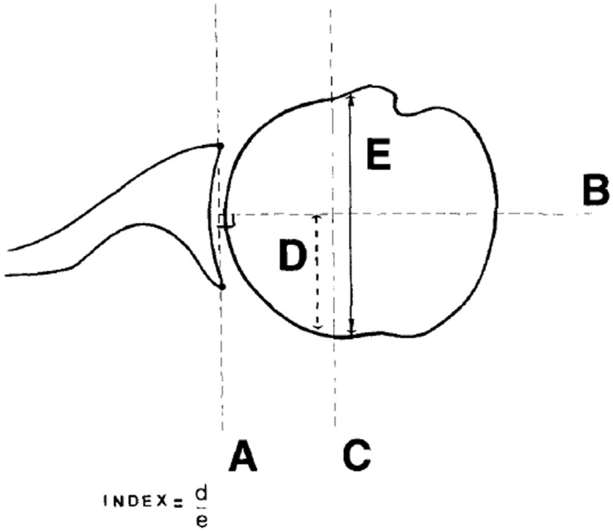

Figure 2 Humeral head subluxation index (HHSI) in reference to the face of the glenoid. *A* represents a line tangent to the anterior and posterior rims of the glenoid on an axillary radiograph; *B* represents a line bisecting the glenoid surface and perpendicular to *A*; *C* represents a line parallel to *A* and transecting the medial one-third of the humeral head; *D* represents the measured portion of the humeral head posterior to line *B* along line *C*; *E* is the measured diameter of the humeral head. 0.45 to 0.55 represents a well-centered humeral head, where <0.45 represents anterior subluxation and >0.55 represents posterior subluxation. (Used with permission from Walch et al 1999.[9])

patterns of GHOA.[8] Although the assumption is that concentric patterns remain concentric, eccentric patterns remain eccentric, and bone loss progresses from A1 to A2 and from B1 to B2 to B3, there is very limited available information on the natural history of GHOA. This is mainly due to the difficulty in collecting radiographs of the same shoulders decades apart. The results of our study seem to indicate that shoulders with an eccentric pattern at the time of presentation remain eccentric. In addition, shoulders with a concentric pattern at the time of presentation may remain concentric or develop eccentricity. Finally, bone loss leading to progression from A1 to A2 or from B2 to B3 occurs in approximately 40%-55% of the shoulders within 5-15 years.

To our knowledge, only one other study has investigated the natural history of primary GHOA. Walker et al[8] performed a retrospective case review of 65 shoulders with GHOA, all of which had 2 CT scans at least 2 years apart.[3] They found that A1 glenoids rarely demonstrated any concentric progression (5/42 or 12% progressed from A1 to A2) and that eccentric bone loss rarely occurred among all A glenoids (3/41 or 7% A1 progressed to a B pattern). The majority of the B1 glenoids in their study progressed to either B2 (79%, 15/19) or B3 (11%, 2/19).

Our study is similar in that we observed a very clear progression of glenoid bone loss along the "B track," with 100% of B1 glenoids and 56% of B2 glenoids becoming B2 and B3, respectively. However, our study differed in that 41% of concentric glenoids demonstrated progressive concentric wear and central glenoid erosion to become classified as A2 glenoids at a later time point. Furthermore, by the time of shoulder arthroplasty, 20% of all A glenoids progressed to an eccentric morphology, with A1 glenoids doing this more often than A2 glenoids.

A few differences between the study by Walker et al[8] and our study may explain the different results obtained. The study by Walker et al used chest CT scans as their image modality; most of these CT scans (74%) were obtained for the evaluation of nonorthopedic conditions (eg, pulmonary embolism, cardiovascular angiogram, and other). These patients may represent poorer hosts with greater severity in pathology to the shoulder stabilizers, and consequently, greater subluxation and pathologic progression over a shorter period of time. By contrast, our study only included radiographs of patients who had initially consulted for shoulder evaluation secondary to symptomatic GHOA.

Another possible explanation for the discrepancy between studies is that the interval time between the earliest and most recent radiographs in our cohort was a mean of 8.9 years whereas the longest follow-up overall in the study by Walker et al[8] was 8.8 years. Naturally, allowing a longer time lapse for progression to occur may increase the capture of stepwise concentric wear. It is possible that this process occurs at a slower rate than eccentric wear given that the pathogenesis is dependent more on use and activity than an imbalance of the shoulder stabilizers.

In our study, with the numbers available, we could not establish associations between Walch classification subtypes and age, gender, or BMI. This is in contrast to the initial observations by Walch, who observed preoperative patient age to be significantly related to patterns of greater erosion. For example, A2 and B2 glenoids occurred in patients 9 and 8 years older on average when compared to A1 and B1 glenoids, respectively.[1] A study by Donohue et al[3] looking at the relationship between glenoid morphology and rotator cuff fatty infiltration in patients undergoing primary TSA for GHOA with an intact rotator cuff similarly found no association between age and glenoid morphology but did identify a trend of a greater number of B3 glenoids in men compared with women (27% vs. 10%, $P = .053$).[4] A recent study by Matsen et al[5] suggests that patient factors outside of a rotator cuff tear or neurogenic atrophy, such as diabetes, BMI, advanced age, or hyperlipidemia, may be predictive of the degree of fatty infiltration seen in rotator cuff musculature.[7] Further, greater fatty infiltration, as indicated by Goutallier score, has been associated with pathologic glenoid retroversion, increased joint-line, medialization, and B3 glenoid morphology, suggesting that fatty infiltration may play a role in the position of the humeral head and consequently a pattern of posterior eccentric wear.[4] Gross rotator cuff

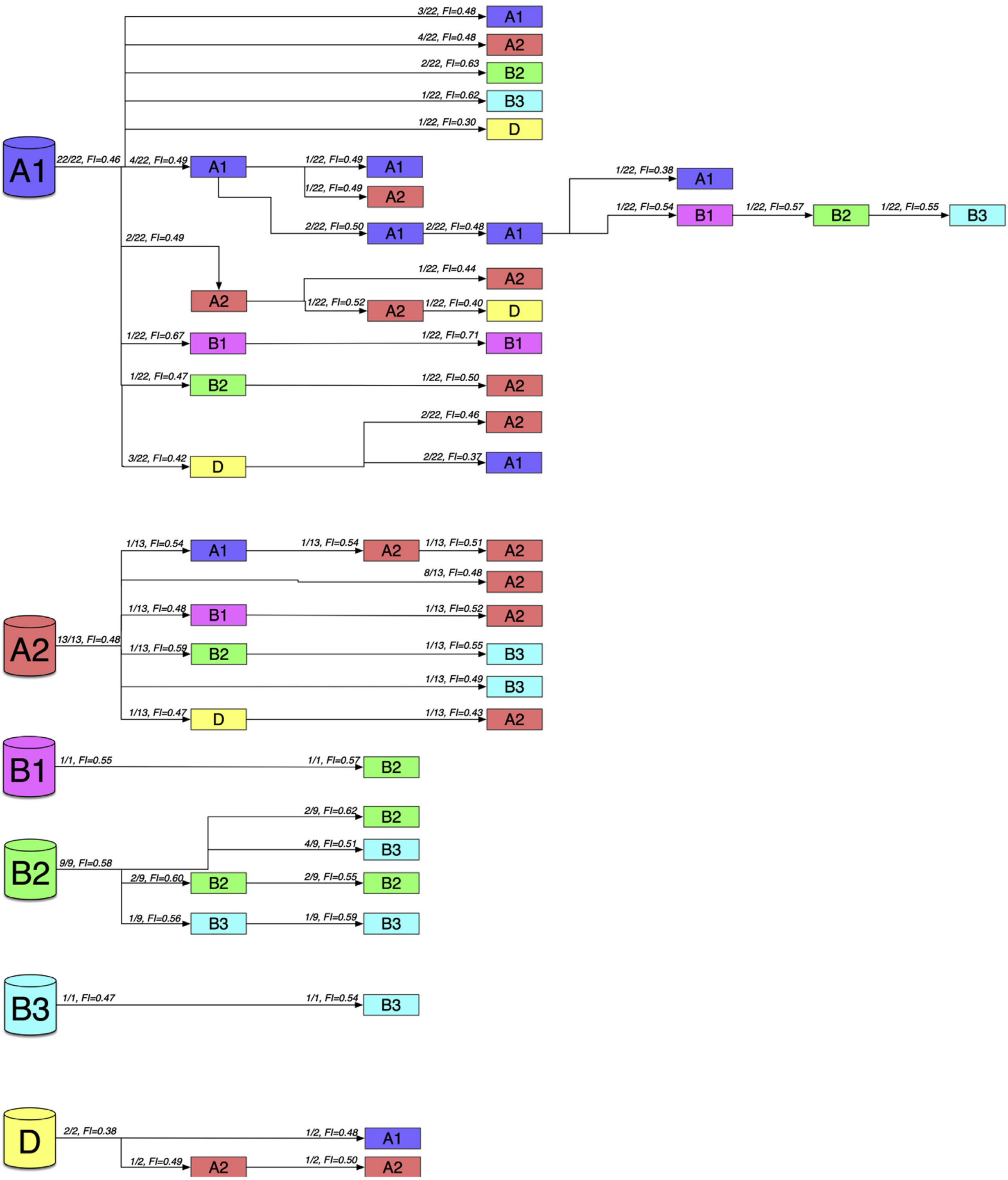

Figure 3 Flow diagram demonstrating the evolution of pathologic glenoid morphology using a modification of the Walch classification. Number of patients progressing to a particular morphologic subtype is denoted as a fraction above the branching limb. Each branching limb denotes a new radiograph being obtained. The mean FI for each subpopulation is also included; anterior subluxation <0.45 and posterior subluxation >0.55. *FI*, Friedman Humeral Index.

insufficiency with clinical manifestations is rare in primary GHOA.[6] If present, there is a theoretical risk of an imbalance in the dynamic stabilizers of the shoulder and, consequently, a change in the forces exerted on the glenoid. In our study, the status of the rotator cuff was not objectively quantified in a way that could be easily captured by a

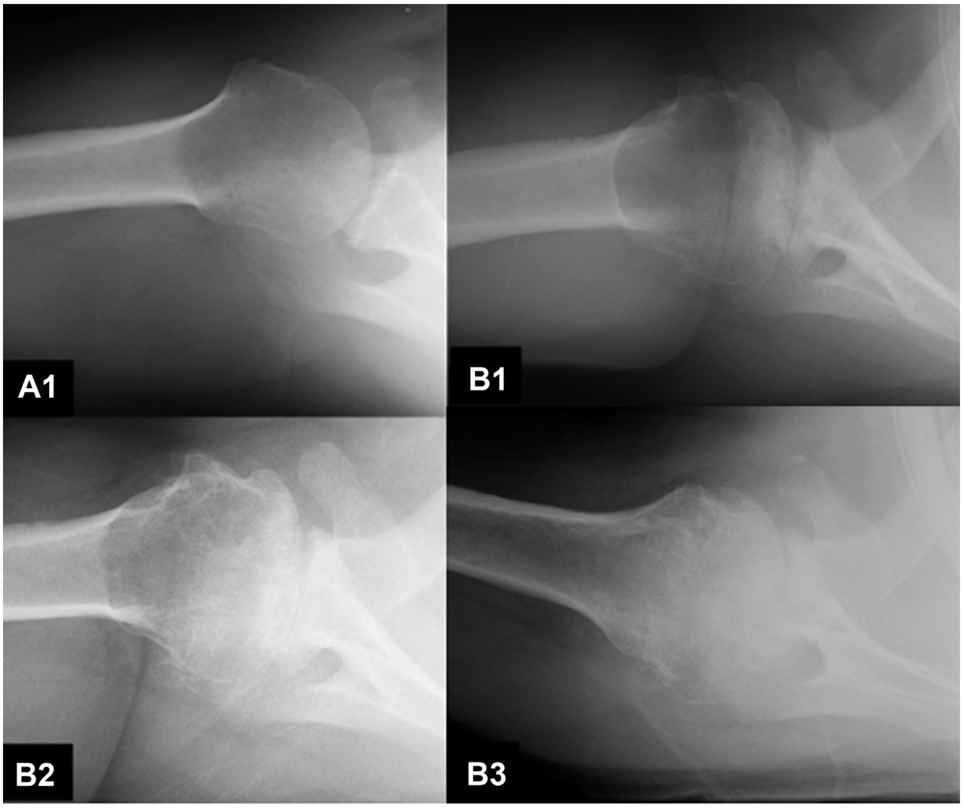

Figure 4 An example of how glenoid morphology progressed over roughly an 8-year period of time from an A1 glenoid to a B3 glenoid. The patient was a 43-year-old male (body mass index 26.6) at initial presentation for symptomatic right shoulder osteoarthritis and went onto an anatomic total shoulder arthroplasty. From presentation to year 5, the glenoid morphology remained A1 with 3 intervening radiographs documented. At year 6, the patient was noted to have a B1 glenoid (top right), a B2 glenoid at year 7 (bottom left), and a B3 glenoid at year 8 before proceeding with surgery (bottom right).

retrospective study, but was presumably satisfactory given the availability of RSA as a surgical solution over the entirety of the study period. Edwards et al[4] showed us that minimally or nonretracted tears limited to the supraspinatus do not appreciably affect outcomes, but that insufficiency of the infraspinatus and, to a lesser degree, the subscapularis musculature does adversely affect outcome scores at a mean of 43.1 months after TSA.[4] However, whether small tears or an imbalance in rotator cuff musculature alters the natural course of axial bone changes in GHOA has not been shown.

The limitations of this study are many. First, patterns of humeral head subluxation and glenoid bone loss in primary GHOA are best appreciated using CT. Although CT studies would have certainly offered incredible value, advanced imaging studies are not typically obtained a decade or more before shoulder arthroplasty, and therefore CT information would have been impossible to incorporate. Prior studies from our group have shown that radiographs provide a reasonable tool to categorize GHOA patterns according to the Walch classification.[1,7] The fact that humeral head subluxation index values were consistent with our qualitative classification is reassuring. Second, images spanned more than a decade and may have incorporated various imaging acquisition protocols with nonstandardized positioning. Although we did not find this to preclude meaningful comparisons, dissimilarity in these protocols could logically alter the relationship between the glenoid and the humeral head, making comparisons difficult. Third, our sample size was limited both by number of shoulders and by the unpredictable timing and number of preoperative radiographs available. Inherently, there exists the possibility of missed periods of time where glenoid pathology progressed unrecorded. This study only provides several "snapshots" of shoulders over their clinical course of GHOA. In addition, we only had 1 B1 glenoid and no dysplastic type-C glenoids in our series, initially making up 17% (19/113) and 9% (10/113) of cases in Walch's original study, respectively.[1] Retrospective series by others have similarly failed to observe one or both of these subtypes.[4,7] This may be attributable to a small sample size or the small fractions of time over which glenoid morphology was recorded. Fourth, of the 7 shoulders that underwent RSA, all were performed for posterior subluxation with or without posterior glenoid bone loss. However, 3 had some element of rotator cuff insufficiency noted pre- or intra-operatively that may have contributed to an uncharacteristic wear pattern for primary GHOA secondary to an imbalance of forces exerted by the shoulder's dynamic stabilizers. Finally, we did not have any outcomes or clinical metrics to associate with the findings of this study. Thus, questions as to the status of the rotator cuff pre-operatively and the clinical relevance of glenoid pathology transitioning or not transitioning between Walch categories is unknown.

Conclusion

In primary GHOA, humeral head subluxation and glenoid bone loss do progress over time but not universally and not always through the same pathway. Shoulders presenting with posterior subluxation (B types) remained posteriorly subluxed over time. Shoulders presenting with concentric arthritis developed an eccentric pattern 20% of the time. For concentric arthritis, progression of bone loss from A1 to A2 occurred 40% of the time. For eccentric arthritis, progression of bone loss from B2 to B3 occurred 56% of the time. The results of this study may be used to counsel patients presenting with a specific pattern of glenohumeral osteoarthritis without known or suspected rotator cuff pathology regarding the likelihood of progressive bone loss when the decision to proceed with shoulder arthroplasty is delayed.

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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