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Glenoid track and subcritical Hill-Sachs lesion

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Background: We have proposed the concept of glenoid track ("on-track/off-track" lesion) to evaluate the risk of engagement of the Hill-Sachs lesion with the glenoid after arthroscopic Bankart repair. This concept has been widely used and many clinical validation studies have been reported. To measure the glenoid track width, we have recommended to use 3-dimensional computed tomography (CT) images. However, the CT method has the issue of radiation exposure and involves time and effort to make 3-dimensional CT images from 2-dimensional images. For these reasons, there are several reports describing the measurement method using magnetic resonance imaging. Recently, the threshold of the critical glenoid bone loss becomes lower. A zone of bone loss below the critical size is called "subcritical bone loss", which might be related to deterioration of quality of life and bone grafting is recommended. We applied the concept of "subcritical bone loss" to the glenoid track. Patients with "on-track" lesions can be divided into 2 subgroups: those with a "peripheral-track" lesion (most medial 1/4) and those with a "central-track" lesion (the rest 3/4). More recently, similar evaluation methods to evaluate the risk of "off-track" lesions have been reported: "distance to dislocation" and "Hill-Sachs interval/glenoid track ratio". Also, similar concept to "peripheral-track" lesion, "near-track" lesion was reported. The concept of "peripheral-track" lesion is a concept of assessing an "on-track" lesion which is very close to the medial margin of the glenoid track (subcritical bone loss).

Methods: Similar evaluation methods to evaluate the risk of "off-track" or "peripheral-track" lesions were proposed in the literature. A review was performed by searching PubMed. Journal articles published between January 2014 and January 2023 were taken into account. They were compared and their differences were explained.

Results: The "near-track" lesion concept is similar to "peripheral-track" lesion. However, the cutoff value is different: Hill-Sachs occupancy $\geq$ 75% is the "peripheral-track" lesion, whereas "distance to dislocation" < 8 mm is the "near-track" lesion.

Conclusion: We introduced update of the glenoid track concept including the evaluation method, peripheral-track lesion, and its clinical application.

The Hill-Sachs lesion (HSL) is one of the most common findings observed in patients with anterior shoulder dislocation. Although the prevalence of HSL is reported to be very high,[18,23] most of these lesions are small to medium in size and do not necessarily require surgical treatment.[5] However, we may sometimes encounter a large HSL, which is known to be a risk factor of postoperative recurrence. Seven percent of these lesions are a large HSL that needs to be treated, which may engage with the glenoid rim even after arthroscopic Bankart repair.[11] When we think about engagement of an HSL, this is an important thing. Engagement always occurs between an HSL and the glenoid rim. This means both the HSL and the glenoid are responsible for the engagement. In a biomechanical study using cadaveric shoulders, we clarified which HSL is risky by determining the location of the glenoid on the humeral head with the arm elevating along the posterior end-range of motion (ROM).[19] We defined the contact zone of the glenoid on the humeral head as the "glenoid track". According to the measurements in cadaveric shoulders, the glenoid track width was 84% of the glenoid width in cadaveric shoulders[19] and 83% in live shoulders.[16] Di Giacomo et al[3] have developed a method that uses the concept of the glenoid track to determine whether an HSL will engage the glenoid rim with and without an anterior glenoid osseous defect. They[3] defined "on-track/off-track" lesion as follows. If the medial margin of an HSL is within the glenoid track, the HSL is

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defined as “on-track” HSL; if the medial margin of the HSL is more medial than the glenoid track, the HSL is defined as “off-track” lesion.

It has generally been accepted that the critical size of the glenoid bone loss is 20% or 25% of the glenoid width.[1,2,14] A recent report by Shaha et al[17] indicated that a bone loss between 13.5% and 20% treated with Bankart repair alone led to a decrease of quality of life, independent of the presence of recurrent dislocation. They called this bone loss “subcritical bone loss”. We applied this concept of “subcritical bone loss” to the glenoid track concept. To clarify whether a subcritical bone loss exists in assessing an HSL, 50 patients with an “on-track” lesion who were treated with arthroscopic Bankart repair were assessed.[21] We found that patients with “on-track” lesions were divided into 2 subgroups: “peripheral-track” lesion (most medial 1/4 of the glenoid track) and “central-track” lesion (the rest 3/4). Patients with a “peripheral-track” lesion showed significantly worse Western Ontario Shoulder Instability Index (WOSI) scores than those with a “central-track” lesion, although both groups had no recurrent instability events.

More recently, similar evaluation methods to evaluate the risk of “off-track” lesions have been reported: “distance to dislocation” (DTD)[13] and “Hill-Sachs interval/glenoid track ratio”.[22] Also, similar concept to “peripheral-track” lesion,[21] “near-track” lesion[13] was reported. The concept of “peripheral-track” lesion is a concept of assessing an “on-track” lesion which is very close to the medial margin of the glenoid track (subcritical bone loss). We think the “near-track” lesion concept is the same as “peripheral-track” lesion. However, the cutoff value is different: Hill-Sachs occupancy $\geq$ 75% is the “peripheral-track” lesion, whereas “DTD” < 8 mm is the “near-track” lesion. In this review article, the peripheral-track HSL is similar to the subcritical bone loss of the glenoid.

Glenoid track measurement

To measure the glenoid track width, we recommend to use 3-dimensional (3D) computed tomography (CT) images. In our practice, we use en face views of both glenoid and the posterior view of the involved humeral head on 3D CT. First, the width of the uninvolved glenoid is measured and 83% of the glenoid width is calculated. Then, this 83% value (0.83D) is applied to the involved glenoid. If there is a glenoid bone loss, the defect width (d) needs to be subtracted from the 83% value (0.83D) to obtain the true glenoid track width (0.83D - d). We apply this width (0.83D - d) to the posterior view of the humeral head. If the medial margin of the HSL stays within the glenoid track (“on-track” lesion), there is no risk that this HSL engages with the anterior rim of the glenoid. If the HSL extends more medially over the medial margin of the glenoid track (“off-track” lesion), there is a risk of engagement. To accurately assess an “off-track” lesion, we recommend this CT method but for the reasons described above, there are several reports describing the measurement method using magnetic resonance imaging (MRI).[4,6,15,22]

Influence of joint laxity and range of motion on glenoid track

Since the glenoid track is defined as a zone of contact between the glenoid and the humeral head, theoretically, the glenoid track width is affected by the shoulder joint laxity or the ROM. It would be ideal to take a patient’s joint laxity or ROM into consideration with the glenoid track concept. It is speculated that if a patient has a greater ROM or joint laxity, his/her glenoid track width is narrower compared with the normal shoulder. We have used a constant value of 83% of the glenoid width for all patients[16] because we did not know the relationship between the glenoid track width and ROM. Therefore, we performed an MRI study.[10] MRI was taken in 41 shoulders of 21 healthy volunteers with the arm in maximum horizontal extension, with the arm kept in 90° of abduction and 90° of external rotation. Three-dimensional surface bone models of the glenoid and the humerus were created with an image analysis software. Active and passive ROM were measured in the supine and sitting positions. The correlations between the glenoid track width and ROM were investigated. We found that the greatest correlation was observed between the glenoid track width and the active ROM in horizontal extension in the sitting position. Our data showed that an individualized glenoid track width can be obtained by measuring the active horizontal extension angle of the uninvolved shoulder with the arm in abduction and external rotation in the sitting position (Table 1). Also, the glenoid track width may change depending on sports type and sex. Our previous data[21] showed that male sex and contact sports are found to be risk factors for recurrent instability. Locher et al[15] also reported that male sex is another significant risk factor for recurrent instability.

Table I
Glenoid track table showing the relationship between horizontal extension angle and glenoid track width.

Horizontal extension*	−15°	−10°	−5°	0°	5°	10°	15°	20°	25°	30°
Glenoid track width†	97	95	93	90	87	85	83	80	78	75

*Minus value indicates horizontal flexion angle.
†Percentage of the glenoid width.

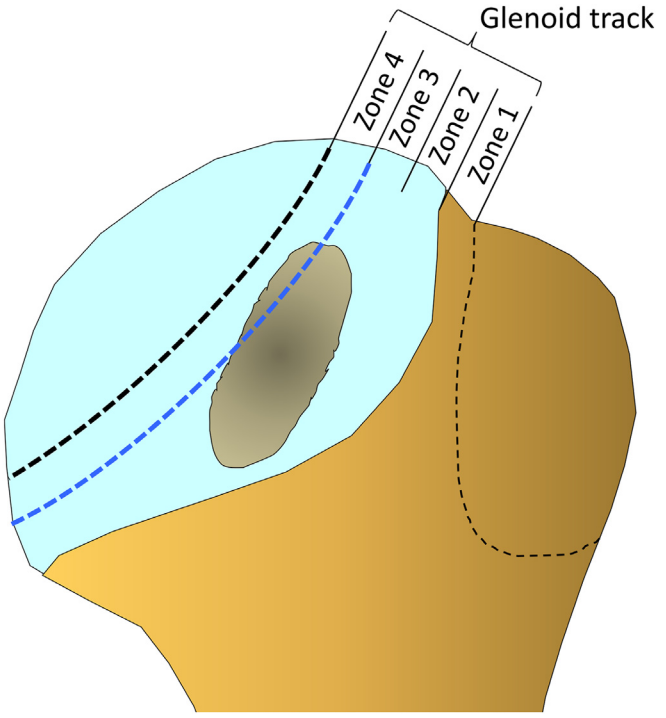

Figure 1 “Peripheral-track” lesion. The glenoid track was divided into 4 zones based on the percentage of Hill-Sachs occupancy: zone 1, < 25%; zone 2, 25% to < 50%; zone 3, 50% to < 75%; and zone 4, $\geq$ 75%. This Hill-Sachs lesion in zone 4 is called “peripheral-track” lesion.

“Peripheral-track” lesion

It has been clinically demonstrated that shoulders with glenoid bone loss just below the critical size (“subcritical bone loss”) led to a

Table II
Similar concept and evaluation methods.

	Definition	Paper
Glenoid track	A contact zone of the glenoid on the humeral head with the arm in various degrees of abduction keeping in maximum external rotation and horizontal extension.	Yamamoto et al J Shoulder Elbow Surg 2007[19]
"On-/off-track" lesion	If the medial margin of a Hill-Sachs lesion is within the glenoid track, it is defined as "on track"; if the medial margin of the Hill-Sachs lesion is more medial than the glenoid track, it is defined as "off track".	Di Giacomo et al Arthroscopy 2014[3]
"Peripheral-/central-track" lesion	"On-track" lesion is divided into 2 subgroups: "peripheral-track" and "central track" lesions. If a Hill-Sachs lesion is located close to the glenoid track line (≥75% of the glenoid track width), it is defined as "peripheral-track" lesion. If a Hill-Sachs lesion is located medial to the glenoid track line (<75% of the glenoid track width), it is defined as "central-track" lesion.	Yamamoto et al Am J Sports Med 2020[21]
Distance-to-dislocation (DTD)	Distance-to-dislocation is defined as the distance between the glenoid track and the Hill-Sachs lesion or between the edge of the anterior aspect of the glenoid and the medial border of the Hill-Sachs lesion.	Li et al J Bone Joint Surg 2021[13]
"Near track" lesion	A "near-track" lesion is defined as a Hill-Sachs lesion with a distance-to-dislocation of < 8 mm.	Li et al J Bone Joint Surg 2021[13]
Hill-Sachs interval/glenoid track (H/G ratio)	Hill-Sachs interval/glenoid track (H/G ratio) is a new parameter "Hill-Sachs interval to glenoid track width ratio" or "H/G ratio" (Hill-Sachs interval divided by glenoid track width)	Yang et al Orthop Trauma Surg Res 2018[22]

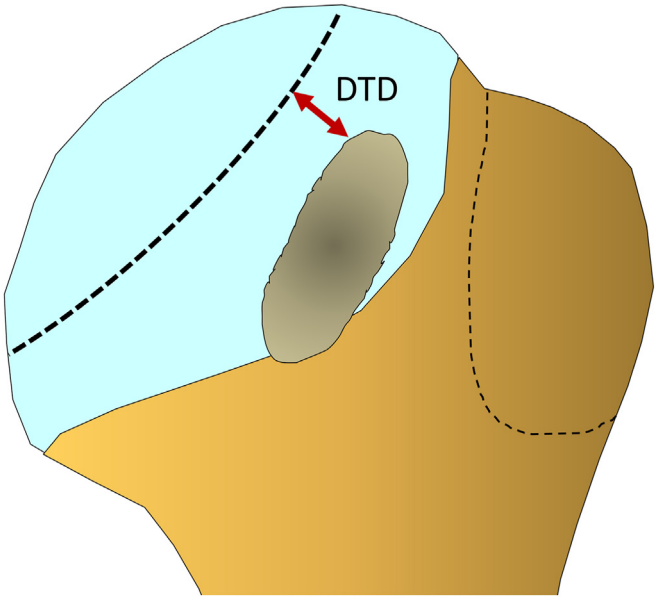

Figure 2 "Distance to dislocation". "Distance to dislocation (*DTD*)" is defined as the distance between the medial edge of the Hill-Sachs lesion and the medial margin of the glenoid track.

decrease of quality of life, independent of the presence of recurrent dislocation. To find out if there was any 'gray zone' in the glenoid track concept, which was similar to the subcritical bone loss of the glenoid, we assessed 50 patients with an "on-track" lesion who were treated with arthroscopic Bankart repair for recurrent anterior dislocation.[21] The Hill-Sachs interval was measured on 3D CT images and divided by the glenoid track width, defined as the Hill-Sachs occupancy. The glenoid track was divided into 4 zones based on the percentage of Hill-Sachs occupancy: zone 1, < 25%; zone 2, 25% to < 50%; zone 3, 50% to < 75%; and zone 4, ≥ 75%. This HSL in zone 4 is called "peripheral-track" lesion (Fig. 1). The WOSI score of patients in zone 4 ("peripheral track" lesion) was significantly lower than those in the other zones ("central-track" lesion). Thus, patients with "on-track" lesions are divided into 2 subgroups: those with a "peripheral-track lesion" (most medial 1/4 of the glenoid track) and those with a "central-track" lesion (the rest 3/4).

Similar concept and evaluation methods

More recently, "near-track" lesion,[13] a similar concept to "peripheral-track" lesion,[21] was reported (Table 2). The concept of "peripheral-track" lesion is a concept of assessing an "on-track" lesion which is close to the medial margin of the glenoid track (subcritical bone loss). We think the "near-track" lesion concept is the same as "peripheral-track" lesion. However, the cutoff value is different: Hill-Sachs occupancy ≥ 75% is the "peripheral-track" lesion, whereas "DTD" < 8 mm is the "near-track" lesion. Also, similar evaluation methods to "Hill-Sachs occupancy" have been reported in the literature: "DTD" (Fig. 2) and "Hill-Sachs interval/glenoid track ratio" (Fig. 3). Li et al[13] recently introduced the "DTD" calculation to determine how close "on-track" lesions are to become "off-track". DTD is defined as the distance between the medial edge of the HSL and the medial margin of the glenoid track and was calculated with the formula DTD = glenoid track width − Hill-Sachs interval. A DTD of > 0 indicates an "on-track" lesion with a defined DTD, whereas a DTD of ≦ 0 indicates an "off-track" lesion. Yang et al[22] designed a new parameter "Hill-Sachs interval/glenoid track ratio (Hill-Sachs interval divided by glenoid track width, H/G ratio)".

"Distance to dislocation"

DTD is a quantitative measure of the glenoid track concept that is predictive of failure after arthroscopic Bankart repair. Li et al[13] reported that a DTD of < 8 mm was a critical threshold for a

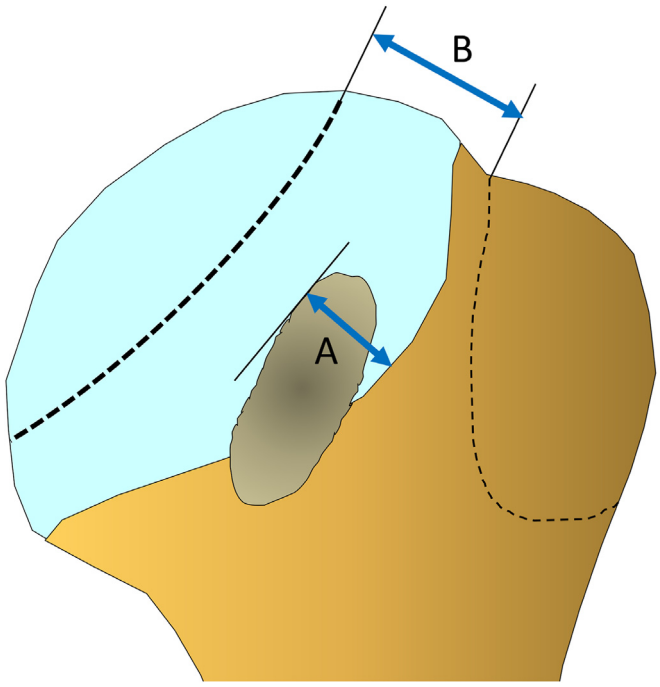

Figure 3 "Hill-Sachs interval/glenoid track (H/G) ratio". H/G ratio is defined as Hill-Sachs interval (*A*) divided by glenoid track width (*B*).

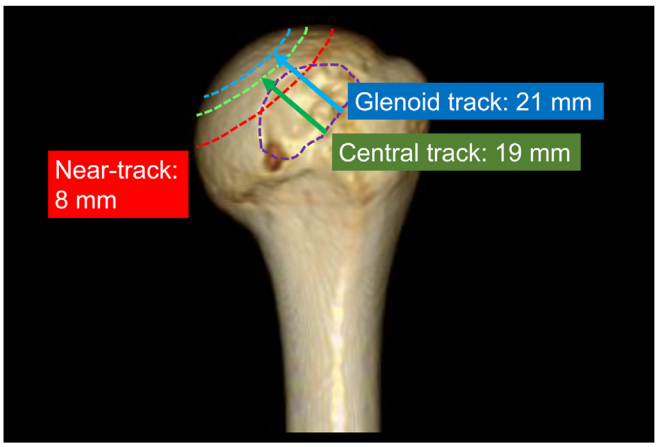

Figure 4 Glenoid track, "central-track", and "near-track" lesion in one shoulder. The width of the glenoid is 25 mm in one shoulder and the glenoid track width is calculated: 25 × 0.83 = 21 mm. The "central-track" width is calculated: 25 × 0.75 = 19 mm. "On-track" lesions with a distance-to-dislocation of < 8 mm is defined as "near-track" lesion. In this shoulder, if we choose the value of 8 mm to judge a subcritical bone loss, we may overdiagnose it.

significantly higher risk of recurrent dislocation after arthroscopic Bankart repair. They determined the association of DTD with recurrent dislocation after arthroscopic Bankart repair. Twenty-eight patients (16%) sustained a recurrent dislocation following Bankart repair. They found that decreased DTD were independent predictors of failure. Receiver operating characteristic curve analysis of DTD alone demonstrated that a threshold value of 8 mm could best predict failure. They suggested that when using the glenoid track concept as the basis for surgical decision-making, clinicians need to consider the DTD value as a continuous variable to estimate failure rather than a binary on-track/off-track designation. DTD is defined as the distance between the glenoid track and the medial margin of the HSL. It seems that the DTD value reflecting a bipolar lesion. However, our paper proposing the concept of the "peripheral-track" lesion showed that there was no significant correlation between the Hill-Sachs occupancy and the WOSI score. This is different from the results of the glenoid bone loss: the greater the glenoid bone loss, the lower the WOSI score, as previously reported.[17,20] This is because the glenoid bone loss is related to mid-range stability of the shoulder (concavity-compression effect).[9,12] With the decrease in glenoid concavity, shoulder stability decreases in the mid-range of shoulder motion. On the other hand, at the end-ROM, both the HSL and the glenoid are related to the engagement because engagement occurs between the HSL and the glenoid and the risk of engagement or dislocation depends not only on the HSL but also on the glenoid bone loss (bipolar lesion).[3] There was no significant correlation between the Hill-Sachs occupancy and the WOSI score: one-on-one relationship between them was not observed. Thus, we think that the value of the glenoid track cannot be used as a continuous variable.

"Near-track" lesion

Li et al[13] pointed out that not all "on-track" lesions are equal, although the glenoid track concept was validated in several studies[7,17] that demonstrated increased risk of failure in association with "off-track" lesions. Specifically, "on-track" lesions with a DTD of < 8 mm, in which the medial margin of the HSL is in close proximity to the medial margin of the glenoid track, also may be at risk for failure. They called this HSL "near-track" lesion. This new concept of "near-track" lesion is very similar to our concept of "peripheral-track" lesion. A "peripheral-track" lesion is the one which is located just medial to the border line of the glenoid track. What is the difference between "near-track" and "peripheral-track" lesion? With a quick calculation, the width of the glenoid is 25 mm in one shoulder and the glenoid track width (83% of the glenoid width) is calculated: 25 × 0.83 = 21 mm. The "central-track" width (75% of the glenoid width) is calculated: 25 × 0.75 = 19 mm. DTD is calculated with the formula DTD = glenoid track width − Hill-Sachs interval: 21 − 19 = 2 mm. If we choose the value of 8 mm to judge a subcritical bone loss, we may overdiagnose it (Fig. 4).

"Hill-Sachs interval/glenoid track ratio"

Yang et al[22] introduced the "Hill-Sachs interval to glenoid track width ratio (H/G ratio)" to adjust the original glenoid track concept because they believe that the postoperative condition of soft tissue *in vivo* was not comparable to that designed in the intact condition. Those authors found that a higher ratio was a significant predictor for recurrent dislocation. They reported that H/G ratio seems to be a reliable parameter for predicting recurrent instability. H/G ratio ≥ 0.7 may be considered as a positive predictor for recurrent instability after arthroscopic Bankart repair. The parameter of "H/G ratio" is the same as Hill-Sachs occupancy which we used in the previous study as a parameter to evaluate the subcritical bone loss.[20] Also, the value of 0.7 is very similar to our value, 0.75. However, these values were interpreted differently. The term "H/G ratio" was used as a parameter for predicting recurrent instability. On the other hand, patients with "peripheral-track" lesion had worse impairment of quality of life without the presence of recurrent instability.[21]

Treatment for "peripheral-track" lesion

There was a significant difference in sex between those with the "peripheral-track" and "central-track" lesions in our study.[21]

Table III
Treatment strategy for a Hill-Sachs lesion.

On-track lesion			Off-track lesion
Central-track lesion	Peripheral-track lesion		
	Noncontact athletes	Contact athletes	
Arthroscopic Bankart repair	Arthroscopic Bankart repair	Latarjet or Remplissage	Latarjet or Remplissage

Of 10 patients with the "peripheral-track" lesion, 7 were male patients and participated in contact sports. This means that with the same location of an HSL, male contact athletes with high activity levels are more likely to be affected than female noncontact athletes. From these results, we need to consider sex and type of sports when thinking about the surgical treatment of "peripheral-track" lesion. In clinical practice, how should an HSL be evaluated? First, we need to evaluate whether an HSL is "on-track" or "off-track"[3,8] (Table 3). If it is "off-track", either Latarjet or remplissage needs to be considered. If it is "on-track", then we need to evaluate whether it is a "peripheral-track" lesion or "central-track" lesion. If a contact athlete has a "peripheral-track" lesion, we need to consider Latarjet procedure or augmentation such as remplissage in addition to arthroscopic Bankart repair. However, if a noncontact patient has a "peripheral-track" lesion, a standard Bankart repair seems to be preferable. Patients with a "central-track" lesion are expected to have satisfactory outcome with a standard Bankart repair regardless of their activity level.

There are many factors related to the patients when considering the surgical treatment. In our clinical study, some factors such as age, sex, type of sports, and activity level are clarified. However, the other factors (dominance, combined lesion, type of sports, and job) are not clarified yet. We need a further study to demonstrate it. Thus, this "peripheral-track" lesion is still a gray zone in terms of surgical treatment.

Conclusion

Since the greatest correlation was observed between the glenoid track width and the active ROM in horizontal extension, an individualized glenoid track width can be better estimated by measuring the active horizontal extension angle of the uninvolved shoulder. We proposed a new concept of assessing an on-track lesion: "peripheral-track" and "central-track" lesions. We need to consider sex and type of sports when thinking about the surgical treatment of "peripheral-track" lesion. If a contact athlete has a "peripheral-track" lesion, we need to consider Latarjet procedure or augmentation such as remplissage in addition to arthroscopic Bankart repair.

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