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Anterior and posterior glenoid bone loss in patients receiving surgery for glenohumeral instability is not the same: a comparative 3-dimensional imaging analysis

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Background: Anterior and posterior glenoid bone loss morphology have both been individually and morphologically described in previous studies. While there exists substantial literature on anterior bone loss, and emerging evidence describing posterior bone loss, a direct comparison between the two is lacking in the current literature. The purpose of this study is to quantitatively compare the anatomic and morphological differences in glenoid bone loss (GBL) in operative patients with anterior versus posterior glenohumeral instability.

Methods: All patients over a 3-year period indicated for operative stabilization with posterior glenohumeral instability and suspected glenoid bone loss who underwent a computed tomography (CT) scan were reviewed. Included patients were then singularly matched by gender, laterality, and age (±3 years) to a collection of patients who presented for operative stabilization of anterior glenohumeral instability. GBL parameters were assessed based on the following characterizing measurements: (1) percentage of GBL, (2) glenoid vault version, (3) slope of the glenoid defect relative to the glenoid surface, (4) superior-inferior defect height, and (5) anterior-posterior defect width.

Results: Sixty patients (30 anterior GBL, 30 posterior GBL) were included in the final analysis (60 males), with a mean age of 28.8 ± 8.15 years (range 16.0 to 51.0 years). Patients with anterior instability presented with higher GBL (24.94% ± 7.69 vs. 9.22% ± 5.58, $P < .001$), greater superior-inferior defect height (23.89 ± 4.21 mm vs. 21.88 ± 3.42 mm, $P = .047$), and steeper slope of glenoid defect (58.80° ± 11.86 vs. 38.59° ± 14.30, $P < .001$), while patients with posterior instability had greater retroversion (1.53° ± 4.04 vs. 7.59° ± 7.71, $P < .001$). Additionally, the anterior instability cohort had significantly more patients with moderate- to high-grade glenoid bone loss (n = 30) than patients with posterior instability (n = 11) ($P < .001$).

Conclusion: Anterior instability presents with a steeper slope of glenoid defect, higher percentage GBL, and greater superior-inferior defect height, whereas posterior instability presents with greater retroversion. This underscores the finding that anterior and posterior instability bone loss are not the same morphologically, and this should be considered in the operative treatment of glenohumeral instability.

Anterior and posterior glenoid bone loss morphology have both been individually, and morphologically described in previous studies.[1,12] It has been found that up to 22% of patients with an acute anterior instability event will demonstrate bone loss or a bony Bankart lesion, whereas >80% of patients with recurrent anterior instability may experience the same.[5,8,11,17,20,21,23,24] It has been well established that anterior glenoid bone loss is typically associated with an acute, traumatic, anterior instability event.[17] In patients with

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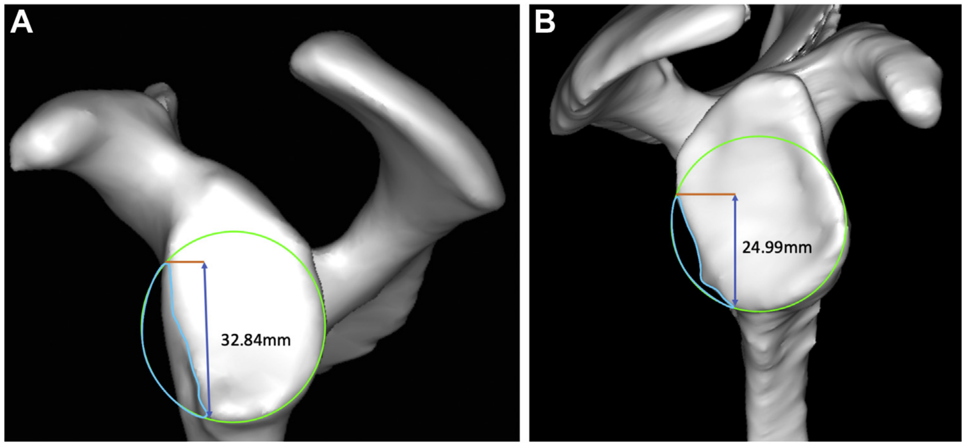

Figure 1 Superior to inferior measurement of the bony defect by utilizing glenoid en face view. Figure (**A**) represents an example of anterior bone loss and figure (**B**) represents an example of posterior bone loss.

recurrent anterior instability, the attritional bone loss that ensues typically evolves over the course of 12 months if not treated, and is worse with a longer duration of symptoms or number of events.[8,14] Conversely, posterior instability has been traditionally described as the result of 3 different causes: repetitive microtrauma, acute traumatic events, and atraumatic events.[2,18,19] Repetitive microtrauma with a posterior loading force in a flexed and internally rotated shoulder compromises the posterior capsulolabral complex, and thus, puts the shoulder at risk for further injury and bone loss. An acute traumatic injury can shear the humeral head along the rim leading to bone loss. Last, atraumatic causes of posterior instability can be found in patients with generalized ligamentous laxity. It has been demonstrated that when bone loss does result, there is loss of the bony concavity and increased anterior to posterior slope in the setting of increased retroversion.[1] The bone loss is typically sloped relative to the glenoid fossa. As such, while there exists substantial literature on anterior bone loss, and emerging evidence describing posterior bone loss, direct comparisons between the two are lacking in the current literature.

The purpose of this study is to quantitatively compare the anatomic and morphological differences in glenoid bone loss (GBL) in patients with anterior versus posterior instability. We hypothesize that posterior glenoid bone loss will typically present with smaller defect height and width, a greater mean degree of retroversion, and lower slope due to the more common result of a gradual attritional loss, whereas the anterior cohort will typically have larger defects and larger slopes due to their initial traumatic event and subsequent attritional loss.

Methodology

Participant selection

Institutional review board-approved (institutional review board number NMCSD.2009.0151) retrospective reviews were performed of patients who presented for operative stabilization of posterior glenohumeral instability from February 2009 to February 2012. The included patients are part of the senior author's (MTP) instability database, which was stopped in 2012 due to a change in the senior surgeon's practice location/institution; however, given the homogeneity of the patient population and the consistency of the protocol used to evaluate bone loss by the senior surgeon, the decision was made to utilize this database to mitigate the potential of confounding variables that may be present in a more heterogeneous patient population or surgeon database.

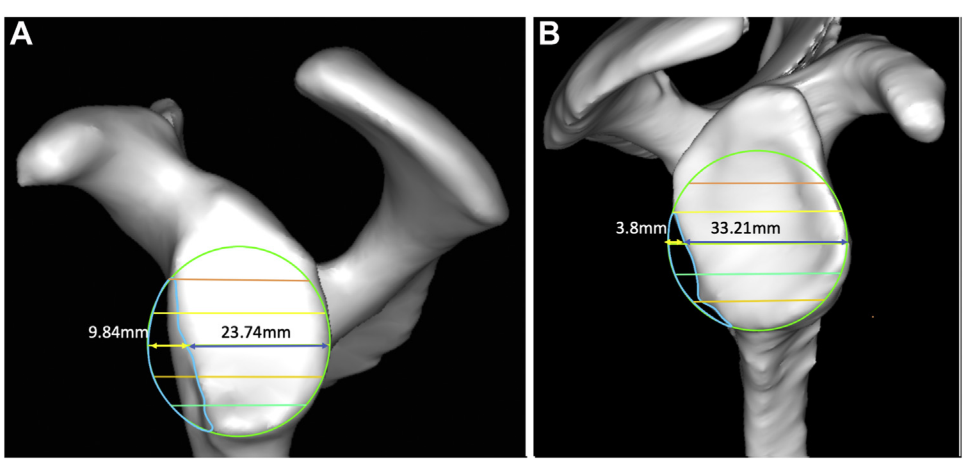

Figure 2 Anterior to posterior width of the defect measured at 5 different levels on the glenoid en face view. This is calculated by subtracting the remaining glenoid width from the width of the uninjured glenoid (perfect fit circle). Figure (**A**) represents anterior bone loss and figure (**B**) represents posterior bone loss.

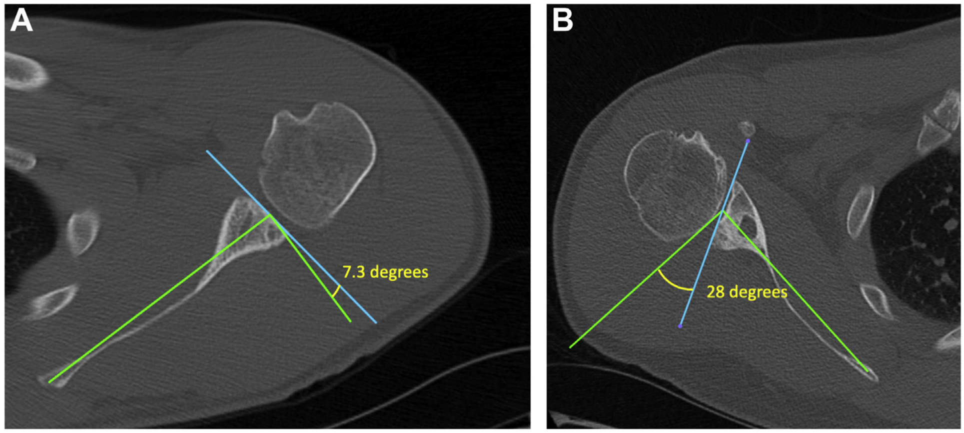

Figure 3 Glenoid vault version measurements. Figure (**A**) represents anterior glenoid bone loss case and Figure (**B**) represents posterior glenoid bone loss.

These patients were then singularly matched to a collection of patients who had presented for operative stabilization of anterior glenohumeral instability by the same surgeon within the same time period. Patients were individually matched based on gender, laterality, and age (±3 years). The senior authors' (M.T.P.) standard diagnostic protocol was utilized in which any patient presenting with a chief complaint of shoulder instability and with concern for glenoid bone loss on plain radiographs obtained a CT scan. Determination of anterior and posterior glenoid bone loss was based on a demonstration of anterior or posterior bony injury on 2-dimensional (2D) CT scans. For consistency, patients with prior ipsilateral shoulder surgery were excluded. The exclusion criteria for this study additionally included the following: patients who did not present with anterior or posterior glenoid bone loss, patients presenting with glenohumeral arthritis, and patients <16 years old. Patients older than 65 years were also excluded to minimize the chance of erosion as a result of glenohumeral osteoarthritis. Age at the time of diagnosis, sex, and injury side were documented for all study participants.

Diagnostic imaging

All CT scans obtained for this study were reviewed by the senior author (M.T.P.) and one additional sports medicine fellowship-trained orthopedic surgeon (J.J.E.). All patients underwent standard glenohumeral CT scans using Siemens Sensation 64 (Siemens, Erlangen, Germany), a 64-detector scanner. Patients were placed supine with arms in an adducted and neutral position. Image data were acquired with 0.6 mm of collimation, 140 kV, and 300 mA-seconds at a slice thickness set to 2 mm.

Mimics software (Materialise NV, Leuven, Belgium) was used to compute all 2D CTs into 3-dimensional (3D) images. DICOM (Digital Imaging and Communications in Medicine) data from the patient 2D CT scans were analyzed using MIMICS by selecting the 2D region of interest and then extracted to the contour of the cortical bone of the scapula. This allowed segmentation of the 2D CT images. The segmented 2D CTs were then used in the creation of 3D models of the scapula for each patient.

Following 3D reconstruction for all patient CTs, screen captures of the glenoid were obtained with orientation to a precise en face sagittal oblique view of the glenoid surface, and exported to OsiriX (Pixmeo, Bernex, Switzerland) to record 2D measurements of the 3D model. 2D measurements of the reconstructed 3D glenoid included total surface area bone loss (%), bone loss width (mm), percent width loss, and defect height (mm). Vault version and slope of the osseous defect were measured on original 2D CT images. Specific measurements obtained are described below.

Anatomic measurements

Surface area of glenoid bone loss

The surface area of glenoid bone loss was measured using the reconstructed 3D CT scans of an en face view of the glenoid surface. Percentage of bone loss was calculated by dividing the surface area

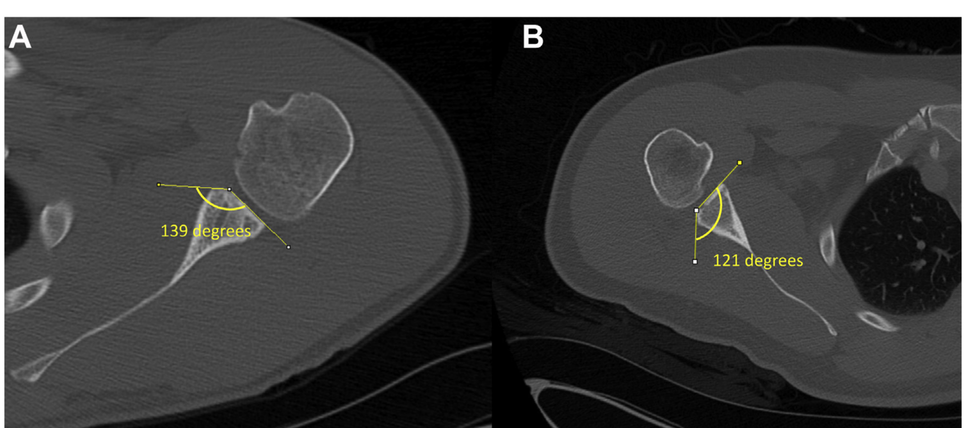

Figure 4 Angle of injured glenoid. Figure (**A**) is an anterior bone loss case and Figure (**B**) is a posterior bone loss case.

Table I

Mean values (S.D.) of different parameters measured between anterior and posterior glenoid bone loss cohorts.

	Anterior	Posterior	*P* value
Glenoid bone loss (%)	24.9 (14.7-39.1)	9.22 (3-26.3)	**<.001**
Glenoid version (degrees)	1.53 (−7.6-13.75)	7.59 (−22.44-6.17)	**<.001**
Defect slope (degrees)	121.21 (100.10-149.7)	141.41 (115.27-175.02)	**<.001**
Superior-inferior height of bony defect (mm)	28.89 (17.15-33.11)	21.88 (16.05-27.8)	**.047**
Anterior-posterior width of bony defect	6.45 (0.84-12.24)	5.34 (2.09-11.78)	.083

S.D., standard deviation.

Mean values (S.D.) of different parameters measured between anterior and posterior glenoid bone loss cohorts. Bold numbers denote significants (alpha = 0.05).

of osseous defect by the area of the true circle, as described by McNeil et al. (2017).[1] Surface area of glenoid bone loss was defined as low- (≤10% GBL), moderate- (11%-20% GBL), and high-grade (≥20% GBL). These values were arbitrarily based on previous anterior shoulder instability literature suggesting that critical or clinically relevant bone loss can occur anywhere from 13.5% to 25%.[21,22]

Superior-inferior height, anterior-posterior width

Superior-inferior height of the osseous defect was measured against the en face view of the reconstructed 3D CT scan glenoid surface by calculating the difference between the minimum and maximum point of the defect (Fig. 1). Anterior-posterior width of the glenoid defect was measured at 5 equidistant vertical intervals across the face of the glenoid. Anterior-posterior width of the defect was calculated by subtracting the width of the healthy glenoid (calculated from a best-fit circle) from the anterior-posterior width of the defect (Fig. 2). Maximum anterior-posterior width was also reported. These methodologies have been previously reported.[1]

Glenoid vault version

For optimization of the glenohumeral image, all 2D CT scans were corrected for anterior sagittal rotation of the scapula and glenoid, as described by Gross et al. [6] prior to anatomic measurements. CT scans were aligned with the plane of the glenoid and scapula, producing axial cuts through the glenoid at angles that were in line with[1-5] the longitudinal axis of the glenoid.

The glenoid vault version was calculated using original 2D CT scans in accordance with the vault method as described by Friedman et al.[6] calculated as the angle between the glenoid line and the line perpendicular to the glenoid vault axis. The glenoid vault axis was defined as the line connecting the tip of the scapular vault and the center of the glenoid (Fig. 3). The glenoid version was measured at 5 equidistant intervals across the glenoid. Mean value was reported.

Slope of the osseous defect

The slope of the osseous defect was measured using original 2D CT scans adapted from Beaulieu-Jones et al. (2019)[1] to further analyze and improve the characterization of the respective slope defect. This slope was calculated as the angle between the line parallel to the osseous defect and the glenoid line (Fig. 4). The osseous defect slope was measured at 3 equidistant intervals along the inferior two-thirds of the glenoid. Mean value was reported.

Statistical analysis

Descriptive statistics were obtained for all demographic data. Interclass correlation coefficients were calculated to assess inter-rater reliability between the 2 sets of measurements recorded for each parameter. Two-sample Student t-tests were computed to assess differences in anatomic measurements between patients with anterior and posterior instability. A chi-square test was performed to compare the proportion of patients with moderate (10%-20%) or severe (≥20%) glenoid bone loss between anterior and posterior instability groups. Statistical analysis was performed using SPSS (version 27.0; IBM Corp., Armonk, NY, USA). A *P* value of <.05 was considered statistically significant.

Results

Sixty patients (30 anterior GBL, 30 posterior GBL) were included in the final analysis (60 male) with a mean age (± standard deviation) of 28.8 ± 8.15 (range 16.0 to 51.0 years)* (*Because both anterior and posterior glenoid bone loss groups were matched by age, laterality, and gender, the makeup of each group was identical, and therefore, demographic analysis was not separated.). The surface area of GBL (%) using 3D reconstruction was significantly greater for patients presenting with anterior bone loss (25.0% ± 7.7) than those presenting with posterior bone loss (9.2% ± 5.6) ($P < .001$). Additionally, the version significantly differed between bone loss cohorts. Patients with anterior bone loss, on average, were more anteverted (1.3° ± 4.0), while posterior bone loss patients were, on average, more retroverted (−7.6° ± 7.7) ($P < .001$). The angle of the bony defect in patients with anterior glenoid bone loss also was significantly steeper (121.2° ± 11.9) than patients with posterior bone loss (141.4° ± 14.3) ($P < .001$). Bony defect height was significantly larger for anterior bone loss patients (23.9 ± 4.2 mm vs. 21.9 ± 3.4 mm, $P = .047$). When assessing the distribution of glenoid bone loss, patients with anterior instability had significantly more patients with moderate- to high-grade glenoid bone loss (n = 30 vs. n = 11) ($P < .001$). The results for these findings are displayed in Table I.

There was no statistically significant difference between mean anterior-posterior width of the defects amongst the cohorts ($P = .25$). However, there was a significant difference between defects width in the middle and inferior glenoid cuts, in which anterior-posterior defect width of patients with anterior bone loss was consistently greater ($P < .003$).

Following the completion of all imaging analyses, interobserver reliability was calculated to have an interclass correlation coefficient of 0.91.

Discussion

The primary finding of the current study is that patients with anterior bone loss present with a significantly larger surface area of GBL, less retroversion, larger bony defect height, and steeper defect slope relative to the glenoid fossa, while posterior bone loss is characterized by smaller defect height and milder slope.

While the pathologies of both anterior and posterior instability are well cited, there exists a paucity of literature that directly compares the distinct osseous geometric characteristics between the two. The current study's findings suggest that patients with posterior glenohumeral instability present with glenoids that are significantly more retroverted relative to patients presenting with anterior instability. This finding is consistent with prior studies, including that of Gottschalk et al.[7] and Owens et al.,[16] which found that retroversion constitutes an osseous anatomic pathology that predisposes patients to posterior shoulder instability. While this finding does not relate to the quantification of glenoid bone loss, it does correlate with the direction of instability and how this directional difference results in statistically different bone loss morphology/volume. Additionally, our results display that patients with anterior shoulder instability present with greater glenoid bone loss (moderate- to high-grade) than subjects with posterior instability. Such findings are consistent with the existing literature, as Dickens et al.[4] reported that patients with anterior instability with >20% GBL were significantly more likely to experience recurrent instability instances, while Beaulieu-Jones et al.[1] reported that over half (57.5%) of all patients with recurrent posterior instability had only minimal (0%-10%) bone loss. These findings highlight the clinical importance of low- to moderate-grade bone loss in patients presenting with posterior instability. The question remains, however, as to whether surgeons should have a lower threshold for intervention for bone loss in posterior instability patients.

In addition to the amount of GBL, the current study displays that anterior GBL patients have a significantly larger bony defect height and steeper slope of the glenoid defect. These findings may have implications when assessing the risk of recurrence in the setting of bipolar bone lesions. The current study displayed that patients with greater anterior osseous defect size presented with increased defect height. These findings are consistent with the premise of the perfect circle concept. As the height of the bony defect increases along the anterior glenoid rim, bone loss presents more anteroinferiorly rather than anteriorly. As suggested in a study by Di Giacomo et al,[3] an increase in bone loss along the anterior glenoid rim increases the glenoid track along which the articular head of the humerus contacts. As such, an increase in anteroinferior glenoid bone loss could increase the likelihood of an off-track lesion.

The defect angle relative to the glenoid fossa in patients with anterior instability has not been studied extensively. We speculate that a steeper defect angle relative to the glenoid fossa in patients with anterior GBL could further exacerbate instances of instability in the setting of bipolar bony lesions. More prominent (sloped) defects along the glenoid rim could increase the significance and severity of Hill-Sachs lesions along the humeral head upon compressive impact with a steeper glenoid defect. Instances of bipolar bone lesions in the setting of anterior instability are consistent with the current study's implications.[25,14,10] Nakagawa et al.[13] demonstrated that the incidence of Hill-Sachs lesions among patients with recurrent anterior instability increased from 66.0% after primary dislocation to 88.0% upon recurrence. These findings, along with those of the current study, could have substantial clinical relevance when assessing the risk for bipolar bony lesions. Physicians treating patients with anterior instability may need to consider bony morphology such as glenoid defect height and slope that could increase the risk of bipolar bony lesions, and ultimately anterior glenohumeral instability.

The clinical significance of the pathoanatomical characteristics of posterior GBL should also be noted. The current study found that 100% of patients with posterior instability presented with low ($\leq$10% GBL) to moderate (11%-20% GBL) bone loss. Arner et al. (*American Journal of Sports Medicine, In Press, 2021*) found that patients with 11% GBL had a 10 times statistically higher surgical failure rate after arthroscopic posterior shoulder capsulolabral repair, while 15% bone loss resulted in a 25 times statistically higher failure rate. In these cases, osseous augmentation procedures may be considered; however, indications for such procedures are not yet clear.[9,15]

Limitations

This study is not without limitations. First, radiographic measurements have the potential to be operator-dependent, and this could introduce variability in the data. We, however, attempted to account for this by performing interobserver reliability calculations, which were high at 0.91, and thus, this likely has limited the impact on our results. We did not calculate intra-rater reliability, which is another limitation. We focused our methodology on the variations that may occur between individuals performing these measurements. In this way, we could obtain an understanding as to whether performing these measurements in real-time generates reproducible findings. Additionally, we only evaluated the parameters of patients with known bone loss as identified on CT scans and did not include patients with minimal bone loss that might not have initially been apparent on plain films, thus warranting a CT scan. Therefore, it is impossible to know if the findings in our study are applicable only to patients with bone loss, or if some morphological findings are also present in patients with no/minimal bone loss. Finally, the small sample size is a notable limitation. The current study, however, exhausted the list of eligible patients for a matched cohort design, and to our knowledge, this is the largest available evidence in the existing literature that directly compares the pathoanatomy of anterior and posterior bone loss.

Conclusion

Anterior instability presents with a steeper slope of glenoid defect, higher percentage GBL, and greater superior-inferior defect height, whereas posterior instability presents with greater retroversion. This underscores the finding that anterior and posterior instability bone loss are not the same morphologically, and this should be considered in the operative treatment of glenohumeral instability.

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