Original Article

Reliability and Accuracy of Three-Dimensional Computed Tomography in Predicting On-Track and Off-Track Lesions

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Abstract

Background and Objectives: The bone defects involving both humeral and glenoid following traumatic dislocation of the shoulder are referred to as bipolar bone lesions. It is essential to identify bipolar bone lesions when considering standard stabilization procedures such as Bankart's repair. We aim to correlate the radiological and arthroscopic assessment of bipolar lesions in predicting "on-track" and "off-track" lesions using three-dimensional-computed tomography (3D-CT). **Materials and Methods:** A prospective observational study was conducted between September 2019 and August 2021. Seventy-four patients with anterior shoulder dislocation were evaluated; of which 45 patients having both radiological imaging and arthroscopic follow-up were included in the study. The radiological and arthroscopic assessment for various parameters such as glenoid diameter (D), defect (d), glenoid track (GT), bone loss (BL), Hill-Sachs (HS) defect, and Hill-Sachs index (HSI) were tabulated and evaluated. **Results and Analysis:** Inter-observer correlation was calculated using intraclass correlation coefficient (ICC) ranging from 0.61 to 0.80 for most variables (D, d, BL%, GT, and HSI) suggesting a substantial agreement. Almost perfect agreement (0.93) was observed in predicting on- and Off-track lesions and moderate agreement (ICC = 0.56) was observed in calculating HS angle. There was a positive strong correlation between glenoid defect (d) and BL percentage (BL%) among both modalities. **Conclusions:** 3D-CT proves an essential tool in the preoperative evaluation of the shoulder in patients with recurrent anterior shoulder dislocation; based on the glenoid BL and characterization of the bipolar lesions through the glenoid track concept.

Keywords: Bankart's lesion, hill-Sachs lesion, Three-dimensional-computed tomography

Introduction

Of all the types of dislocations, an anterior shoulder dislocation is the most common type. Hill-Sach's (HS) lesion and Bankart's lesion develop as a result of recurrent anterior dislocation. HS lesion is a posterolateral humeral head compression fracture as the humeral head comes to rest against the anteroinferior part of the glenoid. It is often associated with a Bankart lesion of the glenoid which may often be labral only and is called "soft Bankart." Occasionally, it may involve the bony glenoid margin (impaction fracture) to be called as "bony Bankart" lesion.

The bone defects involving both humeral and glenoid following traumatic dislocation of the shoulder are referred to as bipolar bone lesions. The prevalence of glenoid defect, HS defect, and bipolar lesions amounts to 86%, 94%, and 81% in the case of recurrent dislocation.[1] The bone tissue strength and structure are quite important in glenohumeral stability, especially during midrange movements. However, till early 2000s, the importance was given only to soft-tissue Bankart's repair ignoring the bony lesions which led to a high recurrence of shoulder instability.

It is vital to identify the bipolar bone lesions at risk based on the integrity of the glenoid track and HS location concerning the glenoid track medial margin. This further aids in considering

Access this article online	
Quick Response Code:	Website: www.archtrauma.com
	DOI: 10.4103/atr.atr_61_22

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How to cite this article: Madhuchandra P, Pawankumar KM, Santhosh GS. Reliability and accuracy of three-dimensional computed tomography in predicting on-track and off-track lesions. Arch Trauma Res 2022;11:177-83.

Received: 10-10-2022, **Revised:** 02-01-2023,
Accepted: 03-01-2023, **Published:** 28-02-2023.

the standard stabilization procedures such as Bankart's repair. Radiological modalities are essential for detecting glenoid bone defects and for bone loss (BL) assessment. These measurements assist further surgical planning.[2]

We hypothesized that CT is highly specific and sensitive in the detection and quantification of glenoid BL. It is considered as the most precise radiological modality for the visualization of cortical glenoid rim.[3-5] However, another potential use of the three-dimensional-computed tomography (3D-CT) image is its ability to provide information concerning the glenoid vault. The three-dimensional geometry of the glenoid vault can be characterized by 3D-CT. It can evaluate the vault relative to the size and position of the glenoid surface.[6] This study was performed to prospectively assess the reliability and accuracy of 3D-CT in predicting on-track and off-track lesions. We aim to correlate the radiological and arthroscopic assessment of bipolar lesions in predicting "on-track" and "off-track" lesions and also individually assess the bipolar lesions to predict an off-track lesion using 3D-CT.

Materials and Methods

This observational prospective study was conducted at the tertiary care hospital for a period of 2 years from September 2019 to August 2021. Around 74 patients with anterior shoulder dislocation were evaluated; of which 45 patients with both radiological imaging and arthroscopic follow-up were included in the study. Among which, 19 of them did not undergo arthroscopic surgery, 6 were lost on follow-up and 4 underwent Latarjet's procedure.

Patients who have shoulders with symptomatic glenohumeral instability with >1 traumatic episode, preoperative, and shoulders with unilateral instability were included in the study.

Bilateral glenohumeral instability, previous shoulder stabilization surgery, an unclosed epiphyseal plate in the glenohumeral joint on CT, shoulder pathology other than anterior instability in the entry criteria (associated lesions were included, but not if such lesions were the primary focus) such as posterior glenohumeral instability, glenohumeral arthritis, rotator cuff tear, and tumor and nonvisualization of the bare spot in the affected shoulder during arthroscopy were excluded from the study.

Informed consent was obtained from all the patients included in the study. Institutional ethics committee approval was taken before the initiation of the study. The study was conducted by the principles laid down by the Declaration of Helsinki.

Radiological assessment

Image acquisition was done using CT: (model)-Philips Brilliance 64-slice (the Netherlands) and Philips Incisive 128-slice. Three-dimensional volume reconstructions of both shoulders were obtained. The glenoid bone enface view of both the affected and normal shoulders was obtained. The assessment on 3D-CT was performed by two radiologists, experienced in musculoskeletal radiology. The best-fit circle is then placed along the posteroinferior margin of the normal glenoid to include the maximum area of the glenoid. The diameter of the best-fit circle is then taken as the diameter of the glenoid (D). This best-fit circle is then superimposed along the posteroinferior margin of the glenoid of the affected shoulder. Accordingly the glenoid defect (d) is determined. By acquiring these two values, the glenoid track is calculated using the formula $GT = 0.84D - d$. The BL is calculated as $d/D \times 100$. Next, the posterior view of the affected humeral head is obtained. The HS defect width and the distance between the lateral margin of the HS defect and the medial attachment of the rotator cuff muscles called the bone bridge (BB) are measured. The Hill-Sach's index (HSI) is calculated as $HSI = HS + BB$. If the $HSI > GT$, the HS is considered off-track. If $HSI < GT$, the HS is "On track."

Arthroscopic assessment

While viewing from the antero-superolateral portal, the radius of the inferior glenoid is calculated by measuring the distance from the bare spot to the posterior glenoid rim. Subsequently, the radius is doubled to obtain the inferior glenoid diameter (D). The distance from the anterior glenoid rim to the bare spot of the glenoid is measured (D'). The difference in D and D' gives the glenoid bone defect (d). The glenoid track is calculated by using the formula 0.84D-d. The width of the HS defect and the width of the intact BB between the rotator cuff and the HS lesion is measured and added to obtain the HSI. Comparison between individual measurements and their inferences (on-track/off-track) obtained through imaging and arthroscopy was performed considering arthroscopy as the gold standard.

Statistical analysis

The sample size was calculated by using G*Power software. (University of Dusseldorf, Dusseldorf, Germany.) Assuming a small effect size (0.25), at a 5% level of significance and 80% power, the sample size obtained was 46 subjects. Here 45 eligible subjects were included in the study. Data were analyzed using the SPSS 22 version software (Norman.H.Nie, IBM, New york, America). Inter-observer variation for the radiological measurements by the two radiologists was calculated using the intraclass correlation coefficient (ICC). ICC index is a statistic used to measure interobserver reliability for the continuous variables. It is measured as ICC index = true variance/true variance + error variance. Based on the 95% confidence interval of the ICC estimate, values <0.5, between 0.5 and 0.75, between 0.75 and 0.9, and >0.90 are indicative of poor, moderate, good, and excellent reliability, respectively.

Each of the radiological quantitative values, namely glenoid BL, glenoid track, BL percentage, glenoid width, and HSI was compared with the same on arthroscopy using Pearson's correlation [Table 1]. The association between radiological and arthroscopic on-track off-track lesions was tested using the Chi-square test and the sensitivity and specificity in identifying an off-track lesion were derived. The receiving operating characteristic (ROC) curve for the BL percentage was generated and the cutoff value (critical BL percentage) having good sensitivity and specificity to identify off-track lesions was derived. The association of HS angle in on-track and off-track lesions was tested using the Independent *t*-test. Graphical representation of data: MS Excel and MS Word were used to obtain the various types of graphs such as bar diagram, pie diagram, and scatter plots. *P* value (probability that the result is true) of <0.05 was considered statistically significant after assuming all the rules of statistical tests.

Results and Analysis

The majority of our cases 23/45 (51.1%) in the study belong to the age group of 20–30 years [Table 2]. Most of the affected population in the study were males 93.3%. Most of the lesions (73.3%) were found to be on the right side.

Descriptive statistics of various parameters were assessed on 3D-CT and arthroscopy are mentioned in Table 3.

Inter-observer correlation ranged from 0.61 to 0.80 for most variables (D, d, BL%, GT, and HSI) suggesting a moderate to a good agreement. Excellent agreement (0.93) was observed in predicting on- and off-track lesions and moderate agreement (ICC = 0.56) was observed for calculating HS angle [Table 4].

Nearly 40 of the 45 cases correlated with arthroscopic findings concerning on-track and off-track status. Two cases which were off-track on imaging were on-track on arthroscopy and 3 cases which were on-track on imaging were off-track on arthroscopy [Table 5]. There was a significant association ($P < 0.001$) between radiological on/off and arthroscopic on/off lesions. Six out of 9 off-track lesions were correctly predicted on imaging (sensitivity – 66.7%) and 34 out of 36 on-track lesions were correctly predicted on imaging (specificity – 94.4%).

Correlation of various quantitative parameters assessed on three-dimensional-computed tomography and arthroscopy

There was a positive strong correlation between glenoid defect (d) and BL percentage BL% among both modalities, i.e. with an increase in radiological d and BL%, there was an increase in arthroscopic d and BL% and vice versa, respectively. There was a significant positive correlation between glenoid diameter (D), GT, and HSI among both modalities. However, the glenoid diameter and HSI showed a tendency toward having lower correlation values (0.515 and 0.616) [Table 6 and Figure 1a-e].

Assessment of bone loss percentage in predicting off-track lesions

The mean glenoid BL % for arthroscopic on-track lesions was 9.2% and for arthroscopic off-track, it was 14.9% which was statistically significant ($P = 0.002$). ROC curves were obtained for the accuracy of BL % in identifying the off-track lesion in our study and the area under the curve obtained

Table 1: Pearson correlation values were interpreted as follows

Correlation coefficient (*r*)	Interpretation
0-0.3	Positive weak correlation
0.3-0.6	Positive moderate correlation
0.6-1.0	Positive strong correlation
0-−0.3	Negative weak correlation
−0.3-−0.6	Negative moderate correlation
−0.6-−1	Negative strong correlation

Table 2: Age distribution

Age group	Frequency
10-20	6
20-30	23
30-40	10
40-50	4
50-60	1
60-70	1

Table 3: The minimum values, maximum values and the mean and standard deviation of the radiological and respective arthroscopic parameters are depicted (*n*=45)

Parameter	Minimum value	Maximum value	Mean±SD
CT D (mm)	22.50	31.20	27.11±1.91
Arthroscopic D[a] (mm)	22.00	32.00	26.75±2.20
CT BL d (mm)	1.00	8.60	2.88±1.80
Arthroscopic BL d[a] (mm)	1.00	7.00	2.65±1.59
CT GT (mm)	15.30	23.70	19.99±1.89
GTA (mm)	15.20	23.70	19.62±2.05
CT GBL (%)	3.50	27.80	10.67±6.10
Arthroscopic BL (%[a])	3.40	25.00	10.46±5.64
CT HSI (mm)	2.00	33.00	15.13±4.65
Arthroscopic HSI[a] (mm)	2.00	22.0	14.21±3.88
HSA (degree)	9.00	48.30	30.66±10.20

D: Glenoid diameter, D[a]: stands for Arthroscopic Glenoid Diameter, d: defect, GT: Glenoid track, GTA: Arthroscopic glenoid track, BL: Bone loss, GBL: Glenoid BL, HSI: Hill Sach's Index, HSA: Hill-Sach's angle, SD: Standard deviation, CT: Computed tomography

Table 4: Inter-observer correlation of radiological parameters of on-track and off-track lesions

	ICC values
Glenoid diameter	0.68
GBL (mm)	0.75
GBL (%)	0.73
GT	0.77
HSI	0.63
On- and off-track lesions	0.93
HSA	0.56

ICC index: True variance/true variance+error variance. <0.5: Poor reliability, 0.5–0.75: Moderate reliability, 0.75–0.9: Good reliability, >0.90: Excellent reliability. BL: Bone loss, GBL: Glenoid BL, HSI: Hill Sach's Index, HSA: Hill-Sach's angle, GT: Glenoid track, ICC: Intraclass correlation coefficient

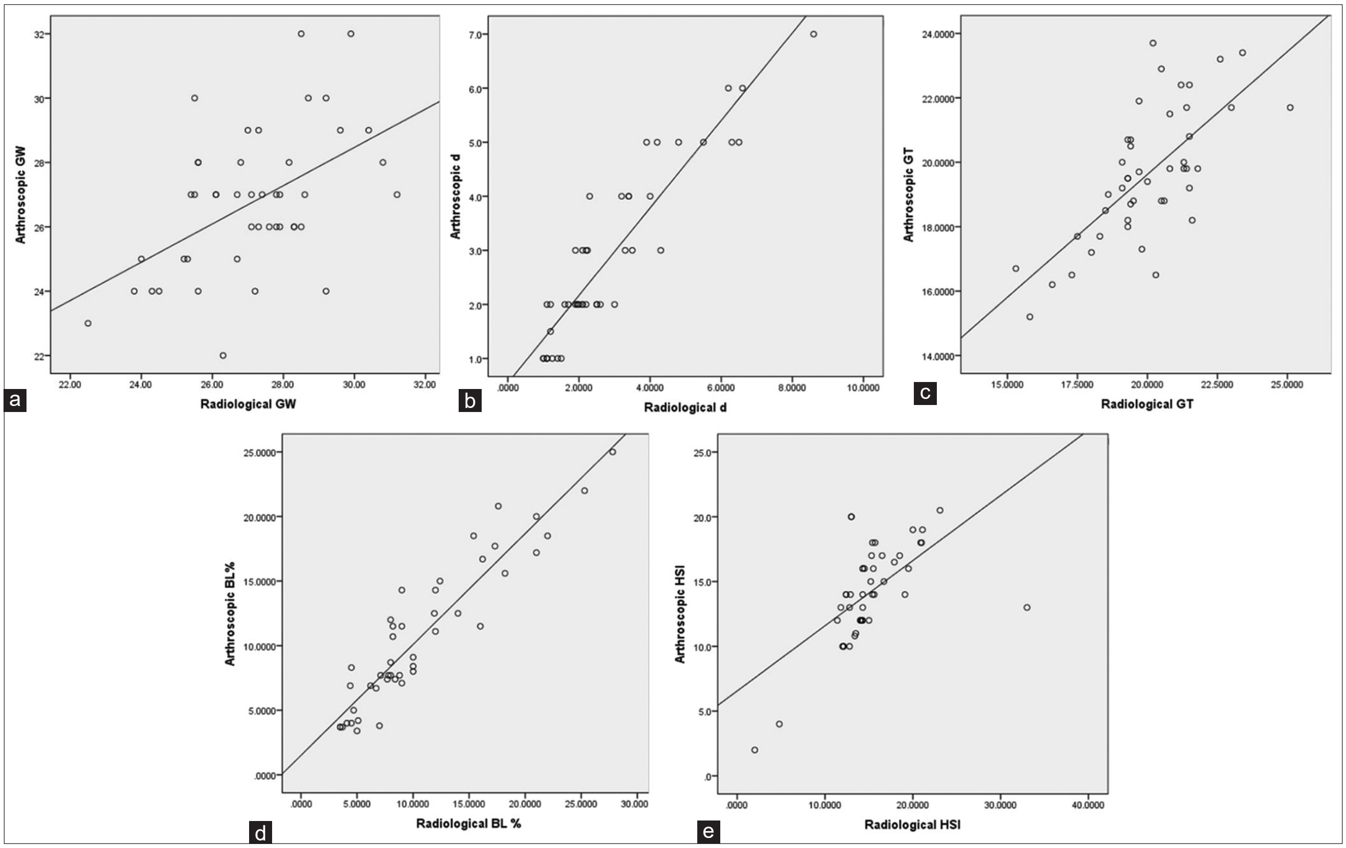

Figure 1: (a-e) Scatter plots showing the correlation between matched and unmatched radiological and arthroscopic (a) GW (b) Bone defect (d and c) GT (d) BL percentage (BL%) (e) HSI. It can be noted all the parameters show moderate to strong positive correlation with the maximum strong correlation being for BL % and BL (mm) which are very close to being linear. GW: Glenoid width, GT: Glenoid track, HSI: Hill Sach's Index, BL: Bone loss

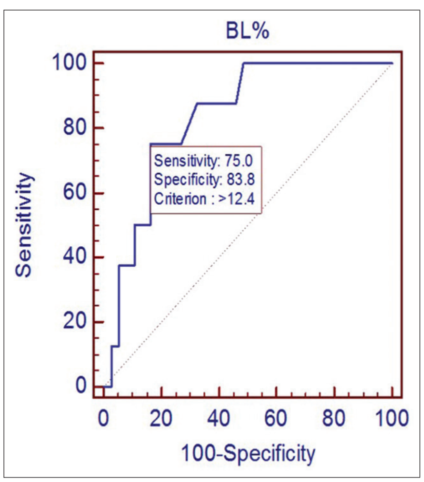

Figure 2: ROC curve showing validity of BL % in predicting off-track lesions. ROC: Receiving operating characteristic, BL: Bone loss

was 0.833 indicating good accuracy. Further, the cutoff value of>12.4% showed a sensitivity of 75% and specificity of 83.78 in identifying an off-track lesion [Figure 2].

The mean HS angle among those with arthroscopic off-track lesions was 25.80 ± 11.23 and arthroscopic track lesions were 31.87 ± 9.71. There was no significant difference in mean HS angle between arthroscopic off and on lesions (P = 0.111). However, a tendency of the off-track lesions to show a lower HS angle was noted.

Table 5: Comparison of on and off lesions between arthroscopy and radiology

	Arthroscopic on/off, count (%)	
	Off	**On**
Radiological on/off		
Off	6 (66.7)	2 (5.6)
On	3 (33.3)	34 (94.4)

*P <0.001. χ^2=18.39, df=1

Discussion

On summarizing the results of our study, a statistically significant correlation (P < 0.001) was found with a sensitivity of 66.7% and specificity of 94.4%, in detecting on-track and off-track lesions by 3D-CT and arthroscopy. Quantification was done with the percentage of BL measurements. A strong positive correlation (0.928) was found concerning the BL percentage between both modalities with a P < 0.001. We found a good agreement between the two observers which was a substantial agreement for glenoid width, glenoid track and HSI, moderate agreement for HS angle and almost perfect agreement for on-track and off-track lesion

Table 6: Correlation between radiological and arthroscopic parameters

	D[a]	d[a]	GT[a]	BL (%[a])	HSI[a]
D					
Pearson correlation	0.515**				
P	<0.001*				
n	45				
d					
Pearson correlation		0.918**			
P		<0.001*			
n		45			
GT					
Pearson correlation			0.703**		
P			<0.001*		
n			45		
BL (%)					
Pearson correlation				0.928**	
P				<0.001*	
n				45	
HSI					
Pearson correlation					0.616**
P					<0.001*
n					45

*Denotes significant P value denoting association between arthroscopy and CT findings. **Denotes Strong Pearson's coefficient assessing bone loss and glenoid diameter. [a]denotes Arthroscopic. D: Glenoid diameter, d: defect, GT: Glenoid track, BL: Bone loss, HSI: Hill Sach's index

Table 7: Represents sensitivity and specificity of radiologically assessing arthroscopic on- and off-track lesions in various studies

	MRI		3D-CT	
	Metzger *et al.*[8]	Gyftopoulos *et al.*[7]	Chuang *et al.*[9]	Our study
Sensitivity (%)	51.6	72.2	92.3	66.7
Specificity (%)	97.2	87.9	92.3	94.4
PPV (%)	84.2	65.0	100	75.0
NPV (%)	87.6	91.1	92.3	91.8

PPV: Positive predictive value, NPV: Negative predictive value, MRI: Magnetic resonance imaging, CT: Computed tomography

assessment. A statistically significant difference was found in the mean glenoid BL % in on-track lesions and off-track lesions ($P = 0.002$). A critical BL percentage of >12.4% gave a sensitivity of 75% and specificity of 83.78% in identifying off-track lesions. No significant difference was found in the means of HS angles in on- and off-track lesions. However, a tendency of the off-track lesions to show a lower HS angle was noted.

In the study conducted by Gyftopoulos *et al*.,[7] they were able to predict 13 out of 18 off-track lesions (sensitivity ~ 72.2%), and among the 58 on-track lesions, they were able to predict 51 lesions (specificity ~ 87.9%). Whereas in the study conducted by Metzger *et al*.[8] out of 19 patients radiologically suggested OUT-E lesions, 16 has clinical evidence of engagement while only 15 out of 121 patients without radiological evidence of engagement showed engagement clinically [Table 7].

The negative predictive value (NPV) of the various studies is almost consistently constant whilst there are variations in their positive predictive value (PPV); this proves that radiological investigations such as 3D-CT and MRI can almost definitely rule out off-track lesions in the true clinical/arthroscopically proven nonengaging lesions. Our study had better agreement with the study conducted by Gyftopoulos *et al*.[7] rather than that of Metzger *et al*.[8] and Chuang *et al*.[9] with regard to sensitivity, specificity, NPV, and PPV.

Critical glenoid BL percentage has been assessed as ≥20%, ≥20%, and ≥25% in studies by Sugaya *et al*.,[10] and Ozaki *et al*.,[11] and Chuang *et al*.,[9] respectively. Critical glenoid BL predicts off-track bipolar lesions and thereby determines the requirement of open surgery over a simple Bankart procedure. In our study, we got a value lesser, however closer to those of Sugaya *et al*.[10] and Ozaki *et al*.[11] [Table 8].

There was greater mean glenoid BL and HS interval in the case of off-track lesions in comparison to those of on-track lesions, whereas the reverse is observed concerning glenoid track in studies by Metzger *et al*.[8] and Gyftopoulos *et al*.[7] Our study results regarding glenoid BL also confirmed the same [Table 9].

The proportion of on-track lesions over off-track lesions in studies by Metzger *et al*.,[8] Locher *et al*.,[12] Gyftopoulos *et al*.,[7] Chuang *et al*.,[9] and our study population shows a close correlation with Gyftopoulos *et al*. [Table 10].

The study conducted by Di Giacomo *et al*.[13] concluded that HS angle was 32° ±4.7° when the HS lesion was acquired with the initial arm position in abduction (i.e. resulting in a more slanted H-S axis concerning the longitudinal axis of the humerus) while 16.1° ±2.9° when it was acquired with the initial arm position in adduction. All the lesions were found to be on track in the study. In our study, we tried to derive significance in HS angle concerning off-track and on-track bipolar lesions but no significant difference in the mean H-S angle in arthroscopic off- and on-track lesions could be derived ($P = 0.111$) [Figure 3a-d].

When individually assessed in the study conducted by Schneider *et al*.,[14] glenoid-related measurements such as glenoid width and glenoid BL demonstrated a low correlation of variability (CoV) (CoV <0.4), but the measurement of the HS interval showed a high CoV (CoV = 19.2) representing a high level of variability. This accounted for the poor inter-observer correlation in the assessment of "on-track" versus "off-track" lesions [Table 11]. In our study, there was a positive strong interobserver correlation for glenoid width and glenoid BL values; which is congruent with that of Schneider

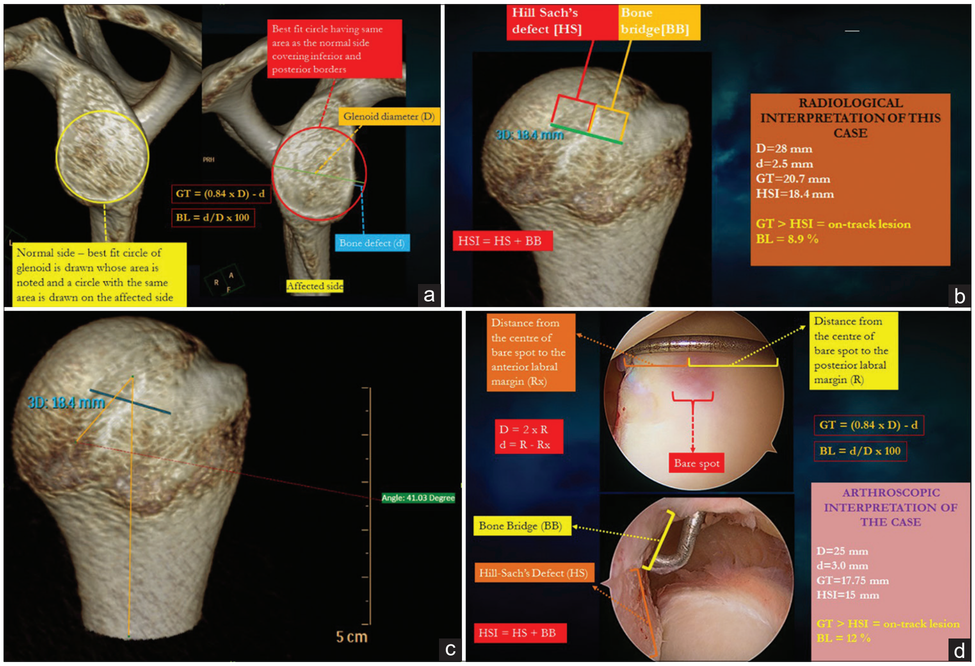

Figure 3: (a) The Best-fit circle was drawn along the posteroinferior glenoid margin of the left normal glenoid with diameter D and this circle was then superimposed on the affected right glenoid. The width of the bone defect along the anterior aspect of the glenoid was calculated. The glenoid track was then calculated using the formula GT = 0.84D − d, (b) The HSI was measured along the posterior aspect of the three-dimensional reconstructed right humerus; which is measured as HSI = Hill-sach's defect width (HS) + BB. Since in this case GT > HSI; it was considered an On-track lesion on Imaging, (c) Hill-Sach's angle was calculated by measuring the angle between the line drawn along the axis of the deepest portion of the Hill-Sach's lesion and another line along the axis of the shaft of the humerus. Hill-Sach's angle in this case measured 41.03°, (d) Arthroscopic Imaging of the right affected glenoid shows the presence of the bare spot which is considered to represent the centre of the glenoid; the posterior radius is measured (R) and the distance from the anterior glenoid margin to the bare spot is measured (Rx). The difference between R and Rx is measured; which is considered as the bone defect "d." The Hill-sach's index is measured by the addition of the BB which is represented as the distance between the rotator cuff and the lateral margin of Hill-sach's lesion with the HSI. GT: Glenoid track, HSI: Hill Sach's Index, BL: Bone loss, D: Glenoid diameter, d: Defect, GT: Glenoid track, BB: Bone bridge

Table 8: Represents the comparison of critical bone loss in various studies

	Ozaki *et al*.[11]	Sugaya *et al*.[10]	Chuang *et al*.[9]	Our study
Critical GBL (%)	≥20	≥20	≥25	≥12.4
Sensitivity for identifying significant BL on CT (%)	-	-	-	75.0
Specificity for identifying significant BL on CT (%)	-	-	96	83.8
PPV (%)	-	-	-	50
NPV (%)	-	-	-	93.9

PPV: Positive predictive value, NPV: Negative predictive value, BL: Bone loss, GBL: Glenoid BL, CT: Computed tomography

et al.[14] (even if the inter-observer correlation tool used was different) as well as the rest of the glenoid values such as GBL% and GT. Whereas positive moderate inter-observer correlation was observed in HSI and H-S angle, this is likely due to the nonuniformity in experience between the two observers (one 8 years and the other 3 years).

Limitations of our study are limited sample size and nonuniformity in the experience of the observers who measured the radiological parameters. Further studies with high sample sizes and uniform experience of the radiologists would be needed to confirm the results of the present study.

Conclusions

3D-CT proves an essential tool in the preoperative evaluation of the shoulder in patients with recurrent anterior shoulder dislocation. Based on the glenoid BL and characterization of the bipolar lesions through the glenoid track concept, 3D-CT plays a vital role in decision-making of recurrent shoulder dislocation management. There is a significant positive inter-observer correlation in the study; however, a stronger positive correlation can be achieved by uniformity in the observer's experience. HS angle assessment for off-track and on-track lesions did not represent as a good predictor for glenoid track status, however, further research with more sample size is suggested as there was a tendency of off-track lesions to have a smaller angle.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

Table 9: Represents a comparison of mean glenoid bone loss, mean Hill-Sach's interval and glenoid track in various studies

	Metzger *et al.*[8] (MRI)		Gyftopoulos *et al.*[7] (MRI)		Our study	
	On-track	Off-track	On-track	Off-track	On-track	Off-track
Mean GBL (%)	6.5	13.7	8.9	13.5	9.2	14.1
Mean HSI	14.5	22.1	16.0	24.7	12.7	16.9
GT (mm)	22.2	20.2	21.4	19.4	19.5	16.28

MRI: Magnetic resonance imaging, BL: Bone loss, GBL: Glenoid BL, HSI: Hill Sach's index, GT: Glenoid track

Table 10: Represents the proportion of on-track and off-track lesions in various studies

	Metzger *et al*.[8] (MRI)	Locher *et al*.[12]	Gyftopoulos *et al*.[7] (MRI)	Chuang *et al*.[9]	Our study
On-track (R)	121 (86.4)	88 (88)	58 (77.3)	12 (48)	36 (80)
Off-track (R)	19 (13.6)	12 (12)	17 (22.7)	13 (52)	9 (20)
Total number of patients	140	100	75	25	45

MRI: Magnetic resonance imaging

Table 11: Represents the Inter-observer correlation seen in our study in comparison to Schneider *et al*.[14]

	Schneider *et al.*[14] (CoV)	Our study (K)
Glenoid width	2.7	0.7
GBL (mm)	3.6	0.7
GBL (%)	-	0.7
GT	-	0.7
HSI	19.2	0.6
On- and off-track lesions	-	0.9
HSA	-	0.5

CoV: Correlation of variability, BL: Bone loss, GBL: Glenoid BL, HSI: Hill Sach's Index, HSA: Hill-Sach's angle, GT: Glenoid track

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