JSES International 5 (2021) 616–622

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

Influence of the glenoid track and glenoid bone loss on the apprehension test for shoulder instability

André Couto Godinho, MD, MSc[a,*], Pedro Couto Godinho, MD[a], Elísio José Salgado Ribeiro, MD[b], Daniel Carvalho de Toledo, MD[a], Frederico de Menezes Figueiredo Couto Bem, MD[a], Armando D'Lucca de Castro e Silva, MD[a], Glaydson Gomes Godinho, MD, PhD[a]

[a]*Department of Orthopedic, Orthopaedic Hospital of Belo Horizonte, Belo Horizonte, Brazil*
[b]*Radiologist of Axial Diagnostic Medicine, Belo Horizonte, Brazil*

A R T I C L E I N F O

Keywords:
Glenoid track
Apprehension
Off track apprehension test
Glenoid bone loss
Shoulder instability
Bipolar bone loss

Level of evidence: Level III; Diagnostic Study

Background: The investigation of Hill-Sachs and bony Bankart lesions continues to evolve. Patients with large bone lesions can present with a positive apprehension test even at ranges below 45° of abduction and external rotation of the shoulder. Modern concepts, such as glenoid track and quantification of glenoid bone loss, have been increasingly applied to shoulder instability. The objective of this study was to assess the correlation of the glenoid track and glenoid bone loss on the apprehension test conducted at 0°, 45°, and 90° of shoulder abduction.
Methods: Ninety-four shoulders of 90 patients with anterior glenohumeral instability were retrospectively assessed. The apprehension test was performed at 0°, 45°, and 90° of shoulder abduction. Computed tomography, magnetic resonance imaging, or magnetic resonance arthrogram scans were performed to calculate the glenoid track and glenoid bone loss. A descriptive analysis, an association analysis, and a logistic regression analysis were used in this study. Logistic regression analysis was used to assess the influence of glenoid track and glenoid bone loss when the apprehension test was positive in lower degrees of abduction.
Results: A positive apprehension test at 0°, 45°, and 90° of abduction revealed significant association with off-track lesions, glenoid bone losses greater than 13.5%, and bipolar bone lesions. Shoulders classified as off-track were 36.4 times more likely to test positive at 0°, 45°, and 90° than on-track shoulders. The logistic regression analysis revealed that the positive apprehension test at 0°, 45°, and 90° of abduction seems to be more influenced by off-track lesions than by glenoid bone loss greater than the 13.5% threshold.
Conclusion: Shoulders with a positive apprehension test at 0°, 45°, and 90° are significantly associated with off-track lesions, bipolar bone lesions, and glenoid bone losses greater than 13.5%.

The cornerstones of evaluation of a patient with anterior shoulder instability are a detailed clinical history and careful physical examination.[20] Several specific tests have been described in the literature, but the apprehension test remains one of the most widely used.[6,15]

Gerber and Ganz[7] defined apprehension as a feeling of fear, followed by involuntary defense, expressed during shoulder subluxation. Patients with anterior instability usually complain about apprehension in the functional athletic stance, described as 90° of abduction and external rotation of the shoulder.[3] Studies have highlighted that patients with large bone loss of the humeral head (Hill-Sachs lesion) and glenoid (bony Bankart) may experience this feeling even at ranges below 45° of abduction and external rotation of the shoulder.[12,22]

Biomechanical studies have investigated the isolated effect of the Hill-Sachs lesion and the bony Bankart lesion on shoulder instability.[22] However, the way in which these lesions interact dynamically was better understood only after the glenoid track (GT) description.[5,23] The GT concept describes the theorical path of the glenoid along the humeral head throughout the range of motion.[23] It defines the prognosis of engagement according to the

Institutional review board approval was received from Lifecenter Sistema de Saude S/A (CNIL authorization number: 2.950.256).
* Corresponding author: André Couto Godinho, MD, MSc, Rua Professor Otávio Coelho de Magalhães, 111 Mangueiras - Belo Horizonte, Minas Gerais, Brazil.
E-mail address: andre_cgod@hotmail.com (A.C. Godinho).

https://doi.org/10.1016/j.jseint.2021.04.002

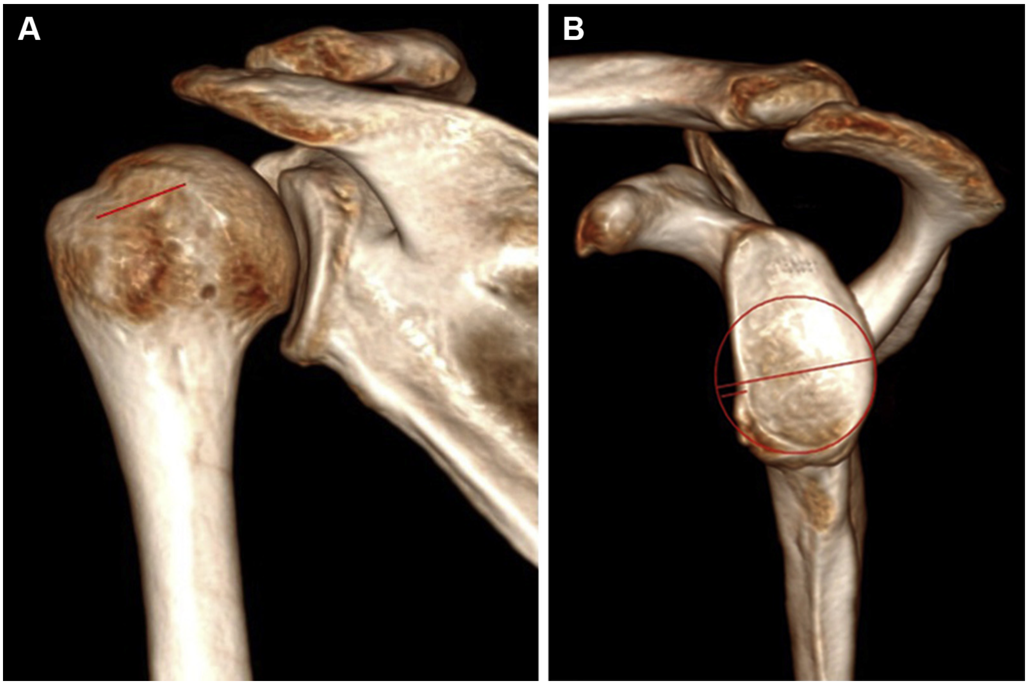

Figure 1 Three-dimensional computed tomography images demonstrating the calculation of GT. (**A**) The Hill-Sachs interval corresponds to the distance between the inner margin of the footprint of the rotator cuff and the medial border of the bone defect. (**B**) From a virtual circle traced in the lower two-thirds of the glenoid, having as reference its intact edges, we obtained the measure that would be the diameter of the same in the absence of the bone defect and the width of the bone defect. The GT corresponds to 83% of the glenoid diameter minus the value of the bone defect. *GT*, glenoid track.

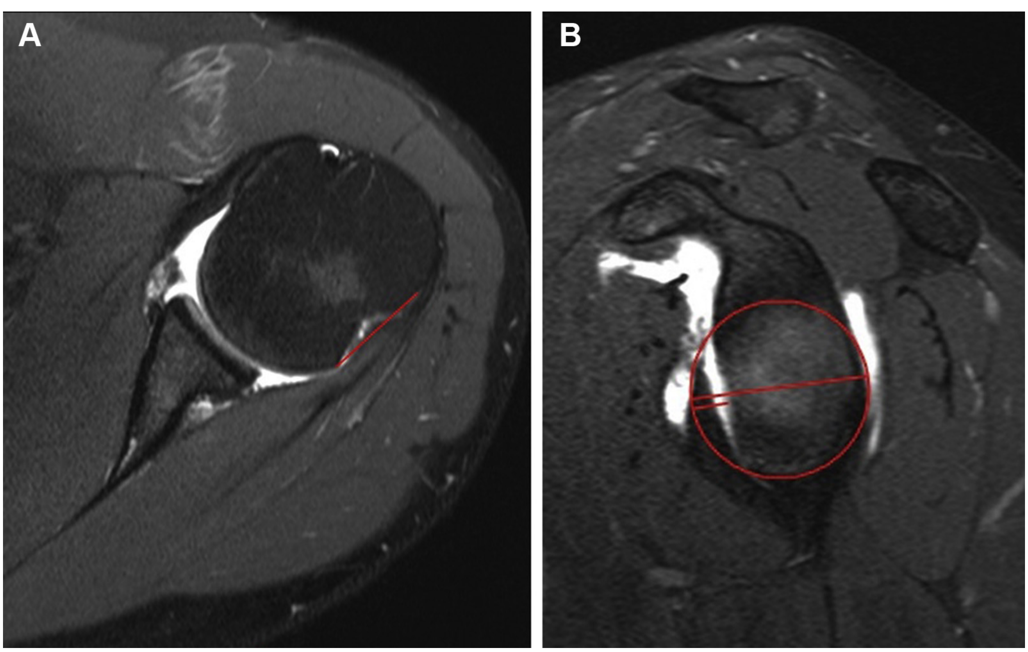

Figure 2 Magnetic resonance images demonstrating the calculation of GT. (**A**) The Hill-Sachs interval corresponds to the distance between the inner margin of the footprint of the rotator cuff and the medial border of the bone defect. (**B**) From a virtual circle traced in the lower two-thirds of the glenoid, having as reference its intact edges, we obtained the measure that would be the diameter of the same in the absence of the bone defect and the width of the bone defect. The GT corresponds to 83% of the glenoid diameter minus the value of the bone defect. *GT*, glenoid track.

presence of bipolar lesions.[5] Considering that, the presence of a Hill-Sachs lesion, especially its medial location, can predispose to engagement, specially if there is a bony Bankart lesion in association. This defines what is called an off-track lesion.

A retrospective analysis of patients diagnosed with anterior shoulder instability treated in our service suggested a strong correlation between a positive apprehension test at 0°, 45°, and 90° of abduction and off-track lesions, and glenoid bone lesions. Based on

Table I
Descriptive analysis of study variables.

Variable	Frequency	%
Sex		
Male	85	90.4
Female	9	9.6
Dominance		
Right-handed	88	93.6
Left-handed	6	6.4
Side of complaint		
Right	57	60.6
Left	37	39.4
Sport level		
Sedentary	34	36.2
Amateur	53	56.4
Professional	7	7.4
Imaging examination performed for calculation of the glenoid track		
CT	63	67.0
MRI	10	10.6
MRA	21	22.3
Classification of the glenoid track		
On-track	58	61.7
Off-track	36	38.3
Glenoid bone loss		
No bone loss	40	42.6
Bone loss <13.5%	29	30.9
Bone loss 13.5%-17.3%	16	17.0
Bone loss 17.3%-20.0%	4	4.3
Bone loss 20.0%-25.0%	3	3.2
Bone loss >25.0%	2	2.1
Total	94	100.0

CT, computed tomography; MRA, magnetic resonance arthrogram; *MRI*, magnetic resonance imaging.

this observation, the objective of this study was to assess the influence of the GT and glenoid bone loss on the apprehension test at different abduction ranges. Our hypothesis was that the apprehension test with a positive result at 0°, 45°, and 90° of abduction is associated with off-track lesions, bipolar lesions, and significant glenoid bone loss.

Materials and methods

This study was approved by the Research Ethics Committee (Lifecenter Sistema De Saude S/A, CNIL authorization number: 2.950.256), and no financial incentives were provided. A retrospective analysis from the database of the clinic was performed. All patients complaining of anterior shoulder instability were considered for study eligibility. We included patients who underwent the apprehension test at 0°, 45°, and 90° of abduction, during their first visit to the surgeon, from January 2015 to March 2018. To assess the influence of the GT and glenoid bone loss on the apprehension test, all of them were subjected to a computed tomography (CT) scan and/or magnetic resonance imaging/magnetic resonance arthrogram (MRI/MRA) in the same clinic with standard protocol. The images were evaluated by a single radiologist specialist in shoulder imaging, blinded to the clinical data, who measured the glenoid bone loss and classified the lesions as on-track or off-track, as described in Figures 1 and 2.

Patients were excluded if they had incomplete data, if the images were performed at at a different institution, and if the images were evaluated by a radiologist other than the one participating in this study. We excluded patients with associated conditions, such as rotator cuff tears, multidirectional and posterior instability, displaced fractures, and severe osteoarthritis.

A 3-dimensional CT scanner with 128 channels was used to collect the images (Siemens Somatom Definition AS); the patients were placed in a supine position with the arm in neutral position. The MRI and MRA images were captured using a 1.5 T Magnetom Essenza machine (Siemens Healthcare, Erlangen, Germany), with the patients in supine position and the shoulder in internal rotation. We used T2 sequences with and without fat suppression (repetition time/echo time 2280/42, field of view 160 × 100 mm, matrix 384 × 70, 3 mm cut) in the axial, sagittal, and coronal planes and the images were processed using the Kodak Carestream PACS software (Rochester, USA).

The Hill-Sachs interval (HSI) corresponds to the distance between the inner margin of the footprint of the rotator cuff and the medial border of the bone defect. GT corresponds to 83% of the glenoid diameter minus the value of the bone defect.[5] The GT and glenoid bone loss were calculated as seen in Figure 1.[5,19] If the HSI > GT, the shoulder is classified off-track, while if the HSI < GT, the shoulder is classified on-track. Isolated Bankart lesions without Hill Sachs will be conceptually classified as on-track lesions.[16] Although the original description was finalized using CT scans, in this study MRI and MRA scans were also used, since literature has already demonstrated that these are accurate and reliable modalities for this purpose[8,9] (Fig. 2).

To evaluate the amount of bone loss necessary to cause apprehension in lower degrees of abduction, the results were grouped according to different cutoffs that the literature has documented as limits for surgical treatment using bone block procedures.[2,10,17,18] Thus, they were classified as follows: without bone loss, bone loss less than 13.5%, bone loss between 13.5% and 17.3%, bone loss between 17.3% and 20% , bone loss between 20% and 25%, and greater than 25%.

Demographic data, such as age, gender, dominance, laterality, and sports activity have also been listed and described in Table I.

Apprehension test

The apprehension test was performed by 3 different examiners, at different times, in a standardized way, following the original description by Rowe and Zarins,[15] but with adaptations (Fig. 3). According to these authors, with the patient in a supine position or in orthostasis, the shoulder is abducted at 90° with maximal external rotation. An external rotation force is then applied. The test is considered positive when it reproduces a feeling of fear of shoulder subluxation, with involuntary defense to the test.[7]

We performed the test with the patient in the supine position only, placed at the edge of the examination table with the arm hanging down (Fig. 3). We believe that, in this position, the patient is less tense, consequently reducing interferences in the examination. The test begins with the limb at 0° of abduction, followed by maximum lateral rotation of the shoulder. Next, the test is performed at 45° and 90° of abduction.

The test is considered positive only when it reproduces a feeling of apprehension. Pain without apprehension was considered a negative test.[6]

Accordingly, the following results could be observed in the end: positive test at 0°, 45°, and 90°; negative test at 0° and positive at 45° and 90°; negative test at 0° and 45° and positive at 90°; and negative test at 0°, 45°, and 90°.

Statistical approach

A descriptive analysis, an association analysis, and a logistic regression analysis were used in this study. Data analyses were carried out using Statistical Package for the Social Sciences 21 software, 2012 (IBM, Armonk, NY, USA). The level of significance was set at 5% ($P < .05$) throughout the study. Pearson's chi-square test with Monte Carlo correction was used for the association

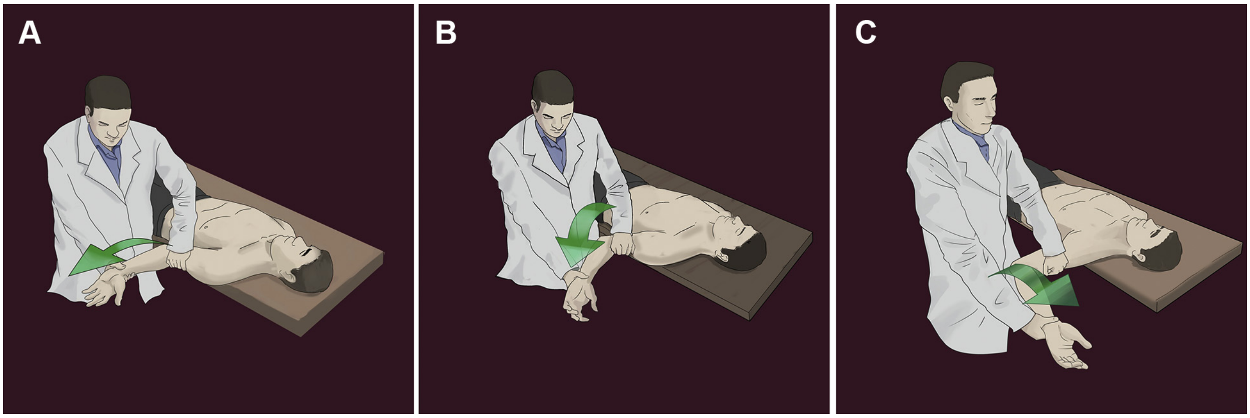

Figure 3 Apprehension test performed at 0°, 45°, and 90°. (**A**) Test performed at 0° of abduction with maximum external rotation of the shoulder; (**B**) test performed at 45° of abduction; and (**C**) test performed at 90° of abduction.

Table II
Results of the apprehension test at 0°, 45°, and 90° of abduction.

Apprehension test	N	%
Positive test at 0°, 45°, and 90°	37	39.3
Negative test at 0° and positive at 45° and 90°	18	19.1
Negative test at 0° and 45° and positive at 90°	26	27.7
Negative test at 0°, 45°, and 90°	13	13.8
Positive test at 0° and negative at 45° and 90°	0	0.0
Positive test at 0° and 45° and negative at 90°	0	0.0
Positive test at 45°	0	0.0
Total	94	100.0

Table III
Frequency of Hill-Sachs lesions, bony Bankart lesions, and bipolar lesions.

Bone loss in glenoid and humeral head	N	%
Presence of Hill-Sachs and bony Bankart lesions	54	57.4
Presence of Hill-Sachs lesions and absence of bony Bankart lesions	34	36.1
Absence of Hill-Sachs lesions and presence of bony Bankart lesions	0	0.0
Absence of Hill-Sachs and bony Bankart lesions	6	6.3
Total	94	100

analysis. Four multiple binary logistic regressions were performed to identify the main variables that could explain the results of the apprehension test in different degrees of abduction.

Results

Descriptive analysis

Of the 124 initially included shoulders, 25 were excluded because they were examined by another radiologist, and 5 were excluded because the apprehension test was not performed at the 3 degrees of abduction. As a result, 90 patients and 94 shoulders were included in the study. Patient age ranged from 15 to 55 years, with an average of 29 years. Most were observed to be right-handed males with a lesion on the right side and who practiced sports as amateurs (Table I).

The results of the apprehension test are described in Table II. There was no positive test at 0° and negative at 45° and 90°, or positive test at 0° and 45° and negative at 90°, or isolated positive test at 45°. The most common presentation was a positive test at 0°, 45°, and 90° followed by a positive test identified only at 90°.

To evaluate the GT and glenoid bone loss, in most of the cases, we used CT scans (Table I). We found 36 shoulders (38%) classified as off-track and 58 shoulders (62%) classified as on-track. Fifty-four (57%) were diagnosed with glenoid bone loss. Of these cases, 29 (54%) showed lesions less than 13.5% and only 2 (4%) greater than 25%. Forty shoulders (43%) showed only labral tear lesion without glenoid bone loss. Fifty-four shoulders (57%) presented with Hill-Sachs and bony Bankart lesions. None of them had glenoid bone loss without Hill-Sachs lesions. Six shoulders (6%) showed anterior instability with labrum detachment only without Hill-Sachs lesions (Table III).

Outcomes of interest

Considering the shoulders classified as off-track, 30 (83.3%) reported a positive test at 0°, 45°, and 90°, and none reported a negative test (Table IV). When the GT was associated with the apprehension test, the shoulders with a positive test at 0°, 45°, and 90° were found to have more off-track lesions than the shoulders with a positive test at 45° and 90°, only 90°, or a negative test ($\chi^2 = 50.631$ and $P < .001$).

The association between glenoid bone loss and the apprehension test (Table V) showed that the shoulders with a positive test at 0°, 45°, and 90° had significantly more glenoid bone lesions than the shoulders with a positive test at 45° and 90°, only 90°, or a negative test ($\chi^2 = 33.401$ and $P < .001$).

From the total that tested positive at 0°, 45°, and 90°, 17 shoulders (68%) demonstrated glenoid bone loss greater than 13.5% (Table V). The association between these variables showed that patients with a positive test at 0°, 45°, and 90° had significantly more glenoid bone loss greater than 13.5% ($\chi^2 = 13.438$ and $P < .001$).

The association between the apprehension test and bipolar lesions revealed that positive tests at 0°, 45°, and 90° had significantly more bipolar lesions ($\chi^2 = 26.200$ and $P < .001$).

All the shoulders with labral tear without HSI had apprehension only at 90° of abduction.

Analysis of potential risk factors

When the glenoid bone loss of 13.5% and 'GT' were evaluated separately, both were observed to be significant at the level of 5% to account for the positive test at 0°, 45°, and 90°.

If we consider only glenoid bone loss of 13.5%, it can predict 70.2% of the positive tests at 0°, 45°, and 90°. When the bone loss is

Table IV
Association of the apprehension test at 0°, 45°, and 90° and the glenoid track.

Apprehension test	Off-track	%	On-track	%
Positive apprehension at 0°, 45°, and 90°	30	83.3	7	12.0
Negative apprehension at 0° and positive at 45° and 90°	5	13.8	13	22.4
Negative apprehension at 0° and 45°, and positive at 90°	1	2.7	25	43.1
Negative apprehension at 0°, 45°, and 90°	0	0.0	13	22.4
Total	36	100	58	100

Table V
Association of the apprehension test at 0°, 45°, and 90° and the glenoid bone loss.

	Apprehension test				
	0°, 45°, and 90°	45° and 90°	90°	Negative	Total
No bone loss	6	7	15	12	40
Bone loss ≤ 13.5%	14	8	6	1	29
Bone loss 13.5%-17.3%	11	2	3	0	16
Bone loss 17.3%-20%	2	0	2	0	4
Bone loss 20%-25%	2	1	0	0	3
Bone loss >25%	2	0	0	0	2
Total	37	18	26	13	94

greater than 13.5%, the chance of a positive apprehension test at 0°, 45°, and 90° increases 5.21 times.

If we consider only the GT, the predictive power is 86.2% for a positive test at 0°, 45°, and 90°. Also, when the lesion is classified as off-track, the patient has a 36.43 times greater chance to have a positive apprehension test at the 3 degrees of abduction.

Thus, in this regression analysis, the GT was more determinant to explain the positive apprehension test at 0°, 45°, and 90° when compared to the glenoid bone loss.

Discussion

The most important finding in this study was that the apprehension tests in lower degrees of abduction present a good correlation to off-track lesions. Also, the fact that a glenoid bone loss of 13.5% is sufficient to produce apprehension in lower degrees of abduction during a physical examination is important. This suggests a clinical parameter to establish the cutoff for bone block procedures during surgical treatment of anterior shoulder instability.

The measurement of the GT and glenoid bone loss was originally evaluated by CT scans with 3-dimensional reconstruction.[5,19] However, to reduce costs and the exposure to radiation, researchers validated the use of MRI and MRA for these calculations.[8,9,13] In this study, 31 shoulders (33%) were studied using MRI or MRA images.

The apprehension test was originally performed at 90° of abduction and maximum external rotation of the shoulder.[15] Patients with anterior shoulder instability usually fear that shoulder subluxation may occur in these ranges of motion.[3] In 2004, Miniaci and Gish[12] reported that patients with an extensive Hill-Sachs lesion could present apprehension even at ranges below 45° of abduction and external rotation. Walia et al[22] concluded that the instability observed at low degrees of abduction would clinically indicate large bone defects of the humeral head and the glenoid. In this study, the apprehension test performed at 0°, 45°, and 90° of abduction showed progressive severity that is, patients testing positive at 0° necessarily evolved to positive results at 45° and 90°, with an off-track lesion and glenoid bone defect greater than 13.5% also being associated, a fact that has not yet been described in the literature.

The concept of engaging lesions was initially proposed by Burkhart and De Beer[3] to explain factors related to the relapse of instability. Patients with these lesions, with the shoulder abducted at 90° and external rotation greater than 30°, would have their Hill-Sachs lesion engaged to the anterior glenoid rim.[3,22] Yamamoto et al[23] examined the anatomic relationship between the humeral head and the glenoid and introduced the concept of GT. Di Giacomo et al[5] developed a method to evaluate the relationship between Hill-Sachs lesions and bony Bankart lesions and proposed the on-track and off-track classification. Among the patients classified as off-track in this study, 30 (83.3%) had a positive apprehension test at 0°, 45°, and 90°, and none demonstrated a negative apprehension test. The shoulders classified as off-track were 36.43 times more likely to have a positive test at 0°, 45°, and 90° than the on-track shoulders.

Shaha et al,[16] in a study with 57 shoulders, validated the clinical application of GT. They concluded that off-track lesions showed a 75% recurrence rate for the Bankart capsulolabral repair, compared with 8% of relapse in those classified as on-track. Our results demonstrated that shoulders with a positive test at the 3 degrees of abduction present significantly more off-track lesions than at other degrees. Based on the fact that the GT involves sophisticated imaging examinations and that off-track lesions must be approached with a remplissage procedure,[13] a low-complexity, reproducible physical test, with the power to predict off-track lesions, is very promising in the propaedeutics of shoulder instability.

Glenoid bone lesions are common in anterior shoulder instability and are present in 49%-86% of recurrent dislocations.[1,2] The bony Bankart lesion changes the biomechanics of the glenoid by harming its function as a static stabilizer.[11,14] Fifty-four shoulders (57%) in this study presented a bony Bankart lesion. The association analysis was found to be significant for shoulders with bony Bankart lesions and a positive test at 0°, 45°, and 90°, demonstrating that the glenoid bone loss seems to influence the positive result of the apprehension test.

To date, medical literature has not presented a consensus over what value of glenoid bone loss has greater clinical implications.[17] Bigliani et al[2] found that deficiencies above 25% should be addressed with transfer of the coracoid process. Itoi et al[10] concluded that shoulder stability deteriorates in the presence of lesions larger than 20%. Shin et al[18] reported failure of the Bankart capsulolabral repair in 43% of patients with losses greater than 17.3%. Shaha et al[17] concluded that patients with defects greater than 13.5% had a worse clinical outcome with arthroscopic repair. In this study, shoulders with a positive apprehension test at 0°, 45°, and 90° showed significantly more bone losses greater than 13.5% than shoulders with a positive test at 45° and 90°, only 90°, or a negative test. Our results suggest that the apprehension test at low degrees of abduction may be a good clinical parameter and assist in the indication of the bone block procedure, as a bone loss greater than 13.5% was associated with apprehension during physical examination.

For the 17.3%, 20%, and 25% values, no association was observed with the apprehension test. This was probably due to the low number of shoulders classified with values above these thresholds, suggesting that the test may perform better in larger samples.

Biomechanically, bipolar lesions are more unstable than isolated lesions of the humeral head and the glenoid.[21] These are present in up to 62% of shoulder instability recurrent cases.[21] In this study, the prevalence of bipolar lesions was 57%. Association analysis indicated that shoulders with a positive test at 0°, 45°, and 90° tended to present more bipolar lesions than at other degrees.

According to some authors, the position of the arm seems to influence anterior shoulder instability.[11,21,22] A recent study evaluated the effect of the glenoid bone defect in 30 daily activities and concluded that lesions greater than 16% pose greater risks of dislocation, even after the Bankart capsulolabral repair.[11] Walia et al[22] reported that the Hill-Sachs lesion causes rotational instability, while the glenoid bone defect leads to translational instability, without any effect on the position of the shoulder at all. In our study, the logistic regression analysis revealed that the apprehension present at 0°, 45°, and 90° of abduction is better explained by off-track lesions than by significant glenoid bone losses, which gives rise to a new paradigm.

To the best of our knowledge, this is the first study to evaluate the practical influence of the GT concept and glenoid bone loss on a physical test for shoulder instability. Bushnell et al[4] conducted a similar study; however, they did not associate the apprehension test with the GT concept. Thus, our results encourage further projects to validate this diagnostic test.

Despite our exciting results, we recognize several drawbacks to our study. Firstly, the study is subject to systematic errors due to its retrospective nature. The absence of randomization and a control group allows bias. All patients were examined only once, and we did not evaluate the interexaminer agreement for the apprehension test. GT can be evaluated using CT scans and MRI or MRA;[5,8] however, in this study, we used both modalities, which may lead to measurement bias. Lastly, since the diagnostic value of the apprehension test at 0°, 45°, and 90° was not studied, we were unable to extrapolate the results to clinical practice or to evaluate treatment outcomes based on our results. However, we paved the way for further investigation.

Conclusion

Positive apprehension test at 0°, 45°, and 90° is associated with off-track lesions, bipolar lesions, and glenoid bone loss greater than 13.5%. Shoulders classified as off-track were 36.43 times more likely to have a positive test at 0°, 45°, and 90° than on-track shoulders. Apprehension reproduction at low degrees of abduction is better explained by off-track lesions than by significant glenoid bone loss.

Disclaimers:

Funding: No funding was disclosed by the author(s).

Conflicts of interest: The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

References

1. Arciero RA, Parrino A, Bernhardson AS, Diaz-Doran V, Obopilwe E, Cote MP, et al. The effect of a combined glenoid and Hill-Sachs defect on glenohumeral stability: a biomechanical cadaveric study using 3-dimensional modelling of 142 patients. Am J Sports Med 2015;43:1422-9. https://doi.org/10.1177/0363546515574677.
2. Bigliani LU, Newton PM, Steinmann SP, Connor PM, Mcllveen SJ. Glenoid rim lesions associated with recurrent anterior dislocation of the shoulder. Am J Sports Med 1998;26:41-5.
3. Burkhart SS, De Beer JF. Traumatic glenohumeral bone defects and their relationship to failure of arthroscopic Bankart repairs: significance of the inverted-pear glenoid and the humeral engaging Hill- Sachs lesion. Arthroscopy 2000;16:677-94.
4. Bushnell BD, Creighton RA, Herring MM. The bony apprehension test for instability of the shoulder: a prospective pilot analysis. Arthroscopy 2008;24: 974-82. https://doi.org/10.1016/j.arthro.2008.07.019.
5. Di Giacomo G, Itoi E, Burkhart SS. Evolving concept of bipolar bone loss and the Hill-Sachs lesion: from "engaging/non-engaging" lesion to "on-track/off-track" lesion. Arthroscopy 2014;30:90-8. https://doi.org/10.1016/j.arthro.2013.10.004.
6. Farber AJ, Castillo R, Clough M, Bahk M, McFarland EG. Clinical assessment of three common tests for traumatic anterior shoulder instability. J Bone Joint Surg Am 2006;88:1467-74. https://doi.org/10.2106/JBJS.E.00594.
7. Gerber C, Ganz R. Clinical assessment of instability of the shoulder. With special reference to anterior and posterior drawer tests. J Bone Joint Surg Br 1984 Aug;66:551-6.
8. Gyftopoulos S, Beltran LS, Bookman J, Rokito A. MRI evaluation of bipolar bone loss using the on-track off-track method: a Feasibility study. AJR 2015;205: 848-52. https://doi.org/10.2214/AJR.14.14266.
9. Huijsmans PE, Haen PS, Kidd M, Dhert WJ, van der Hulst VP, Willems WJ. Quantification of a glenoid defect with three-dimensional computed tomography and magnetic resonance imaging: a cadaveric study. J Shoulder Elbow Surg 2007;16:803-9. https://doi.org/10.1016/j.jse.2007.02.115.
10. Itoi E, Lee SB, Berglund LJ, Berge LL, An KN. The effect of a glenoid defect on anteroinferior stability of the shoulder after bankart repair: a cadaveric study. J Bone Joint Surg Am 2000;82:35-46.
11. Klemt C1, Toderita D1, Nolte D1, Di Federico E1, Reilly P2, Bull AMJ1. The critical size of a defect in the glenoid causing anterior instability of the shoulder after a Bankart repair, under physiological joint loading. Bone Joint J 2019;101-B:68-74. https://doi.org/10.1302/0301-620X.101B1.BJJ-2018-0974.R1.
12. Miniaci A, Gish MW. Management of anterior glenohumeral instability associated with large Hill-Sachs defects. Tech Shoulder Elbow Surg 2004;5:170-5. https://doi.org/10.2174/1874325001711011245.
13. Momaya AM, Tokish JM. Applying the glenoid track concept in the Management of patients with anterior shoulder instability. Curr Rev Musculoskelet Med 2017;10:463-8. https://doi.org/10.1007/s12178-017-9436-1.
14. Rabinowitz J, Friedman R, Eichinger JK. Management of glenoid bone loss with anterior shoulder instability: Indications and outcomes. Curr Rev Musculoskelet Med 2017;10:452-62. https://doi.org/10.1007/s12178-017-9439-y.
15. Rowe CR, Zarins B. Recurrent transient subluxation of the shoulder. J Bone Joint Surg Am 1981;63:863-72.
16. Shaha JS, Cook JB, Rowles DJ, Bottoni CR, Shaha SH, Tokish JM. Clinical validation of the glenoid track concept in anterior glenohumeral instability. J Bone Joint Surg Am 2016;98:1918-23. https://doi.org/10.2106/JBJS.15.01099.
17. Shaha JS, Cook JB, Song DJ, Rowles DJ, Bottoni CR, Shaha SH, et al. Redefining “critical” bone loss in shoulder instability: functional outcomes worsen with “subcritical” bone loss. Am J Sports Med 2015;43:1719-25. https://doi.org/10.1177/0363546515578250.
18. Shin SJ, Kim RG, Jeon YS, Kwon TH. Critical value of anterior glenoid bone loss that leads to recurrent glenohumeral instability after arthroscopic bankart repair. Am J Sports Med 2017;45:1975-81. https://doi.org/10.1177/0363546517697963.
19. Sugaya H, Moriishi J, Dohi M, Kon Y, Tsuchiya A. Glenoid rim morphology in recurrent anterior glenohumeral instability. J Bone Joint Surg Am 2003;85:878-84. https://doi.org/10.2106/00004623-200305000-00016.
20. van Kampen DA, van den Berg T, van der Woude HJ, Castelein RM, Terwee CB, Willems WJ. Diagnostic value of patient characteristics, history, and six clinical tests for traumatic anterior shoulder instability. J Shoulder Elbow Surg 2013;22:1310-9. https://doi.org/10.1016/j.jse.2013.05.006.
21. Walia P, Miniaci A, Jones MH, Fening SD. Theoretical model of the effect of combined glenohumeral bone defects on anterior shoulder instability: a finite element approach. J Orthop Res 2013;31:601-7. https://doi.org/10.1002/jor.22267.

22. Walia P, Patel RM, Gottschalk L, Kuklis M, Jones MH, Fening SD, et al. The Reduction in stability from combined humeral head and glenoid bony defects is influenced by arm position. Am J Sports Med 2016;44:715-22. https://doi.org/10.1177/0363546515620588.

23. Yamamoto N, Itoi E, Abe H, Minagawa H, Seki N, Shimada Y, et al. Contact between the glenoid and the humeral head in abduction, external rotation, and horizontal extension: a new concept of glenoid track. J Shoulder Elbow Surg 2007;16:649-56. https://doi.org/10.1016/j.jse.2006.12.012.