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A comparative analysis of glenoid morphology in on-track and off-track lesions following anterior shoulder dislocation

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Background: Anterior shoulder dislocation is a prevalent clinical issue, with high recurrence rates after initial dislocation. Stability of the shoulder joint is maintained by the interplay of static and dynamic stabilizers, including the glenoid and humeral head morphology. Glenoid morphology has been identified as particularly influential in joint stability, and thus the evaluation of glenoid bone loss is crucial in managing shoulder dislocations. This study aimed to investigate the differences in glenoid morphologies between on-track and off-track lesions postdislocation.

Methods: This retrospective case-control study included patients who presented with shoulder dislocation at a level 1 trauma center from 2011 to 2020. Patients with anterior shoulder dislocation, complete computed tomography imaging, visible bone loss, and those aged 18 years or more were included. Radiographic parameters were assessed using a certified picture achieving and communication system workstation. The groups were divided into on-track or off-track lesions and their glenoid version, glenoid concavity, and the morphometrical-based bony shoulder stability ratio (BSSR) were compared.

Results: Two hundred twelve patients (70% male and mean age of 50 years) were included and no significant difference was found between the on-track and off-track groups in terms of demographics or injury mechanism. Significant differences were noted in the glenoid defect (1.28 mm vs. 4.67 mm, $P = .001$), glenoid concavity/depth (1.7 mm vs. 1.3 mm, $P = .001$), the BSSR (40% vs. 33%, $P = .001$), and glenoid retroversion (4.4 vs. 2.9°, $P = .009$).

Conclusion: Glenoid morphology has become an increasing focus in the treatment of anterior shoulder dislocation. Patients with an off-track lesion appear to have not only greater glenoid loss and a larger Hill-Sachs but also a flatter glenoid with less retroversion. This also appears to lead to a lower BSSR.

Anterior shoulder dislocation represents a significant clinical problem. Despite advances in the management of shoulder instability, recurrence rates after primary dislocation remain high, ranging from 10% to 80% depending on both the treatment method and the population.[29,31,32] The stability of the glenohumeral joint relies on delicate balance between static and dynamic stabilizers, including the glenoid and the humeral head morphology, soft tissues (capsule, labrum), and the rotator cuff.[1] In the last decade, other factors contributing to glenohumeral stability have been identified. One such factor, glenoid morphology, may play a role in the stability of the shoulder.[7,14,19,24]

The assessment of glenoid bone loss is vital for the management after anterior shoulder dislocation.[4] Beside other risk factors, Balg and Boileau described glenoid bone loss as a significant contributor to recurrent shoulder dislocation.[3] The concept of glenoid bone loss has been further developed.[4] The “glenoid track” was described as the contact zone between the humeral head and the glenoid in the abducted and externally rotated position of the arm.[34] Based on this, the concept of on-track and off-track lesions was introduced. Together with the amount of bone loss, di Giacomo et al recommended the Latarjet procedure when bone loss exceeded 20% and an off-track lesion is present.[8] Furthermore, the version of the glenoid and the concavity of the glenoid also seem to have influence on the likelihood of recurrent dislocation.[19] In normal shoulders, the glenoid version

This retrospective case-control study has been approved by the ethics committee of the medical faculty of Technical University Munich (TUM), Germany (Project number: 2021-747-S-SR). The study performed in accordance to the ethical standards of the 1964 Declaration of Helsinki and its later amendments.

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ranges from 5° anteversion to 9° retroversion.[5,25] However, it has been shown that patients with an anterior inferior shoulder dislocation have less retroversion of the glenoid.[18] The concavity of the glenoid also appears to be of interest in the stability of the glenohumeral joint.[28,33] Related to the concavity of the glenoid, Moroder et al developed the so-called "bony shoulder stability ratio" (BSSR) in 2015, which can be determined using the glenoid depth and the radius of the humeral head on computed tomography (CT).[27] As shown by Moroder et al, the BSSR has a high linear correlation with the stability ratio, which has already been used in other studies as a reliable parameter for estimating the stability in glenohumeral joint.[17,21,22] The aim of this study was to investigate whether there are differences in the glenoid morphologies of on-track and off-track lesions. It was hypothesized that off-track lesions are associated with a less retroverted glenoid and a lower BSSR.

Methods

Study participants

This study has been approved by the ethics committee of the medical faculty of Technical University Munich, Germany (Project number: 2021-747-S-SR).

This study was designed as a retrospective case-control study. First, all patients who presented with a shoulder dislocation to our level 1 trauma center between 2011 and 2020 were identified. An electronic documentation system was used to obtain the demographic data, injury mechanism, and treatment.

Patients with anterior shoulder dislocation and complete CT imaging of the shoulder (in particular, the entire scapula had to be depicted) were included. For patients who presented at the hospital several times, only the first visit with a CT scan was evaluated. Exclusion criteria comprised age <18 years, patients without complete CT scan, posterior or inferior dislocation, and patients without humeral or glenoidal bone loss.

All radiographic examinations (plain radiographs in 2 planes and CT) were performed in our radiology department. CT scans were obtained by a 64-slice CT scanner (Somatom Sensation 64; Siemens, Erlangen, Germany) with a slice thickness of 1 mm. The patients were divided into on-track and off-track lesions according to Di Giacomo's classification[7] (Flowchart, Fig. 1). Radiographic parameters were assessed on CT scans using a picture achieving and communication system work station certified for clinical use (IDS7 21.2, Sectra).

First, we used the best fit circle method to measure the area of the glenoid.[15] To calculate the glenoid track, the formula 0.83D-d (D = diameter of the glenoid; d = defect in the glenoid) was used.[7]

Glenoid version was measured with the "Friedman method".[11] The concavity diameter was measured by drawing a straight line from one apex of the concavity to the opposite apex.[27] The depth was defined as the distance from the deepest point of the concavity to the diameter line of the glenoid.[27] The greater the distance, the deeper the glenoid and therefore the more concave it is. To calculate the humeral head BSSR, the radius of the humeral head (=r) and the depth of the glenoid (=d) are required.[27] The formula is:

$$BSSR = \frac{\sqrt{1-\left(\frac{r-d}{r}\right)^2}}{\frac{r-d}{r}}$$

Measurements were performed by 2 raters. An interclass correlation was performed.

Statistical analysis

Statistical analysis was conducted using SPSS statistical package software (IBM SPSS Statistics for Macintosh Version 27.0 Released 2020; IBM Corp., Armonk, NY, USA). The Kolmogorov-Smirnov test was used to assess for normal distribution. If normal distribution was confirmed, Student's *t*-test was used to compare differences in means. Otherwise, Mann-Whitney U test was used for analysis. Categorical variables were compared using the Fisher's exact test and the chi-square test (Pearson chi-square). $P < .05$ was considered statistically significant. Inter-rater assessment was evaluated with interclass correlation coefficient.

Results

Two hundred twelve patients (64 female and 148 male) with a mean age of 50.4 ± 20.3 years were included. There were 88 on-track (Group 1) and 124 off-track lesions (Group 2). No significant difference was found between the groups in terms of age, sex, time from injury to CT scan, and affected side (Table I). The most common injury mechanism were falls on level ground (n = 79), falls from height (n = 29), and sports accidents (n = 28) (Graph, Fig. 2). There were also no significant differences with respect to the trauma mechanism ($P = .511$).

Measurements

The interclass correlation between the 2 raters was excellent at 0.977 (95% confidence interval 0.948-0.990) for the measurement of the glenoid defect and lowest at 0.840 (95% confidence interval 0.636-0.931) for the measurement of the bony bridge.

There was significant difference between the glenoid defect and the Hill-Sachs interval. On-track lesions showed a mean defect of 1.28 ± 1.90 mm (4.29 ± 6.37%) and off-track lesions showed 4.67 ± 3.39 mm (15.9 ± 11.2%) ($P < .001$). The glenoid track was significantly smaller in the group with the off-track lesions (off-track: 19.4 ± 3.4 mm vs. on-track: 23.0 ± 2.4 mm; $P < .001$). Hill-Sachs width (10.1 ± 3.9 mm vs. 14.8 ± 4.8 mm) and the bony bridge (7.29 ± 3.20 mm vs. 11.12 ± 4.72 mm) were significantly larger in the off-track group ($P = .001$). Consequently, the Hill-Sachs interval was significantly larger in the off-track group (17.4 ± 3.8 mm vs. 25.9 ± 5.7 mm, $P < .001$).

The mean depth of Hill-Sachs lesion was 6.67 ± 3.28 mm in the off-track lesion group and 4.28 ± 2.32 mm in the on-track lesion group ($P < .001$). The glenoid retroversion was significantly lower in off-track lesions (4.4 ± 3.7° vs. 2.9 ± 4.1°; $P < .01$). The depth of the glenoid, which gives an indication of the concavity of the glenoid, was significantly smaller in off-track lesions (1.73 ± 0.87 mm vs. 1.28 ± 0.74 mm; $P < .001$). This results in a significantly lower BSSR. In on-track lesions, mean BSSR was 39.98 ± 12.40% vs. 33.15 ± 11.82% in off-track lesions ($P < .001$).

The area of the best fit circle of the glenoid showed no significant difference in both groups ($P = .554$). On-track lesions had an average area of 665.1 ± 108.9 mm^2 vs. 664.7 ± 136.2 mm^2 in off-track lesions. There was no significant difference in the glenoid diameter, 29.2 ± 2.3 mm (group 1) vs. 28.9 ± 2.9 mm (group 2), nor in the diameter of the humeral head, 46.2 ± 3.8 mm (group 1) vs. 46.4 ± 4.1 mm (group 2) (see Table I).

Discussion

The major findings in this study were that patients with an off-track lesion have both a lower amount of glenoid retroversion and a lower glenoid depth. Also, the BSSR has shown itself significantly

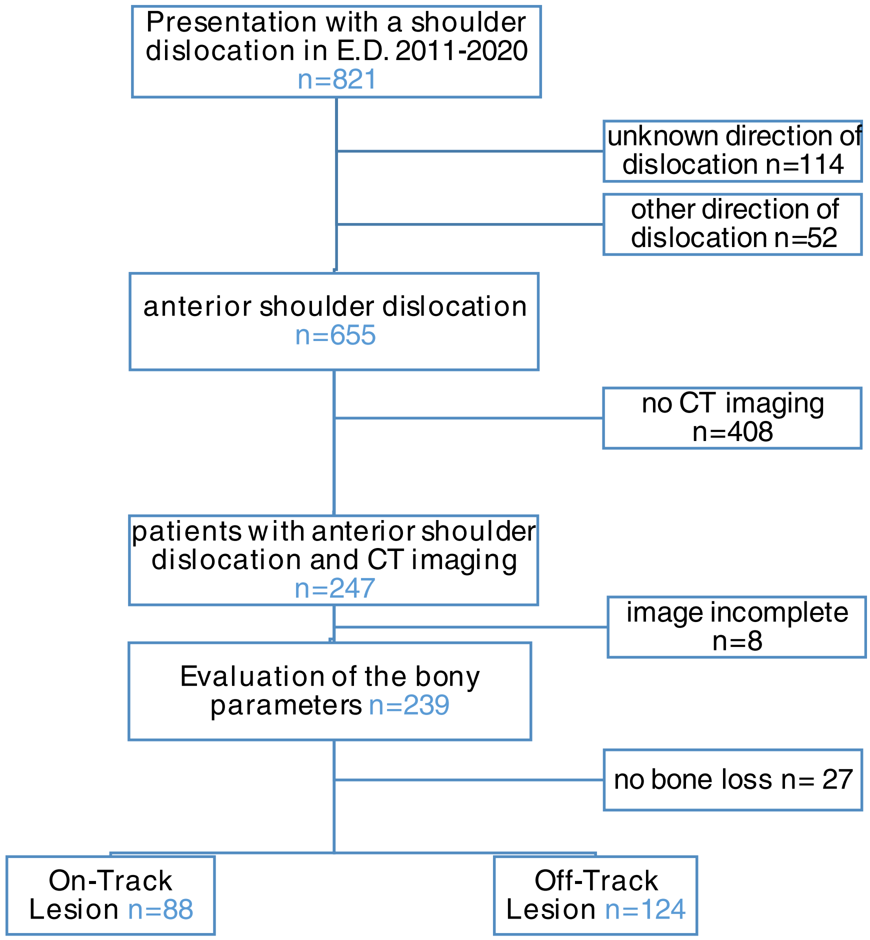

Figure 1 Flowchart.

lower in patients with an off-track lesion compared to patients with an on-track lesion.

In addition to a lesion being on-track vs. off-track, the size of the defect plays a critical role in determining the treatment of shoulder instability. The decision-making with respect to the treatment of choice should be made upon the defect size as well as the on-track/off-track concept.[8,13,20] In most cases, values between 20% and 25% are given as critical threshold of the glenoid bone loss, above which bony augmentation should be performed.[23,35] However, some surgeons no longer consider a Bankart procedure to be sufficient beyond a glenoid loss of more than 13.5%.[6,9]

This raises the question of whether there are other bony factors that contributes to the glenohumeral stability in addition to on-track and off-track lesions. Numerous authors consider glenoid concavity as one of the major risk factors in bony instability.[27,26,10] Wermers et al even proclaim that concavity has a higher impact on shoulder stability than the size of the bony defect.[33] They showed that concavity is a crucial factor for stability ratio. We showed that that glenoid was shallower in off-track lesions compared to patients with on-track lesions, which could be caused by the anterior bone loss itself. It is important to recognize that our study only evaluates the bony defects involved in instability and that Wermers et al's study was a cadaveric study. Both studies fail to incorporate the soft tissue contribution to shoulder stability.[12] Aygun et al consider glenoid version to be a major factor contributing to shoulder stability. They showed that less glenoid retroversion is a high risk for anterior glenohumeral instability.[2,18] One indication of this could be the lower retroversion in the off-track group. Moroder et al designed a tool (BSSR) which shows that the glenoid concavity does influence the bony shoulder stabilizers.[27] They describe the flatter the glenoid is in dependence of the humerus size, the greater is the risk of further dislocations. This seems to be consistent with our results. The off-track lesions with a flat glenoid and less retroversion also have a smaller BSSR. If one assumes that the lower retroversion, the flatter glenoid, and an off-track lesion are predictors of shoulder instability, then the BSSR also appears to be.[8,28]

However, all these findings haven't led to treatment recommendations yet. Only Di Giacomo et al give a clear treatment recommendation with their on-track/off-track model.[8] Our findings showed that off-track lesions are associated with a flatter glenoid, lower BSSR, and lower retroversion. This might be explained by the anterior bony defect of the glenoid. If erosions occur in multiple dislocations, the glenoid flattens. In our opinion, this can lead to a lower depth of the glenoid, which in turn could lead to a lower BSSR and a less retroverted glenoid. As we know, major damage to the glenoid in off-track lesions requires bony augmentation.[8,14,30] But due to our findings, the flat glenoid and less retroversion should be considered in an off-track lesion, if applicable, and the needed bone transfer could be adjusted accordingly. For example, you could also try to increase the retroversion and concavity. Consequently, it might be more pertinent to ask whether a high BSSR, along with a deep and retroverted glenoid, offers protection against redislocation in cases of anterior shoulder dislocation. This consideration could influence treatment options for marginal cases, such as

Table I
Overview on-track/off-track.

	On-track (n = 88)	Off-track (n = 124)	*P* value
Age in years	53.4 (±22.1)	48.3 (±20.0)	.082
Female gender in %	30.7	29.8	.895
Right handed in %	62.5	57.3	.444
Duration until CT in days	0.21 (±0.84)	0.16 (±1.04)	.719
Surface of the glenoid in mm^2	665.1 (±108.9)	664.7 (±136.2)	.554
Glenoid diameter in mm	29.2 (±2.3)	28.9 (±2.9)	.426
Diameter humeral head in mm	46.2 (±3.8)	46.4 (±4.1)	.795
Glenoid defect (surface) in mm^2	24.8 (±39.7)	85.7 (±70.0)	**.001**
Glenoid defect in mm	1.28 (±1.90)	4.67 (±3.39)	**.001**
Glenoid defect in %	4.29 (± 6.37)	15.9 (± 11.2)	**.001**
Glenoid track in mm	23.0 (±2.4)	19.4 (±3.4)	**.001**
Hill-Sachs width in mm	10.1 (±3.9)	14.8 (±4.8)	**.001**
Hill-Sachs depth in mm	4.28 (±2.32)	6.67 (±3.28)	**.001**
Bony Bridge in mm	7.29 (±3.20)	11.12 (±4.72)	**.001**
Hill-Sachs Index in mm	17.4 (±3.8)	25.9 (±5.7)	**.001**
Glenoid retroversion in °	4.39 (±3.71)	2.90 (±4.11)	**.009**
Glenoid depth in mm	1.73 (±0.87)	1.28 (±0.74)	**.001**
BSSR in %	39.98 (±12.40)	33.15 (±11.82)	**.001**

CT, computed tomography; *BSSR*, bony shoulder stability ratio.
Bold: $P < .05$ was evaluated as significant.

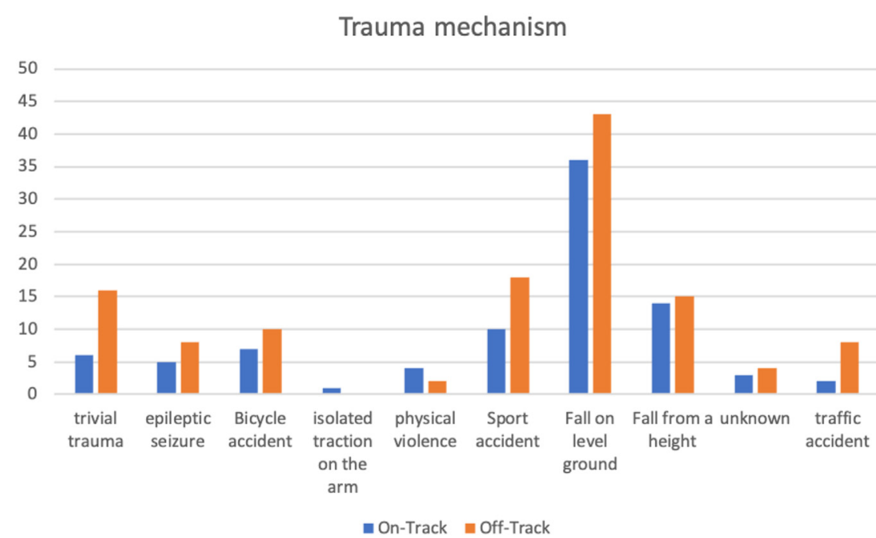

Figure 2 Graph—trauma mechanism.

minor glenoid defects. On the other hand, it is worth exploring whether shallow glenoids with minimal retroversion but slight surface damage might benefit from anterior bone augmentation to enhance concavity and retroversion, as seen in the treatment model for dorsal shoulder dislocation.[16] However, further clinical studies are needed to investigate redislocation rates in relation to these anatomical variables. Identifying specific thresholds could lead to more tailored treatment recommendations.

This study has several limitations. This work is a retrospective study. No patient follow-up was performed, and no conclusions could be drawn regarding the prognosis of the defect parameters considered in this study. Due to the retrospective nature of this work, there was also no influence on which patients received CT imaging. On the one hand, this led to the exclusion of many patients and a sampling bias. On the other hand, we assume that many younger patients were more likely to have received a magnetic resonance imaging and that the patient selection is therefore older than usual. We also assume that the indication for CT was more generous in the case of a suspected glenoid lesion on X-ray. This explains the significantly higher number of off-track lesions compared to the literature. Another limitation is the limited inter-rater reliability and the lack of intrarater reliability control. As with all study of bony risk factors, this study lacks assessment of nonbony stabilizers. The labrum, in particular, is thought to have a major influence because it increases the effective glenoid depth.[17]

Conclusion

Glenoid morphology has become an increasing focus in the treatment of anterior shoulder dislocation. Patients with off-track lesions after anterior-inferior shoulder dislocation exhibited a greater glenoid defect, a shallower glenoid, a lower BSSR, and less retroverted glenoid version.

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