Association of Instability History and Off-Track Hill-Sachs Lesions in Anterior Shoulder Instability

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Background: The glenoid track concept is now widely accepted, and its evaluation is considered essential for making decisions about surgery.

Purpose: To define preoperative descriptive data and clinical and functional features in patients with anterior glenohumeral instability according to glenoid track status and to analyze the influence of off-track Hill-Sachs (HS) lesions on preoperative shoulder function.

Study Design: Case-control study; Level of evidence, 3.

Methods: Preoperative magnetic resonance imaging or computed tomography scans were used to measure the glenoid track. Descriptive data and preoperative objective and subjective clinical and functional features were compared between patients with on-track HS lesions versus off-track HS lesions. Multivariate regression analysis was conducted to identify potential risk factors for off-track HS lesion development.

Results: A total of 235 patients (201 men, 34 women; mean age, 29.6 ± 8.6 years) were included— 134 shoulders (57%) with on-track HS lesions and 101 shoulders (43%) with off-track HS lesions. Age <20 years at first dislocation, number of dislocations, and ≥2 years between first dislocation and surgery were significantly different between the study groups (P = .005, P = .0001, and P = .01, respectively). Regarding these characteristics, the odds ratios for the risk of developing an off-track lesion were 2.67 (95% CI, 1.2-5.99)—1.2 times higher for each additional instability episode (95% CI, 1.025-1.14) and 2.42 times higher (95% CI, 1.176-4.608) for patients whose first dislocation was ≥2 years before surgery, respectively. Patients with off-track HS lesions had a significantly greater degree of instability (P = .04), worse Rowe scores (48.8 ± 15.3 vs 54.8 ± 28.3 for on-track HS lesions; P = .04), and lower Western Ontario Shoulder Instability scores (975 ± 454 vs 1179 ± 428 for on-track HS lesions; P = .01).

Conclusion: Characteristics related to a history of instability (age <20 years at first instability episode, larger number of dislocations, ≥2 years between first dislocation and surgery) were found to be risk factors for the development of an off-track HS lesion in this study. Off-track lesions led to a higher degree of instability and worse objective and subjective preoperative shoulder function versus on-track HS lesions.

Keywords: glenoid track; off-track; preoperative clinical outcomes; prognostic factors; shoulder instability

Bone loss is commonly observed in anterior glenohumeral instability. Large bone lesions are well-known risk factors for recurrence of instability[2,7] and worse outcomes after a soft tissue repair.[27] Despite the importance of bone defects in anterior shoulder instability management, only a few studies analyzing risk factors for bone loss development have been published. Milano et al[17] found that age at first dislocation and male sex were significantly associated with glenoid bone defects. In addition to these risk factors, Matsumura et al[15] stated that the longer the instability symptoms were, the larger the humeral bone loss was. With regard to bipolar bone lesions, Nakagawa et al[18] claimed that a larger number of dislocations and overhead sports were risk factors for bipolar lesion development.

Glenoid and humeral bone defects should not be regarded as static independent problems. Still, a dynamic interaction between them during shoulder motion should be evaluated

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as suggested by the *glenoid track concept*.[29] The glenoid track concept has been clinically validated and is widely accepted, and it provides more valuable information than isolated evaluation of glenoid bone loss or humeral defect.[3] According to Shaha et al,[26] the glenoid track provides a more accurate prediction of risk failure compared with isolated bone defects measurement, and it is also known that off-track Hill-Sachs (HS) lesions have higher rates of postoperative instability and the need for revision surgery is more likely.[1,12] Moreover, Hatta et al[6] and Itoi et al[7] stated that the glenoid track is an accurate and useful tool for preoperative planning. Since glenoid track status affects clinical results after surgical stabilization and its evaluation is considered important for surgical planning, it is important to identify factors associated with off-track HS lesions.

The purpose of this study was to determine the descriptive data and clinical and functional features in patients with anterior glenohumeral instability that are associated with off-track HS lesions and to analyze the influence of off-track HS lesions in preoperative objective and subjective shoulder function. We hypothesized that risk factors associated with off-track HS lesions could be identified and that patients with off-track HS lesions would have worse clinical and functional results and lower preoperative subjective evaluation of the shoulder compared with those with on-track lesions.

METHODS

Study Population

Our institutional review board approved the study protocol. We conducted an observational, retrospective, single-cohort study of prospectively registered preoperative data of patients with anterior glenohumeral instability. The availability of magnetic resonance imaging (MRI) or computed tomography (CT) scans was required as the inclusion criterion. Patients >50 years old and those with posterior, multidirectional glenohumeral instability and voluntary instability were excluded. Documented lesions not addressed in this study but potentially linked to instability (ie, superior labrum anterior-posterior and humeral avulsion of the glenohumeral ligaments) and history of surgery or fractures in the index shoulder, as well as neurologic or degenerative diseases involving the shoulder girdle, were also considered exclusion criteria.

Imaging Evaluation

All patients had standard shoulder radiographs. CT or MRI scans were evaluated in every case. The glenoid track was measured on the 2-dimensional (2D) CT images as described by Gyftopoulos et al.[5] A best-fit circle was placed along the posterior and inferior margins of the glenoid on the en face 2D view. The circle diameter and the bone loss length were measured. The defect size was expressed as a percentage of the circle's diameter according to the formula $d/D \times 100$, where D is the diameter of the fitted circle and d is the width of the defect. The glenoid track was calculated according to Di Giacomo et al[4] using the following formula: *Glenoid track* $= 0.83{*}D - d$. If glenoid bone loss existed, the distance (d) was subtracted from 83% of the glenoid width, which determined the width of the glenoid track (Figure 1A). Then, on axial view, the HS interval was measured at the level of the widest medial extent of the HS lesion. Measurements to obtain the HS index (HSI) included the bony bridge and the HS interval. The HSI was calculated as the distance between the medial edge of the HS interval to the insertion of the articular fibers of the rotator cuff (*HSI = bony bridge + HS interval*). The HS lesion was classified as off-track when the HS interval was larger than the glenoid track. If the HS interval was smaller than the glenoid track width, the HS lesion was determined to be on-track[29] (Figure 1B).

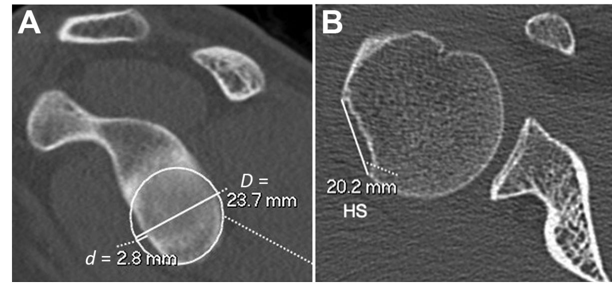

Figure 1. Evaluation of the glenoid track. (A) Measurement of the glenoid diameter (*D*) and bone loss (*d*) using the best-fit circle technique on a sagittal CT scan. (B) Measurement of the HS length on an axial CT scan from the medial edge of the HS lesion to the insertion of the rotator cuff. According to the formula *Glenoid track* = 0.83*D – d*, the glenoid track in this patient was 16.9. The HS lesion length was 20.2 mm. Since the HS lesion was larger than the glenoid track, the lesion was classified as off-track. CT, computed tomography; HS, Hill-Sachs.

Measurements on CT scan (Siemens Somatom Definition Flash 128 slice CT Dual Energy; Siemens Healthcare) or MRI scan (Siemens Magnetom Verio 3T; A Tim + Dom System; Siemens Healthcare) were performed by a previously trained shoulder and elbow fellow (C.D.) using Digital Imaging and Communications in Medicine, Picture

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Archiving and Communication System, and Syngo.via imaging software (Siemens Healthcare).

Data Collection and Clinical Assessment

Patients were allocated to 2 groups after imaging measurement: those with preoperative on-track HS lesions and those with preoperative off-track HS lesions.

Patient characteristics and clinical and functional performance data were recorded for each participant. We considered the following variables: descriptive data (age, sex), generalized ligamentous laxity, dislocation-related features (age at first episode, number of dislocations, and time between dislocation and surgery), sports activity level (including type and sports participation level), and type of work (manual or nonmanual[11]). The activity level was graded as defined by Calvo et al[2] into 5 categories: type 0, a sedentary life; type 1, noncontact sports; type 2, sports that do not require overhead movements of the arm; type 3, sports that require overhead use of the arm without adopting a forced abduction and external rotation position; and type 4, sports that include overhead hitting movements or contact sports with a high risk of falls. Sports participation levels were categorized as no sports practice (level 0), recreational (level 1), high-school team sport (level 2), college team sport (level 3), or professional (level 4).[2] Hyperlaxity diagnosis was based on the Marshall et al[14] criteria that consider patients to have ligamentous hyperlaxity if 2 of the following 3 findings are found on the physical examination: (1) elbow hyperextension beyond neutral; (2) index metacarpophalangeal joint hyperextension beyond 90°; and (3) thumb hyperabduction to the forearm.

The objective clinical and functional performances were defined as instability degree[13] and the Rowe score.[25] The instability degree was determined by the activity that produces instability symptoms and graded in 4 levels according to Manta et al[13]: level 1, instability after traumatic events or forceful movements; level 2, instability related to sports involving abduction and external rotation; level 3, instability performing activities of daily living; and level 4, instability during the night or spontaneous instability. The subjective clinical status was assessed using the Spanish-validated version of the Western Ontario Shoulder Instability (WOSI) Index.[31]

Statistical Analysis

Patient characteristics were analyzed using frequencies and percentages for qualitative variables and means and standard deviation for quantitative variables. The Student *t* test was used to compare quantitative variables, and the chi-square test was used for qualitative variables between the on-track and off-track groups.

For patient characteristics with significant group differences, we conducted a multivariate regression analysis to identify potential risk factors for off-track HS lesion development. Results were presented as odds ratios (ORs) and 95% CIs. In addition, objective and subjective clinical shoulder function was compared between the study groups. For all comparisons, the statistical threshold for significance was established at $P < .05$. All statistical analyses were performed with SPSS Version 26 (IBM Corp).

RESULTS

A total of 235 patients with anterior glenohumeral instability were studied—134 shoulders (57%) in the on-track group and 101 shoulders (43%) in the off-track group.

Table 1 shows the results of the multivariate regression analysis for the presence of an off-track HS lesion for those patient characteristics significantly different between the on-track and off-track groups. Significant group differences were found regarding age at first instability episode (P = .005), and multivariate regression analysis indicated that patients aged <20 years at primary injury were 2.67 times (95% CI, 1.2-5.99) more likely to experience an off-track HS lesion compared with those aged ≥20 years. There were also significant group differences in the number of instability episodes and time between the first dislocation and surgery (P = .0001 for both), with the risk of developing an off-track HS lesion being 1.2 times higher for each additional instability episode (95% CI, 1.025-1.14) and 2.42 times higher for patients whose first dislocation was ≥2 years before surgery (95% CI, 1.176-4.608).

Significant differences existed between the study groups in type of sport played (P = .01), and multivariate analysis indicated that patients who participated in overhead sports showed a higher risk of developing an off-track HS lesion (OR, 0.251 [95% CI, 0.07-0.72]). Finally, significant differences were seen in hyperlaxity rates between groups (P = .026). Patients with hyperlaxity had a higher risk of developing an off-track HS lesion versus those without hyperlaxity (OR, 2.99 (95% CI, 1.14-7.85); P = 0.26). There were no significant differences between the study groups regarding patient sex (P = .085), level of sports (P = .99), or ratio of manual to nonmanual workers (P = .228).

The results of clinical and functional evaluations are shown in Table 2. Patients with off-track HS lesions had a significantly greater degree of instability when compared with those with on-track lesions (P = .04). The mean Rowe and WOSI scores were significantly worse in the off-track group compared with the on-track group (P = .04 and P = .01, respectively).

DISCUSSION

The main finding of this study was that patients with off-track HS lesions had a significantly longer time between instability symptoms and surgery and had significantly worse clinical and functional outcomes when compared with patients with on-track lesions. In addition, all variables related to a history of instability (ie, age <20 years at first instability episode, larger number of dislocations, and ≥2 years between first dislocation and surgery) were found to be risk factors for the development of an off-track HS lesion. Both humeral and glenoid defects have been

TABLE 1
Results of Multivariate Analysis of Risk Factors for Developing an Off-Track HS Lesions[a]

Risk Factor	On-Track Shoulders (n = 134)	Off-Track Shoulders (n = 101)	*P*	OR (95% CI)
Sex			.085	—
Male	112 (83.6)	92 (91.1)		
Female	22 (16.4)	9 (8.9)		
Dominant side affected			.335	—
Yes	75 (56)	54 (53.5)		
No	59 (44)	47 (46.5)		
Age <20 y at first instability episode			**.005**	2.67 (1.2-5.99)
Yes	61 (45.5)	57 (56.4)		
No	73 (54.5)	44 (43.6)		
Number of instability episodes	8.9 ± 18.9	18.3 ± 29.2	**.0001**	1.2 (1.025-1.14)
Time between first dislocation and surgery, y			**.01**	2.42 (1.176-4.608)
<2	39 (29.1)	14 (13.9)		
≥2	95 (70.9)	87 (86.1)		
Type of sport			**.01**	0.25 (0.07-0.72)
0	24 (17.9)	16 (15.8)		
1	13 (9.7)	10 (9.9)		
2	31 (23.1)	14 (13.9)		
3	12 (8.9)	5 (4.9)		
4	54 (40.3)	56 (55.5)		
Sports level			.99	—
0	22 (16.4)	23 (22.8)		
1	40 (29.9)	31 (30.7)		
2	47 (35.1)	28 (27.7)		
3	15 (11.2)	10 (9.9)		
4	10 (7.46)	9 (8.9)		
Manual work			.228	—
Yes	51 (38.1)	41 (40.6)		
No	83 (61.9)	60 (59.4)		
Hyperlaxity			**.026**	2.99 (1.14-7.85)
Yes	28 (20.9)	54 (53.5)		
No	106 (79.1)	47 (46.5)		

[a]Data are reported as mean ± SD or n (%). Dashes indicate areas not applicable. Bold *P* values indicate a statistically significant difference between groups ($P < .05$). HS, Hill-Sachs; OR, odds ratio.

TABLE 2
Comparison of Objective and Subjective Clinical and Functional Status[a]

Measurement	On-Track Shoulders (n = 134)	Off-Track Shoulders (n = 101)	*P*
Rowe score	54.8 ± 28.3	48.8 ± 15.3	**.04**
WOSI score	1179 ± 428	975 ± 454	**.01**
Degree of instability			**.04**
Traumatic	34 (25.4)	15 (14.4)	
Sports	20 (14.9)	17 (16.8)	
Daily living activities	32 (23.9)	18 (17.8)	
Sleeping/spontaneous	48 (35.8)	50 (50.5)	

[a]Data are reported as mean ± SD or n (%). Bold *P* values indicate a statistically significant difference between groups ($P < .05$). WOSI, Western Ontario Shoulder Instability.

identified as risk factors for recurrence of instability and failure of soft tissue repairs.[2] However, when evaluating these defects, it is important to consider their size and the dynamic interaction between them according to the glenoid track concept. To our knowledge, few investigations have analyzed factors associated with the preoperative development of bone defects,[15,17,19] and the study here reported is the first to analyze the influence of these factors on the glenoid track.

The number of instability episodes has previously been strongly related to bone defect, prevalence, and size. According to the literature, as the number of dislocations rises, the incidence and length of both glenoid and humeral defects increase.[8,17,19] Moreover, the number of dislocations is predictive of an off-track HS lesion. Metzger et al[16] noted that a larger number of instability episodes were predictive of being off-track, with a mean number of dislocations of 11.8 in the off-track group versus 6.4 episodes in the on-track group. Similarly, Lau et al[9] reported a 4.2-fold higher risk of developing an off-track HS lesion in patients with multiple dislocations ($\geq$2) than those with a single dislocation. Our results are similar to these series.[9,16] A significantly larger number of dislocations were seen in the off-track group compared with the on-track group. However, it is important to note that glenoid track measurements after the first dislocation episode were not available. Thus, whether this bone defect has increased with the increased number of dislocations or whether the presence of an off-track lesion caused more frequent instability events is unknown. A prolonged history of instability may also be considered a predictor of an off-track HS lesion, and a longer time from the first dislocation and surgery had a 2.4 higher rate of a concomitant off-track HS lesion in our series. A delay of more than 6 months between the first dislocation and the Bankart repair has previously been associated with the failure of the repair.[10,23] Younger age has been identified as an independent risk factor for recurrent instability,[20] development of glenoid defects,[17] and in the present study, as a risk factor for developing an off-track HS lesion. Younger age was also reported as a risk factor for developing an off-track HS lesion by Metzger et al[16] and Lau et al.[9] In the latter, authors found a 9.4-fold higher risk of developing an off-track HS lesion in patients aged <20 years.[9]

On the other hand, athletic activity, and more specifically, overhead sports, was a weaker but also significant predictor of the presence of an off-track HS lesion (OR, 0.251). These results are in line with those previously presented by Nakagawa et al[18] who identified an off-track HS lesion in 12% of athletes enrolled in collision and overhead sports. We also found that hyperlaxity was a risk factor for developing an off-track HS lesion, a feature previously identified as a risk factor for instability recurrence[20] but not for bone loss development. Finally, interestingly, in our series, patient sex was not identified as a risk factor for off-track HS lesions. Sex was also found not to be a risk factor for the development of a bipolar lesion in the report by Nakagawa et al.[18] These results differ from those reported by Milano et al[17] and Matsumura et al,[15] who reported that male sex was a risk factor for developing a glenoid and humeral bone defect, respectively. However, it has been suggested that there may be an interaction between sex and other risk factors, such as the mechanism of injury or sports practiced.[21] Therefore, differences between sexes may not be related to sex itself but differences between the sports in which patients are enrolled or a more traumatic mechanism of injury.

The second most important finding of our study was that patients with preoperative off-track HS lesions had a higher degree of instability and worse objective and subjective clinical and functional status when compared with the on-track group. More specifically, preoperative Rowe and WOSI scores were significantly worse in patients with off-track lesions. These differences exceeded the minimal clinically important differences.[22] It is well known that off-track lesions have an impact on postoperative outcomes, not only in rates of failure[1] but also in functional outcomes. Shaha et al[26] described in their series that on-track HS lesions had significantly better postoperative WOSI scores (668 points) compared with those off-track lesions (1134 points). Similar results were found by Yamamoto et al.[30] They stated that an off-track HS lesion would cause quality of life impairment. However, to our knowledge, this is the first study to evaluate preoperative status according to the glenoid track concept. The objective and subjective clinical evaluations were both significantly worse in the off-track group compared with the on-track group (see Table 2). In addition, a higher degree of instability was observed in the off-track group.

Clinical consequences of these findings may be relevant since predictors of an off-track HS lesion can be better identified; therefore, an earlier therapeutic approach can be established. A longer history of shoulder instability was shown to be a risk factor for off-track HS lesion development. Current results may support earlier surgical intervention for unstable shoulders to avoid more severe bony lesions and the need for more complex surgeries such as remplissage or bone block procedures. Milano et al[17] recommended early stabilization in patients with anterior shoulder instability, especially those with associated risk factors. Early surgical treatment was later supported by Provencher.[24] He stated that an isolated Bankart repair should not be considered in patients with a prolonged history of instability or multiple dislocation episodes. He goes on to say that early surgery may be considered after a first dislocation event so that the development of more severe lesions, culminating in overall poorer outcomes, is avoided. However, it is important to note that off-track lesions are both a cause and a consequence of these factors. The present study cannot separate cause from effect but can only find connections between these factors and off-track lesions. Further studies analyzing the development of HS lesions from the first episode until surgery may help to better understand whether the off-track lesion is the cause or the consequence.

Limitations and Strengths

This study has some limitations. First, a retrospective study is a potential source of bias. Second, not all patients had both MRI and CT scans preoperatively, and both methods to evaluate the glenoid track were used. However, several studies have validated the use of these 2 methods to measure both glenoid and humeral head bone defects.[28] In addition, measurements were performed using 2D instead of 3D images and a single examiner (C.D.) read CT scans and MRIs; no assessment of intrarater reliability was performed. However, as suggested by Gyftopoulos et al,[5] the glenoid track can accurately be assessed using this technique. This limitation was mitigated after a strict protocol of imaging analysis consisting of reorientating glenoid orientation to obtain a true en face view and measuring at the same parasagittal imaging lateral to the coracoid base in a reproducible manner. Finally, since all patients were undergoing surgery, the preoperative outcome scores may be skewed toward worse results.

Nevertheless, this study has strengths. First, a relatively large sample size of 235 patients were included in the study. Second, all the patients have been evaluated by the same experienced surgeon (E.C.). Third, the patients were obtained from a general population sample not specifically related to sports. This makes our results representative. Finally, these results have some clinical relevance, as we showed that patients with persistent anterior shoulder instability may be better addressed with an early surgery to reduce the risk of developing an off-track lesion.

CONCLUSION

Characteristics related to a history of instability (age <20 years at first instability episode, larger number of dislocations, and ≥ 2 years between first dislocation and surgery) were found to be risk factors for the development of an off-track HS lesion in this study. These lesions led to a higher degree of instability and worse objective and subjective preoperative shoulder function impairment versus on-track HS lesions. Early recognition and surgical stabilization may prevent more severe bony lesions and functional limitations in patients with anterior shoulder instability.

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