

Advanced 3-Dimensional Characterization of Hill-Sachs Lesions in 100 Anterior Shoulder Instability Patients



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Purpose: We sought to qualitatively and quantitatively describe characteristics of Hill-Sachs lesions (HSL) in a cohort of anterior shoulder instability patients using advanced 3-dimensional (3-D) modeling software and assess the impact of various HSL parameters on the HSL volume, location, and orientation in patients with anterior shoulder instability. **Methods:** A total of 100 recurrent anterior instability patients with evidence of HSL with a mean age of 27.2 years (range = 18 to 43 years) were evaluated. Three-dimensional models of unilateral proximal humeri were reconstructed from CT scans, and the volume, surface area (SA), width, and depth of identified HSLs were quantified along with their location (medial, superior, and inferior extent). Multiple angular orientation measures of HSLs were recorded, including Hill-Sachs rim (HSLr) angle in order to classify the level and location of potential humeral head engagement. Mann-Whitney *U* test assessed the relationship between measured parameters. **Results:** By volume, larger HSL had greater humeral head surface area (HH SA) loss ($P = .001$), HSL width ($P = .001$), were more medial ($P = .015$), and more inferior ($P = .001$). Additionally, more medial lesions had greater HSLr angles ($P = 0.001$). The mean depth, width, and volume of HSLs were 3.3 mm (range = 1.2–7.1 mm), 16.0 mm (range = 6.2–30.4 mm) and 449.2 mm³ (range = 62.0–1365.6 mm³), respectively. The medial border of the HSL extended to 17.2 ± 4.4 (range = 9.3–28.3 mm) off the most medial edge of the HH cartilage margin (medialization). The mean HSLr was 29.3 ± 10.5°. **Conclusion:** There was a statistically significant association between HSL medialization and HSL volume, position, and orientation. More medialized HSL have larger volume, greater width, more SA loss and higher lesion angles and are more inferior in the humeral head. As it has been established that more medialized lesions have poorer clinical outcomes, this study highlights that HS lesions have varying angles and medialization, which may portend eventual treatment and outcomes. **Level of Evidence:** IV, case series.

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Introduction

The glenohumeral articulation consists of the relatively large humeral head and shallow glenoid fossa. This lack of bony constraint allows great mobility but renders the glenohumeral joint prone to instability. During anterior shoulder dislocation, the humeral head is forced beyond its physiological range of motion and over the anterior glenoid rim. This can result in an anterior glenoid rim fracture in up to one-third of patients.¹ A corresponding compression fracture in the humeral head (Hill-Sachs lesion, HSL), which occurs posterolaterally is common and is observed in up to 90% of patients following a first-time anterior shoulder dislocation.¹

The amount of glenoid bone loss (GBL) is of increasing clinical interest as it has been associated with increased risk of recurrent dislocation.² Until recently, there has been little focus on the HSL's contribution to overall glenohumeral instability, as it was thought that its contribution was minimal. The on-track vs. off-track concept highlighted the important contributions of both the HSL and GBL.¹ Little is known regarding the characteristics of HSLs when compared with the more extensively studied GBL. In clinical studies, engagement of the HSL on the anterior glenoid rim has been shown to increase the risk of recurrence which leads to inferior clinical results.³⁻⁵ In a recently study, Yamamoto et al. investigated HSL characteristics in relation to glenoid width and reported those with wider HSL had poorer patient reported outcomes following arthroscopic capsulolabral repair.⁶ However, the detailed topography of HSLs is not well defined or well understood.

The purpose of this study was 1) to qualitatively and quantitatively describe characteristics of HSL in a cohort of anterior shoulder instability patients using advanced 3-dimensional (3-D) modeling software and 2) to assess the impact of various HSL parameters on the HSL volume, location and orientation in patients with anterior shoulder instability. It was hypothesized that Hill-Sachs rim (HSLr) angle, Hill-Sachs center (HSLc) angle, surface area (SA) loss, width, volume, and depth would have no effect on volume, location and orientation of HSL.

Methods

After Institutional Review Board approval was obtained (IRB Study Number: CIP #NMCS.D.2005.0038), patient data were prospectively collected between January 2004 and January 2010. A cohort of 100 patients with recurrent anterior shoulder instability with available computed tomography (CT) scans showing visible HSLs were included. Patients that had a history of posterior shoulder instability, multidirectional instability, or a history of previous shoulder surgeries were excluded from the study.

Computed Tomography Images

All patients who met inclusion criteria were deidentified for analysis. They all had standard glenohumeral computed tomography (CT) scan using a Siemens Sensation 64 (Siemens, Erlangen, Germany), a 64-detector scanner. Image data were acquired with 0.6 mm of collimation, at 140 kV, and for 300 mA-seconds. Slice thickness was set to 2 mm. The patients were placed supine with their arms in an adducted and neutral position.

Creation of 3D Surface Models

DICOM (Digital Imaging and Communications in Medicine) data from the 100 patient CT scans were analyzed using the MIMICS software (Materialise NV, Leuven, Belgium). This software allowed segmentation of the CT images by selecting the area of interest from the scans and extracting the contours of the cortical bone of the humerus and scapula. The segmented two-dimensional (2D) CTs were then used in the creation of three-dimensional (3D) models of the humerus and scapula for each patient.

Measurement of the Hill-Sachs Lesion)

The 3D reconstructions were exported to 3Matic (Materialise). A touchscreen and stylus pen were used

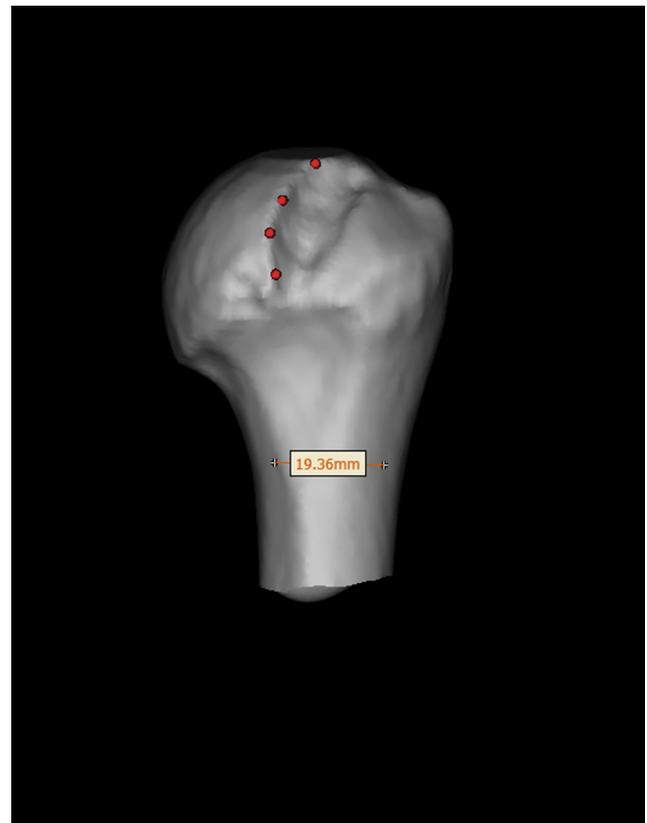


Fig 1. Hill-Sachs lesion (HSL) of the humerus that is generated using three-dimensional modeling software (Materialise NV), with the most medial edge of the HSL delineated (red dots).

to precisely mark areas on the humeral head, including the articular surface area and the **Hill-Sachs lesion (HSL)** surface area. The 3Matic software was used to match the contour of the HSL rim and the humeral head in order to create a 3D representation of a “fixed” humerus without an HSL. The HSL humerus model was then digitally subtracted from the fixed humerus model, leaving only a 3D model of the HSL (Fig 1). This model was used to measure the volume, width, and depth of the HSL in all specimens. The width and depth measurements were taken from each axial slice of the 2D CT to calculate the mean and maximum width and depth for both measures. The surface area of the HSL model was also obtained by marking the surface with a stylus pen to determine the “surface area lost.”

Screen captures of the humeral head in the true posterior view were then recorded and exported into ImageJ (U.S. National Institutes of Health, Bethesda, MD, USA) for 2D measurements on the reconstructed 3D model. Medialization of the HSLs was evaluated by measuring 4 points along the medial portion of the HSL rim (Fig 2). The vertical position of the HSL was obtained by measuring the distance from a horizontal line that intersected the superior most point of the humeral head (Fig 3).

HSL angle was also measured using ImageJ. HSLr angle was defined as the angle between the best fit line along the medial rim of the HSL and the diaphysis axis of the humeral shaft (Fig 4). HSLc angle was defined as the best fit line through the deepest aspect of the lesion and the humeral shaft diaphysis axis (Fig 4). Similar to the medialization methods, these measurements were taken on reconstructed 3D models.

Statistical Analysis

Continuous data were presented as mean with standard deviation (SD). HS volume, medialization, HSLc and HSLr angles were divided into two groups based on their distribution and current literature,⁷⁻⁹ small and large. Mann-Whitney *U* test was run to assess the relationship between measured parameters between the groups. All statistical analysis was performed using IBM SPSS Statistics for Windows, version 27.0 (IBM Corp., Armonk, NY, USA).

Results

132 cases were reviewed, and 100 patients met the inclusion criteria. The study cohort consisted of 58 right shoulders and 42 left shoulders. 84 patients were male, and 16 were female. The mean age was 27.2 years (range = 18 to 43 years). Variability in measurements difference between the two reviewers (interclass correlation coefficient, ICC) for medialization was 0.974, for HSL angle, the difference was 0.841, and for HSL volume, the difference was 0.796. The patient imaging

assessment was performed by two fellowship-trained orthopaedic surgeons.

The mean depth and width of identified HSLs were 3.3 ± 1.3 mm (range = 1.2-7.1 mm) and 16.0 ± 4.6 mm (range = 6.2-30.4 mm), respectively. The mean distance from the top of the humeral head to the superior aspect of the HSL was 5.7 ± 3.0 mm and 30.0 ± 11.2 mm to the defect's most interior aspect. The mean volume of the HSL was 449.2 ± 249.6 mm³ (range = 62.0-1365.6 mm³) and mean Humeral Head Surface Area (HH SA) loss was 284.1 ± 108.0 mm² (range = 81.2-584.6 mm²). On average, the medial border of the HSL extended to 17.2 ± 4.4 mm (range = 9.3-28.3 mm) off the most medial edge of the HH cartilage margin (medialization) on the direct posterior-anterior view. The mean HSLr and HSLc angles were $29.3 \pm$

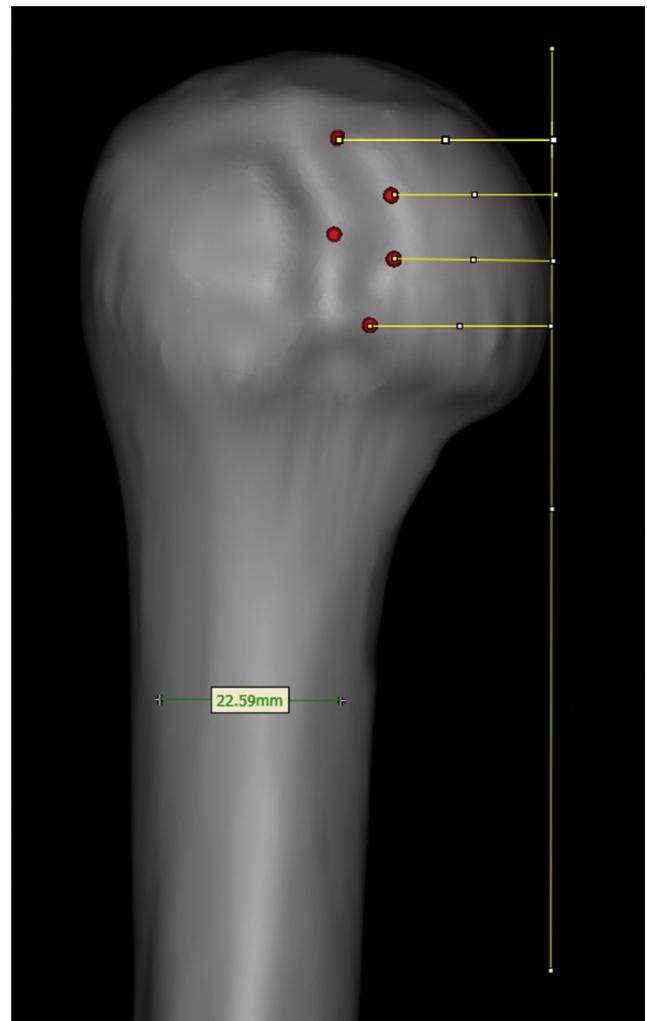


Fig 2. Measurement of medialization of the Hill-Sachs lesion (HSL) is shown with normalized distance from the apex of the humerus, and with the biceps groove taken in a true anterior position. Four points were measured at equidistant intervals along the total of the HSL. The most medialized HSL would be the smallest length of the medialization.

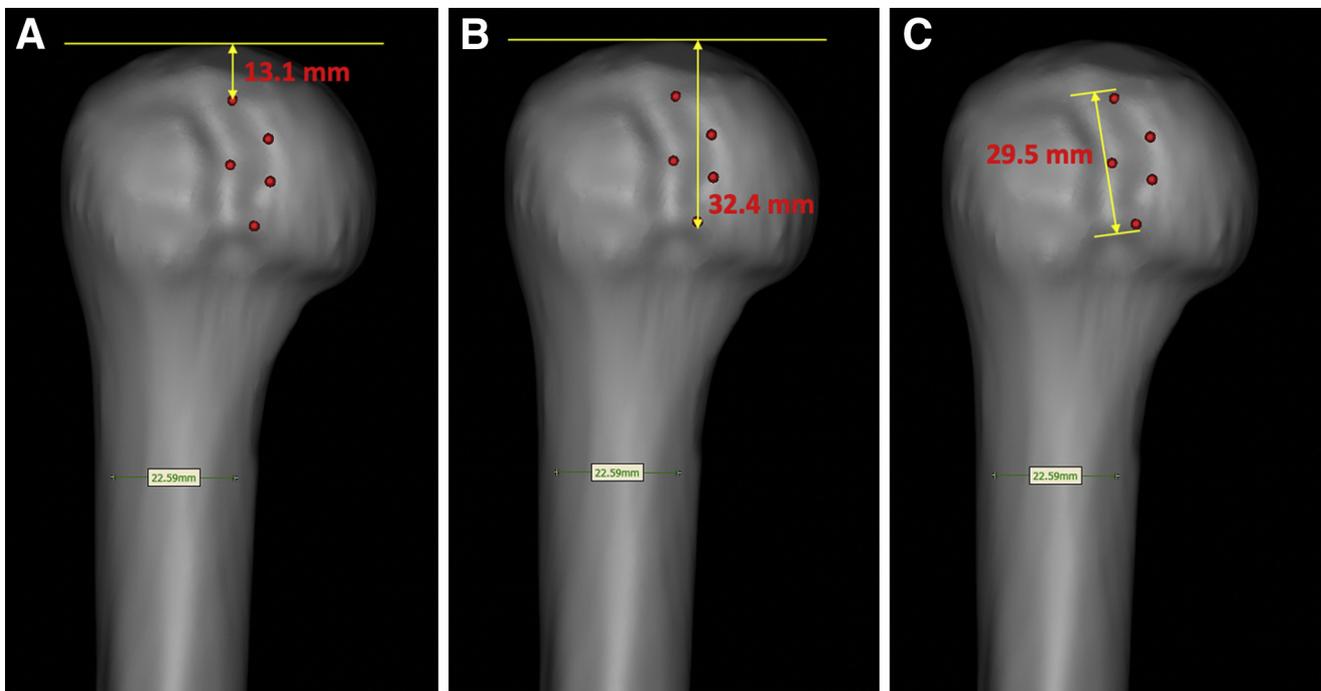


Fig 3. The measurement of vertical length and location of the Hill-Sachs lesion (HSL) of the left side humeral head. This was obtained by measuring the distance between a horizontal line that was orthogonal to the superior most portion of the humeral head and the most superior point of the HSL (A) at 13.1 mm. The inferior extent measurement is also shown (B) at 32.4 mm, as well as the total length of the HSL (C) at 29.5 mm.

10.5° and $30.1 \pm 11.2^\circ$, respectively. The summary of these measurements is represented in [Table 1](#).

HSL volume, medialization, HSLr, and HSLc were analyzed and divided into two groups: small and large, on the basis of data distribution and current literature.⁷⁻⁹ HSL volume was divided into small $0.25 \pm 0.089 \text{ cm}^3$ (range = 0.069-0.38 cm^3) and large $0.67 \pm 0.27 \text{ cm}^3$ (range = 0.41-1.37 cm^3) groups. Medialization was divided into small $13.52 \pm 2.45 \text{ mm}$ (range = 9.31-16.92 mm) and large $20.61 \pm 3.03 \text{ mm}$ (range = 17.15-28.33 mm) groups. HSLr angles were divided into small $26.23 \pm 16.45^\circ$ (range = 9.27-29.74°) and large $41.87 \pm 16.30^\circ$ (range = 30.43-53.39°) groups. HSLc angles were divided into small $21.71 \pm 5.87^\circ$ (range = 6.88-29.62°) and large $38.94 \pm 6.0^\circ$ (range = 30.01-51.13°) groups.

HSLs with larger volume had significantly larger HH SA loss ($P = .001$), average HSL width ($P = 0.001$), and significantly smaller medialization value ($P = .015$). HSL with large medialization had statistically significant smaller HSL volume ($P = .038$), HSL width ($P = .011$), HH SA loss ($P = .04$), HSLc angle ($P = .006$), and significantly more superior extent of the lesion ($P = .023$). Lesions with large HSLc angle had significantly larger HSL width ($P = 0.015$), HSLr angle ($P = .001$), and significantly smaller medialization value ($P = 0.001$). HSL with large-HSLr angle statistically significant larger HSLc angle ($P = 0.001$) ([Table 2](#)).

Discussion

The principal findings of this study demonstrate that HSLs that extend more medially on the humeral head represent wider and larger HSLs in terms of volume and SA loss, have greater rim and central angles and are located more inferiorly. In addition to the size of the HSL, the location and orientation have been shown to influence a patient's risk of engagement and recurrence. The current study further describes the impact of these factors on one another and helps to better describe the different parameters of the complex HSL, rather than just width and depth. Further, as done in this study, it is imperative to assess large or clinically concerning HSLs via 3D modeling to allow accurate preoperative knowledge of the HSL's characteristics as physical examination and non-3D imaging may be limited in these cases.^{10,11} Appropriate HSL evaluation is imperative to optimize patient outcomes and reduce recurrent instability.¹²⁻¹⁴ This study better characterizes these complex lesions which to date, have been overly simplified.

Osseous injuries constitute a common cause of surgical failure in glenohumeral instability treatment. As such, properly identifying and addressing osseous defects is critical.^{15,16} The quantitative and qualitative assessment of bipolar bone loss plays an increasingly important role in developing efficacious treatment algorithms for this challenging problem.¹⁷⁻²⁰ In the

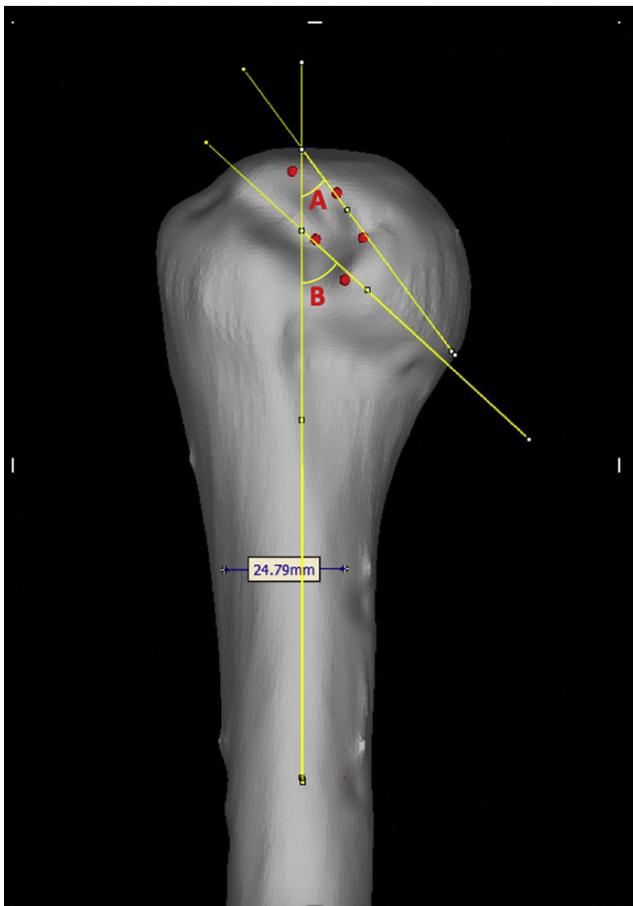


Fig 4. Two angles were measured of the Hill-Sachs lesion (HSL) that were both taken relative to the long axis of the humerus. The first is the HS rim angle (HSLr) (marked A) and is defined as the angle between the best fit line along the medial rim of the HSL and the long axis of the diaphysis of the humeral shaft. The second is the HS center angled (HSLc) (marked B), which is defined as the best fit line through the deepest aspect of the HSL and the humeral shaft diaphysis axis.

setting of recurrent anterior instability, the contribution and importance of glenoid bone loss (GBL) have been studied extensively.^{1,2,21} The glenoid track is an important clinical concept that takes both the GBL and HSL into consideration when predicting future glenohumeral instability. On the basis of this, it has reported that HSL location, in particular, its medial extent, may

be the most important characteristic in clinical and cadaveric studies.^{1,17,22} Although the glenoid track is a novel and important clinical tool, the glenoid and humeral bone loss characteristics are more complex. Yamamoto et al.⁶ recently applied this thought to more accurately characterize HSLs as either “peripheral” or “central-track,” based on the HSL’s medial extent relative to the glenoid track. They reported that patients with “peripheral-track” HSLs occupying $\geq 75\%$ of the glenoid track had significantly worse clinical outcomes but no difference in recurrence following arthroscopic Bankart repair.⁶

Another important characteristic of the HSL is the lesion angle. Di Giacomo et al.²³ demonstrated that HSLs created with the arm in abduction compared with adduction resulted in lesions with significantly greater HSL angles ($32.4^\circ \pm 4.7^\circ$ vs $16.1^\circ \pm 2.9^\circ$, respectively). They concluded that this greater slanting of the lesion relative to the diaphyseal axis resulted in a greater risk of engagement and, thus, an increased risk of recurrent instability. However, to our current knowledge, there are no studies that analyzed multiple parameters of HSL and their correlation among each other by using high-quality 3D remodeling. The present study reveals a strong relationship between a greater HSL angle and more medialized lesions.

Additionally, the current study identified and described other characteristics that are associated with more medial and larger lesions. These include greater width, SA loss, greater lesion angles, and a more inferior position. Thus, during surgical decision making, it is important to keep all these characteristics in mind, given that they can help identify lesions that are at higher risk for recurrent instability.

While the HSL volume has been an important factor, and still is, other factors are important to consider. This study improves identification and evaluation of high-risk lesions, though further analysis is needed in order to evaluate these findings in the setting of glenoid bone loss. Future studies should aim to assess the impact of HSL medialization, volume, width, SA loss, and lesion angles in the setting of different amounts of GBL and how those impact the risk for recurrent instability. Additionally, a new scoring system should be developed

Table 1. —Mean Values and Standard Deviations of all Measures Taken

Parameter Mean (Range) SD	Parameter Mean (Range) SD	Parameter Mean (Range) SD
HSL volume	449.23 (62.0-1365.6) mm ³	249.61 mm ³
HH SA loss	284.07 (81.2-584.6) mm ²	108.0 mm ²
HSL medialization	17.17 (9.3-28.3) mm	4.44 mm
HSL depth	3.3 (1.2-7.1) mm	1.3 mm
HSL width	16.0 mm (6.2-30.4) mm	4.6 mm
Most superior point of HSL	5.7 (1.41-11.12) mm	3.0 mm
Most inferior point of HSL	30.0 (22.13-39.91) mm	11.2 mm
∠HSLr	29.34 (6.47-53.39°)	10.54°
∠HSLc	30.14 (8.13-51.13°)	11.20°

Table 2. Mean value comparison of HSL volume, medialization, HH SA loss, HSL width, most superior point of HSL, HSLc and HSLr angles subgroups (small vs large) and their relationship to size, location and orientation parameters (small vs large).

	HSL Volume		Medialization		HSLc Angle		HSLr Angle	
	Small	Large	Small	Large	Small	Large	Small	Large
HH SA loss (mm²)								
Average	201.20	356.26	315.03	251.98	259.90	302.91	274.54	287.15
SD	66.96	85.13	110.64	99.98	96.45	117.85	103.84	114.45
P value	0.001		0.04		0.075		0.592	
HSL width (mm)								
Average	10.76	13.90	13.42	11.48	11.44	13.33	12.09	12.64
SD	3.49	2.85	3.83	3.00	2.96	3.83	3.40	3.66
P value	0.001		0.01		0.015		0.474	
HSL volume (mm³)								
Average			492.26	398.39	408.98	475.44	433.55	449.34
SD			256.31	241.05	233.28	266.85	239.05	264.11
P value			0.038		0.139		0.811	
Medialization (mm)								
Average	18.36	16.19			18.62	15.81	17.54	17.00
SD	4.62	4.17			4.08	4.52	4.57	4.48
P value	0.015				0.001		0.623	
Most superior point of HSL (mm)								
Average	6.75	4.64	4.91	6.38	5.87	5.49	5.66	5.70
SD	3.51	2.07	2.37	3.43	3.58	2.37	2.61	3.44
P value	0.001		0.023		0.969		0.628	
HSLc angle (degrees)								
Average	29.31	30.78	33.11	27.31			24.05	35.68
SD	10.68	10.33	9.49	10.65			8.78	8.70
P value	0.480		0.006				0.001	
HSLr angle (degrees)								
Average	28.14	30.97	31.08	28.21	25.15	34.28		
SD	10.22	10.20	10.11	10.30	9.06	9.39		
P value	0.345		0.275		0.001			

Bolded values indicate statistically significant difference.

in order to correlate these specific parameters with patient outcomes.

Limitations

This study's applicability may be limited for some surgeons, who solely rely on MRI as 3D CT scans were used. However, the authors recommended 3D CT when HSL or GBL is concerning, as it provides the most accurate evaluation of bone loss. Although patients with HSLs rarely present without GBL (bipolar bone loss), only humeral sided bone loss was assessed in the present study. This was done to focus solely on the characterization of HSLs and the relationships between various advanced measures.

Conclusion

There was a statistically significant association between HSL medialization and HSL volume, position, and orientation. More medialized HSL have larger volume, greater width, more SA loss, and higher lesion angles and are more inferior in the humeral head. As it has been established that more medialized lesions have poorer clinical outcomes, this study highlights that HS lesions have varying angles and medialization, which may portend eventual treatment and outcomes.

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