EOR | volume 2 | august 2017
DOI: 10.1302/2058-5241.2.170007
www.efortopenreviews.org

EFORT open reviews

‘On-track’ and ‘off-track’ shoulder lesions

E. Itoi

- Shoulder stability depends on the position of the arm as well as activities of the muscles around the shoulder. The capsulo-ligamentous structures are the main stabilisers with the arm at the end-range of movement, whereas negative intra-articular pressure and concavity-compression effect are the main stabilisers with the arm in the mid-range of movement.
- There are two types of glenoid bone loss: fragment type and erosion type. A bone loss of the humeral head, known as a Hill-Sachs lesion (HSL), is a compression fracture of the humeral head caused by the anterior rim of the glenoid when the humeral head is dislocated anteriorly in front of the glenoid. Four out of five patients with anterior instability have both Hill-Sachs and glenoid bone lesions, which is called a ‘bipolar lesion’.
- With the arm moving along the posterior end-range of movement, or with the arm in various degrees of abduction, maximum external rotation and maximum horizontal extension, the glenoid moves along the posterior articular margin of the humeral head. This contact zone of the glenoid with the humeral head is called the ‘glenoid track’.
- A HSL, which stays on the glenoid track (on-track lesion), cannot engage with the glenoid and cannot cause dislocation. On the other hand, a HSL, which is out of the glenoid track (off-track lesion), has a risk of engagement and dislocation. Clinical validation studies show that the ‘on-track/off-track’ concept is able to predict reliably the risk of a HSL being engaged with the glenoid. For off-track lesions, either remplissage or Latarjet procedure is indicated, depending upon the glenoid defect size and the risk of recurrence.

Cite this article: *EFORT Open Rev* 2017;2:343-351.

Keywords: shoulder instability; glenoid bone loss; Hill-Sachs lesion; glenoid track; on-track lesion; off-track lesion

Shoulder stability

The basic concept of shoulder stability is explained in the first section of this article so that the following explanation of bony stability will be better and more easily understood by the readers. The shoulder joint is a ball-and-socket joint. Since the socket (glenoid) covers only one-quarter of the surface of the ball (humeral head),[1] it has the greatest range of movement of all the joints in the body. When the arm comes to the limit of shoulder movement, it is defined as the ‘end-range’. The track of the extended arm moved along the end-range creates a large circle around the shoulder joint. The area surrounded by this circle is called the ‘mid-range’ of movement. At the end-range of movement, a part of the shoulder capsule is tight, which prevents a translation of the humeral head on the glenoid socket.[2] On the other hand, the shoulder capsule is lax in the mid-range of movement, which allows the humeral head to translate freely in any direction on the glenoid socket. This translation of the humeral head is called laxity. The anterior and posterior drawer tests (load and shift test) and sulcus test are performed with the arm in the mid-range of movement because these tests are aimed to detect the laxity of the shoulder joint.

Mid-range stability is provided by the negative intra-articular pressure[3,4] and the concavity-compression effect.[5] When all the shoulder muscles are silent (when the arm is hanging relaxed) the shoulder is pulled downward by the weight of the arm. This creates a negative intra-articular pressure, which sucks the humeral head into the glenoid socket and prevents a downward translation of the humeral head. If the arm is pulled downward (sulcus test), the humeral head may translate inferiorly in varying degrees. In general, the negative value of the intra-articular pressure increases linearly with an increase of downward pull.[4] This increase in negative value prevents further translation of the humeral head when the negative pressure and the weight of the arm come to an equilibrium. The responsiveness of intra-articular pressure to the external load is determined by the volume of the joint as well as the thickness and quality of the surrounding soft-tissue envelope, such as the joint capsule and the muscles.[6] Due to varying degrees in the responsiveness of intra-articular pressure, there is no normal value for shoulder laxity. Some people may be able to subluxate or even dislocate the shoulder in the mid-range of movement due to a great amount of laxity. If this subluxation or dislocation

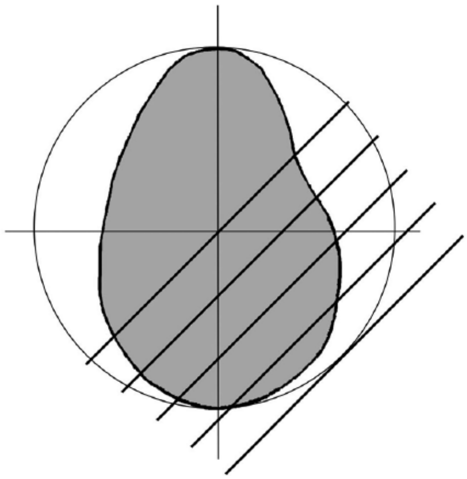

Fig. 1 Bony defects created anteroinferiorly. Anteroinferior bony defects were created at the 4:30 clock position stepwise.

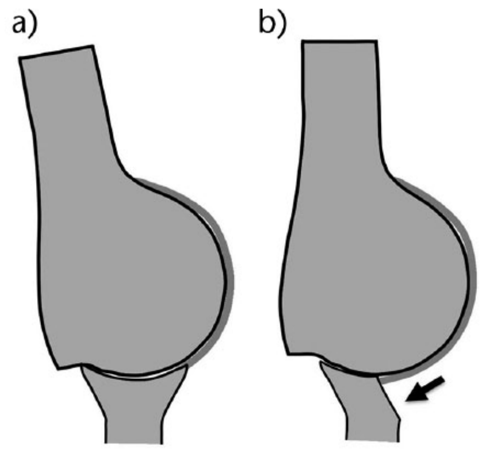

Fig. 2 End-range stability: a) normal shoulder at the end-range of movement. The anterior capsule is tight; b) with a large glenoid bony defect (arrow), the end-range stability is still well preserved after the Bankart repair because the repaired capsule is tight and prevents the anterior translation of the humeral head.

accompanies no symptoms, this laxity is just physiological and no treatment is necessary.

As soon as the muscle contraction occurs with the arm elevated, the contraction force by the shoulder muscles pulls the humeral head against the glenoid socket, which in turn creates a resistance force against translation of the humeral head. This stabilising mechanism is called a concavity-compression effect.[5] This effect depends on the depth of the glenoid concavity and the magnitude of contraction force created by the muscles. The glenoid socket is twice as deep in the superior-inferior direction as in the anteroposterior (AP) direction.[7] As a result, a force necessary to translate the humeral head under a constant compressive force is twice as large in the superior-inferior direction as in the AP direction. A ratio of translational force/compressive force is defined as the stability ratio.[8] It is 0.33 to 0.35 in the AP direction and 0.59 to 0.64 in the superior-inferior direction. The magnitude and direction of the resultant force by the shoulder muscles depend on the activity and position of the arm. Whatever the magnitude and direction, the perpendicular component of the resultant force against the glenoid socket multiplied by the stability ratio determines the resistance force.

At the end-range of movement, a part of the shoulder joint capsule becomes tight and prevents further movement of the arm. For example, the anteroinferior capsule including the inferior glenohumeral ligament (IGHL) becomes tight when the arm is in abduction, external rotation and horizontal extension. The tight capsulo-ligamentous structure functions as a stabiliser of the humeral head in the direction of the tight capsule. If a force greater than the IGHL resistance is applied, the IGHL may be avulsed or ruptured and the humeral head comes out of the glenoid socket. This is a traumatic shoulder dislocation, which is pathological and needs to be treated. Therefore, a dislocation could be physiological or pathological depending on which position of the arm the dislocation occurs in and whether it is accompanied by symptoms.

Glenoid bony defect

What is wrong with a glenoid bony defect? It is a very fundamental question. When we first paid attention to this issue, there had been no quantitative biomechanical studies. It had been said that a bony defect of one-third of the glenoid or greater needs to be treated.[9,10] This assessment of one-third is very subjective and not quantitative. No-one can tell precisely what one-third of the glenoid is. As long as we use the subjective assessment, such as one-third or one-quarter, we will never be able to determine the critical size of a defect which needs to be treated. This was the very beginning of our serial studies of shoulder stability related to the glenoid and humeral head defects. We created anteroinferior glenoid bony defects of four different sizes (9%, 21%, 34% and 46% of the glenoid length) stepwise and measured the shoulder stability after the Bankart repair with each size of bony defect (Fig. 1).[11] It was interesting that the shoulder stability was well preserved even with the greatest bony defect of the glenoid as long as the shoulder was at the end-range of movement, i.e. abduction and external rotation. This was because in this position, the repaired anteroinferior capsule became tight and prevented the anterior translation of the humeral head, even with a large glenoid defect (Fig. 2). However, once the arm came into the mid-range of movement, the head easily translated anteroinferiorly

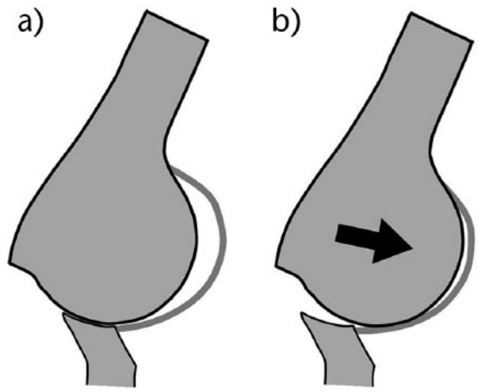

Fig. 3 Mid-range stability: a) in the mid-range, the anterior capsule is lax and does not hold the humeral head in place; b) the head comes out of the glenoid socket because the socket is very shallow due to a large bony defect.

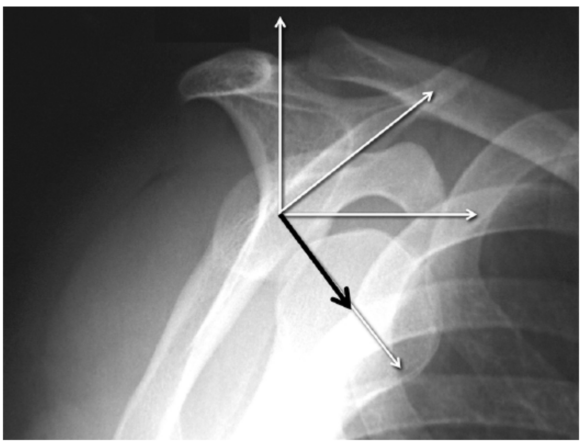

Fig. 4 Direction of dislocation. The head dislocates anteroinferiorly relative to the trunk, but anteriorly relative to the scapula.

with a certain size of glenoid defect because there was no more protection by the tight capsule, and the glenoid socket was too shallow to keep the humeral head in the socket (Fig. 3). This defect size was 21% of the glenoid length or 28% of the glenoid width. These findings clearly tell us that the glenoid bony defect is related to the mid-range instability, not to the end-range instability.

After this study, we determined the precise location of the glenoid bony defect using 3D CT.[12] The humeral head dislocates in the anteroinferior direction relative to the trunk. However, due to the anterior tilt of the scapula, the direction of humeral head dislocation relative to the scapula was almost anterior (3:01 on the 'clock face' of the right shoulder) (Fig. 4). We repeated the similar biomechanical studies with a bony defect created in the anterior portion of the glenoid (Fig. 5). First, we measured the bony stability using the stability ratio without any soft-tissue

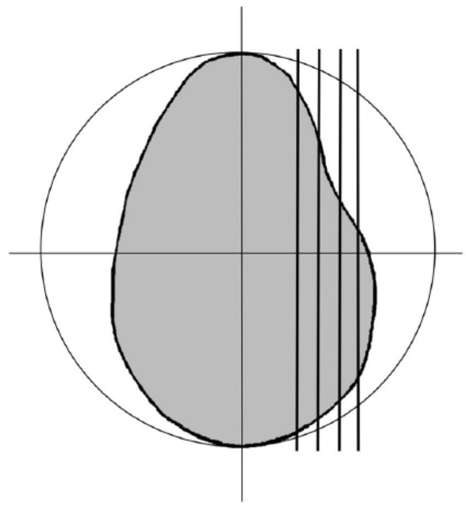

Fig. 5 Bony defects created anteriorly. Anterior bony defects were created at 3:00 clock position stepwise.

contribution;[13] next, we measured the shoulder stability after the Bankart repair in a displacement control study.[14] According to these studies, the critical size of the glenoid defect was demonstrated to be 25% of the glenoid width.

Assessment of the glenoid defect

There are various methods of assessing the bony defect of the glenoid, such as radiography,[15-17] CT,[18] 3D CT,[19] MRI[20] and arthroscopy.[21] An 'en face' view of the glenoid using 3D CT is considered the benchmark nowadays[22] because it provides the most accurate assessment of the glenoid bony defect.[23] On an en face view of the glenoid, we have to decide two things: 1) how to estimate the original glenoid shape and; 2) how to express the defect size. For the former, there are two methods: 1) use a best-fit circle (Fig. 6)[20,24,25] and; 2) use the contralateral glenoid as a reference (Fig. 7).[19,26] Since bilateral shoulder images are always available when taking the CT scans and the side-to-side difference is $<$ 1% of the length and width,[27] using the contralateral glenoid seems to be the best method unless the contralateral side is also involved in shoulder instability. In that case, a best-fit circle method can be used instead. For the latter, there are also two methods to express the defect size: 1) area measurement and; 2) linear measurement. Most people prefer to use the linear measurement (Fig. 8) because it is easy and no special software is needed. All that is needed is a ruler.

Hill-Sachs lesion (HSL)

The HSL is also commonly observed in shoulders with anterior instability. The prevalence of HSL is reported to be 65% to 67% after initial dislocation and 84% to 93% after

Fig. 6 'Best-fit' circle method. A best-fit circle is applied, which fits perfectly to the posterior and to the inferior part of the glenoid. This circle is considered to be close to the original shape of the glenoid.

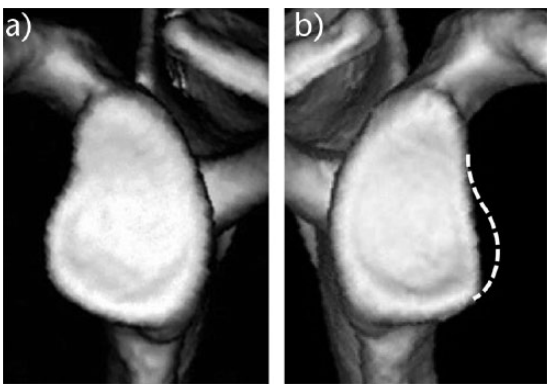

Fig. 7 Contralateral method: the contralateral shoulder (a), if it is intact, can be used as a control (dotted line) (b).

recurrent dislocation.[28,29] It is a compression fracture of the humeral head created by the anterior rim of the glenoid (Fig. 9). It is located at the posterior aspect of the humeral head, extending from 0 mm to 24 mm from the top of the head.[30] Usually, a small HSL is located close to the greater tuberosity, whereas a large HSL extends more medially, away from the greater tuberosity. A HSL which is small and narrow but is located medially needs special attention in selecting an optimum treatment option (Fig. 10).[31]

A HSL is not related to the mid-range stability because it is located away from the glenoid in the mid-range of movement (Fig. 11). With the arm at the posterior end-range of movement such as abduction and external rotation, the

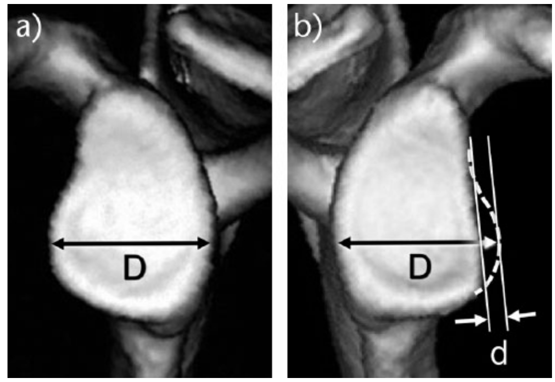

Fig. 8 Linear measurement: a) this is the contralateral glenoid, which is intact. 'D' represents the width of the intact glenoid; b) this is the involved side with a glenoid bony defect. 'D' comes from the intact side and the difference between the intact glenoid width 'D' and the width of the deficient glenoid is the defect width 'd'. The size of the defect is expressed as d/D x 100 (%).

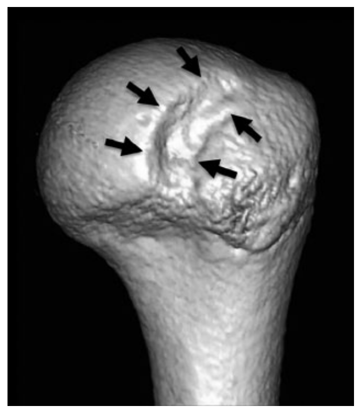

Fig. 9 Hill-Sachs lesion (HSL): arrows indicate the compression fracture of the posterior aspect of the humeral head, which is called a HSL. This lesion is located close to the greater tuberosity.

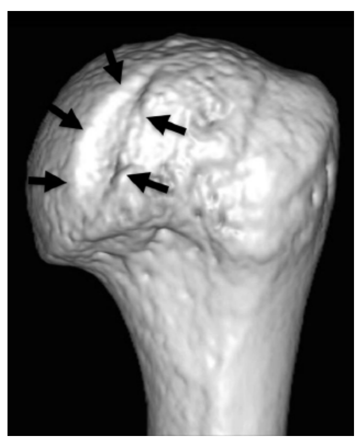

Fig. 10 Hill-Sachs lesion (HSL) located medially: this HSL is narrow, but located medially. This type of HSL has a high risk of becoming an 'off-track lesion'.

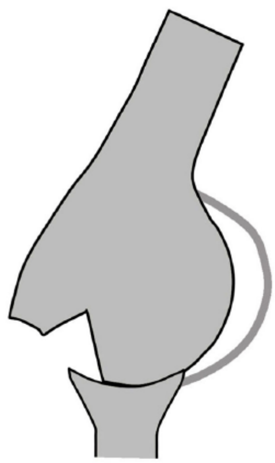

Fig. 11 Hill-Sachs lesion (HSL) in the mid-range: it does not cause any instability in the mid-range of movement.

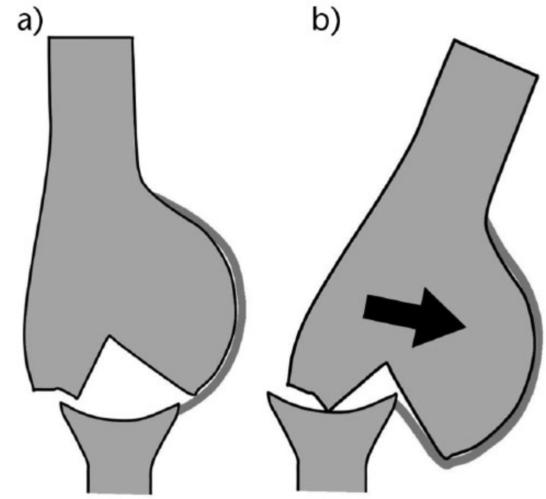

Fig. 13 Hill-Sachs lesion (HSL) not entirely covered by the glenoid at the end-range: a) the anterior rim of the glenoid is on the HSL; b) it engages with the HSL and a dislocation occurs.

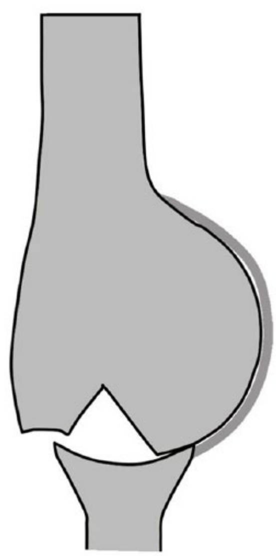

Fig. 12 Hill-Sachs lesion (HSL) entirely covered by the glenoid at the end-range: if the HSL is entirely covered by the glenoid when it comes to the end-range of movement, it is stable.

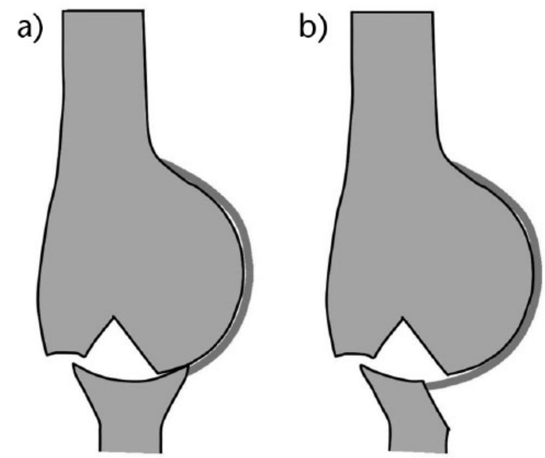

Fig. 14 Hill-Sachs lesion (HSL) and the glenoid: a) this HSL is entirely covered by the glenoid at the end-range of movement. Therefore, this is a stable shoulder; b) the HSL is the same size as in (a), but it is not entirely covered by the glenoid due to a bony defect of the glenoid. Thus, this shoulder is unstable. The risk of the HSL engaging or not depends on the relative size of the HSL to the glenoid.

glenoid comes to the posterolateral portion of the humeral head, where the HSL is located. If the HSL is entirely covered by the glenoid in this arm position, it cannot cause any instability (Fig. 12). However, if it is out of the glenoid coverage, it may engage with the anterior rim of the glenoid and cause a dislocation (Fig. 13). Thus, different from a glenoid bony defect, a HSL is related to the end-range instability.

Assessment of the risk of HSL

How can we assess the risk of instability caused by a HSL? What is the critical size of HSL? As mentioned previously, HSL is related to the end-range instability. This means that a risk of engagement/dislocation depends on the relative size and location of the HSL to the glenoid (Fig. 14). There are two methods to assess the risk of HSL. One method is dynamic examination. During arthroscopic surgery, the relative relationship between the HSL and the glenoid can be assessed. The important thing is that this dynamic examination should be performed after the Bankart repair (Figs 15 and 16). It does not matter if the HSL engages with the glenoid before the Bankart repair; what we would like to know is whether there is a remnant risk of

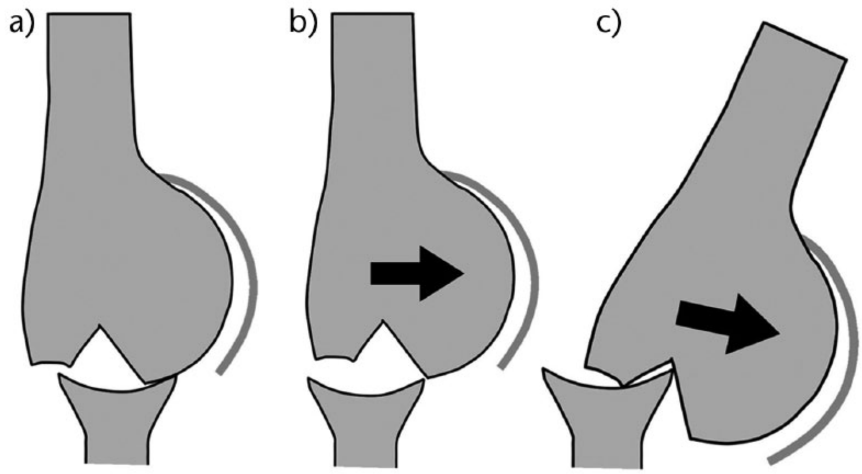

Fig. 15 Dynamic examination before the Bankart repair: a) the shoulder is unstable anteriorly because of the Bankart lesion; b) the head translates anteriorly during dynamic examination; c) as a result, the HSL easily engages and the head dislocates.

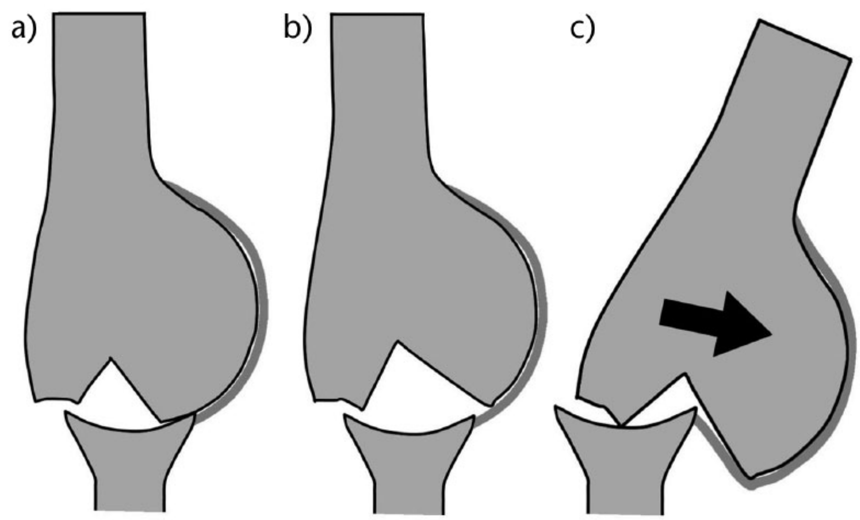

Fig. 16 Dynamic examination after the Bankart repair: a) The Hill-Sachs lesion (HSL) (the same size as in Figure 15) does not engage because the shoulder is stable due to the tight anterior capsule after the Bankart repair; b) this HSL is not covered by the glenoid after the Bankart repair; c) this may engage and the head may dislocate even after the Bankart repair. This is the true 'engaging' HSL.

engagement afterwards. This is the one and only purpose of carrying out the dynamic examination. Therefore, it should be performed after the Bankart repair. Unfortunately, most investigators perform the dynamic examination before the Bankart repair and call it an engaging HSL if this examination is positive.[32-34] According to these reports, the prevalence of engaging HSL was 34% to 52%. This is not the correct way to determine an engaging HSL and the prevalence was definitely overestimated. Parke et al[35] evaluated engagement before and after the Bankart repair. In their series of 983 shoulder stabilisations, 70 shoulders showed an engagement during dynamic examination after the Bankart repair and they added remplissage in these cases. The prevalence of true 'engaging' HSL was 7% (70 out of 983). The disadvantage of this method is that there is a risk of damaging the repair during the dynamic examination.

The second method is to use the 'glenoid track' concept. The risk of HSL being engaged with the anterior rim of the glenoid becomes greatest when the arm is at the posterior end-range of movement because it is in this position that the glenoid overrides the HSL. For the purpose of assessing the risk of HSL relative to the glenoid, the glenoid track concept was introduced.[36,37] The

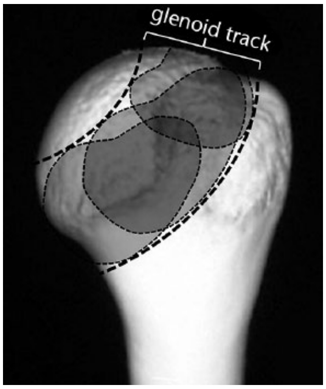

Fig. 17 Glenoid track: when the arm is moved along the posterior end-range of movement keeping in maximum external rotation and maximum horizontal extension, the glenoid moves along the posterior articular surface of the humeral head. This contact zone is defined as the 'glenoid track'. Reproduced with permission from Itoi E, Yamamoto N. Shoulder instability: treating bone loss. *Current Orthop Practice* 2012;23:609-615.[38]

glenoid track is the area of posterior humeral articular surface in contact with the glenoid when the arm moves along the posterior end-range of movement (Fig. 17). If the HSL stays within the glenoid track, no engagement/dislocation occurs. However, if it goes out of the glenoid track, the anterior rim of the glenoid may fall into the HSL, causing a new dislocation. The width of the glenoid track, defined as the distance between the medial margin of the glenoid track and the medial margin of the footprint of the rotator cuff, was 84% of the glenoid width in cadaveric shoulders[36] and was 83% of the glenoid width when the arm was at 90° of abduction in live shoulders.[37]

In our daily practice, we use en face views of both glenoids and the posterior view of the involved humeral head on 3D CT.[26,38] First, we measure the width of the intact glenoid and calculate 83% of the glenoid width (0.83D) (Fig. 18a). Then, this 83% value (0.83D) is applied to the involved glenoid en face view (Fig. 18b). If there is a bony defect of the glenoid, the defect width 'd' needs to be subtracted from the 83% value (0.83D) to obtain the true width of the glenoid track (0.83D - d). We apply this width (0.83D - d) to the posterior view of the humeral head (Fig. 18c). If the medial margin of the HSL stays within the glenoid track, 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, there is a risk of engagement. The former used to be called 'non-engaging HSL' and the latter 'engaging HSL'. However, as described above, these terms are almost always misused and cause a lot of confusion. In order to avoid this confusion, we proposed a new terminology: 'on-track HSL' and 'off-track HSL'.[26] If the HSL stays on the glenoid track (on-track lesion), there is no risk of engagement. If the HSL is out of the glenoid track (off-track lesion), there is a risk of engagement and dislocation.

Recently, there are some clinical studies showing the validity of this on-track/off-track concept. Locher et al[39] retrospectively analysed 100 patients who underwent arthroscopic Bankart repair. Among these 100 patients, 88 of them had on-track HSLs and 12 had off-track HSLs. The on-track patients had 6% of recurrence (five out of 88), but the off-track patients had 33% (four out of 12). The odds ratio of off-track patients over the on-track patients to experience recurrence was 8.3. Shaha et al[40] also looked at 57 patients who underwent arthroscopic Bankart repair. The recurrence rate was 8% in the on-track patients and 75% in the off-track patients. The positive predictive value of off-track concept to predict the recurrence was 75%, whereas that of the glenoid bone loss of $>$ 20% was 43%.

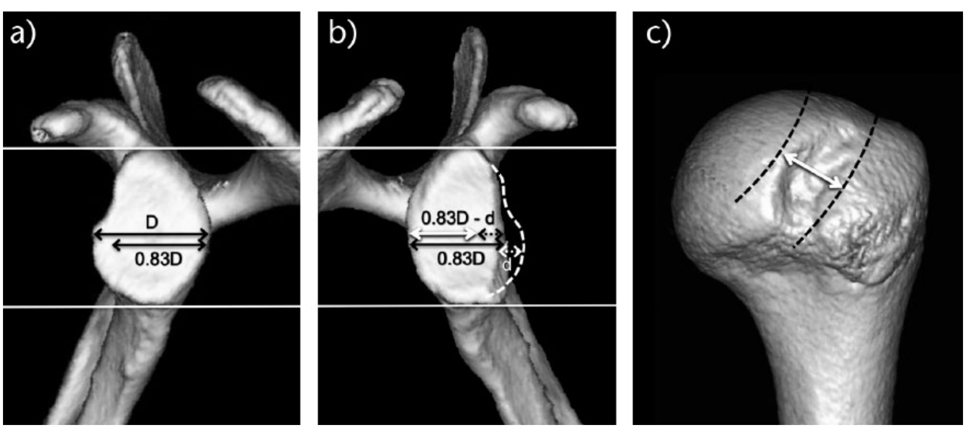

Fig. 18 Drawing of the glenoid track: a) on the 'en face' view of the intact glenoid, 83% of the glenoid width is obtained (0.83D); b) on the involved side, there is a defect (d; white dotted double-headed arrow). The width of the glenoid track is obtained by subtracting 'd' (black dotted double-headed arrow) from 83% value (0.83D - d; white double-headed arrow); c) this glenoid track width (0.83D - d) is applied to the posterior view of the humeral head. In this case, the HSL stays in the glenoid track, making this lesion an 'on-track' HSL.

They concluded that the off-track method was accurate and it was promoted as a routine pre-operative evaluation of all patients under consideration for arthroscopic anterior stabilisation.

Treatment strategy

Based on the on-track/off-track concept, our treatment strategy is as follows.[26] For shoulders with on-track HSL and glenoid bone loss of $< 25\%$, only soft-tissue repair is sufficient. With on-track HSL and glenoid bone loss of $\geqslant 25\%$, the glenoid bone loss needs to be fixed, for example by the Latarjet procedure. With off-track HSL and the glenoid bone loss of $< 25\%$, remplissage may be a good procedure. However, if the patient is a throwing athlete who requires full range of external rotation or if the patient is a contact/collision athlete with high risk of recurrence, then the Latarjet procedure is a good procedure because it can convert an off-track lesion to an on-track lesion and also provides extra stability to the shoulder.[41] The outcome of the Latarjet procedure in rugby players is quite satisfactory.[42] With off-track HSL and the glenoid bone loss of $\geqslant 25\%$, the glenoid defect needs to be fixed. The Latarjet procedure can convert an off-track lesion to an on-track lesion. However, if the HSL is still off-track after the Latarjet procedure, either remplissage or bone graft to the HSL needs to be added to the Latarjet procedure.

Bony Bankart lesion

The above mentioned treatment strategy is for the erosion type of glenoid bone loss. Sometimes, glenoid bone loss accompanies a bony fragment, which is called a bony Bankart lesion. This is observed in 22% to 50% of the cases with recurrent anterior instability.[19,24,43,44] The treatment strategy for a bony Bankart lesion is still controversial. Some reported that it was sufficient to fix a fragment back to the glenoid even though the fragment size was much smaller than the size of the glenoid defect.[45] The five- to eight-year follow-up study showed that after fixing a small fragment, the remnant defect was filled by the new bone formation and eventually the shape of the glenoid returned close to the original shape.[46] On the other hand, others reported that the smaller the fragment, the worse the union between the fragment and the glenoid, which in turn made the outcome worse.[44] At present, we recommend that the fragment be fixed to the glenoid if the reconstructed glenoid (native glenoid + bone fragment) is wide enough to cover the HSL (on-track lesion). We still do not know how much size discrepancy between a glenoid defect and a fragment would be acceptable. Further long-term clinical studies are necessary.

AUTHOR INFORMATION

E. Itoi, Department of Orthopaedic Surgery, Tohoku University School of Medicine, Sendai, Japan

ACKNOWLEDGEMENTS

The author thanks K-N. An, B. F. Morrey, N. Yamamoto, Y. Omori, D. Kurokawa, G. Di Giacomo, S. S. Burkhart, N. E. Motzkin and S-B. Lee for their support in the serial works on shoulder instability.

Correspondence should be sent to: Eiji Itoi, 1-1 Seiryo-machi, Aoba-ku, Sendai 980-8574, Japan.
E-mail: itoi-eiji@med.tohoku.ac.jp

FUNDING

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

ICMJE CONFLICT OF INTEREST STATEMENT

The author is a paid member of the Board of Trustees of the *Journal of Shoulder and Elbow Surgery*.

REFERENCES

1. **Hertz H.** Significance of the limbus glenoidalis for the stability of the shoulder joint. *Wien klin Wochenschr Suppl* 1984;152:1-23. (In German)

2. **Itoi E, Morrey BF, An KN.** Biomechanics of the shoulder. In: Matsen FA, Wirth MA, Lippitt SB, Rockwood CA, eds. *The shoulder*. Fourth ed. Philadelphia: Saunders/Elsevier, 2009:213-265.

3. **Kumar VP, Balasubramaniam P.** The role of atmospheric pressure in stabilising the shoulder. An experimental study. *J Bone Joint Surg [Br]* 1985;67-B:719-721.

4. **Itoi E, Motzkin NE, Browne AO, et al.** Intraarticular pressure of the shoulder. *Arthroscopy* 1993;9:406-413.

5. **Matsen FA III, Harryman DT II, Sidles JA.** Mechanics of glenohumeral instability. *Clin Sports Medicine* 1991;10:783-788.

6. **Itoi E.** Pathophysiology and treatment of atraumatic instability of the shoulder. *J Orthop Sci* 2004;9:208-213.

7. **Howell SM, Galinat BJ.** The glenoid-labral socket. A constrained articular surface. *Clin Orthop Relat Res* 1989;243:122-125.

8. **Lippitt SB, Vanderhooft JE, Harris SL, et al.** Glenohumeral stability from concavity-compression: A quantitative analysis. *J Shoulder Elbow Surg* 1993;2:27-35.

9. **Matsen FA III, Thomas SC.** Glenohumeral instability. In: Evarts C, ed. *Surgery of the Musculoskeletal System*. Second ed. New York: Churchill Livingstone, 1990:1439-1469.

10. **Matsen FA III, Thomas SC, Rockwood CA Jr, Wirth MA.** Glenohumeral instability. In: *The Shoulder*. Rockwood CA Jr, Matsen FA III, eds. Philadelphia: W. B. Saunders, 1998:611-754.

11. 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-A:35-46.

12. Saito H, Itoi E, Sugaya H, et al. Location of the glenoid defect in shoulders with recurrent anterior dislocation. *Am J Sports Med* 2005;33:889-893.

13. Yamamoto N, Itoi E, Abe H, et al. Effect of an anterior glenoid defect on anterior shoulder stability: a cadaveric study. *Am J Sports Med* 2009;37:949-954.

14. Yamamoto N, Muraki T, Sperling JW, et al. Stabilizing mechanism in bone-grafting of a large glenoid defect. *J Bone Joint Surg [Am]* 2010;92-A:2059-2066.

15. Rokous JR, Feagin JA, Abbott HG. Modified axillary roentgenogram. A useful adjunct in the diagnosis of recurrent instability of the shoulder. *Clinical Orthop Relat Res* 1972;82:84-86.

16. Bernageau J, Patte D, Debeyre J, Ferrane J. Value of the glenoid profil in recurrent luxations of the shoulder. *Rev Chir Orthop Reparatrice Appar Mot* 1976;62:142-147. (In French)

17. Garth WP Jr, Slappey CE, Ochs CW. Roentgenographic demonstration of instability of the shoulder: the apical oblique projection. A technical note. *J Bone Joint Surg [Am]* 1984;66-A:1450-1453.

18. Baudi P, Righi P, Bolognesi D, et al. How to identify and calculate glenoid bone deficit. *La Chirurgia degli organi di movimento* 2005;90:145-152. (In Italian)

19. Griffith JF, Antonio GE, Tong CW, Ming CK. Anterior shoulder dislocation: quantification of glenoid bone loss with CT. *AJR Am J Roentgenol* 2003;180:1423-1430.

20. Huijsmans PE, Haen PS, Kidd M, et al. Quantification of a glenoid defect with three-dimensional computed tomography and magnetic resonance imaging: a cadaveric study. *J Shoulder Elbow Surg* 2007;16:803-809.

21. Burkhart SS, Debeer JF, Tehrany AM, Parten PM. Quantifying glenoid bone loss arthroscopically in shoulder instability. *Arthroscopy* 2002;18:488-491.

22. Provencher MT, Bhatia S, Ghodadra NS, et al. Recurrent shoulder instability: current concepts for evaluation and management of glenoid bone loss. *J Bone Joint Surg [Am]* 2010;92-A:133-151.

23. Bishop JY, Jones GL, Rerko MA, Donaldson C. 3-D CT is the most reliable imaging modality when quantifying glenoid bone loss. *Clin Orthop Relat Res* 2013;471:1251-1256.

24. 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-A:878-884.

25. Huijsmans PE, de Witte PB, de Villiers RV, et al. Recurrent anterior shoulder instability: accuracy of estimations of glenoid bone loss with computed tomography is insufficient for therapeutic decision-making. *Skeletal Radiol* 2011;40:1329-1334.

26. 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;30:90-98.

27. Shi L, Griffith JF, Huang J, Wang D. Excellent side-to-side symmetry in glenoid size and shape. *Skeletal Radiol* 2013;42:1711-1715.

28. Spatschil A, Landsiedl F, Anderl W, et al. Posttraumatic anterior-inferior instability of the shoulder: arthroscopic findings and clinical correlations. *Arch Orthop Trauma Surg* 2005;126:217-222.

29. Yiannakopoulos CK, Mataragas E, Antonogiannakis E. A comparison of the spectrum of intra-articular lesions in acute and chronic anterior shoulder instability. *Arthroscopy* 2007;23:985-990.

30. Saito H, Itoi E, Minagawa H, et al. Location of the Hill-Sachs lesion in shoulders with recurrent anterior dislocation. *Arch Orthop Trauma Surg* 2009;129:1327-1334.

31. Kurokawa D, Yamamoto N, Nagamoto H, et al. The prevalence of a large Hill-Sachs lesion that needs to be treated. *J Shoulder Elbow Surg* 2013;22:1285-1289.

32. Cho SH, Cho NS, Rhee YG. Preoperative analysis of the Hill-Sachs lesion in anterior shoulder instability: how to predict engagement of the lesion. *Am J Sports Med* 2011;39:2389-2395.

33. Haviv B, Mayo L, Biggs D. Outcomes of arthroscopic "remplissage": capsulo-tenodesis of the engaging large Hill-Sachs lesion. *J Orthop Surg Res* 2011;6:29.

34. Zhu YM, Lu Y, Zhang J, Shen JW, Jiang CY. Arthroscopic Bankart repair combined with remplissage technique for the treatment of anterior shoulder instability with engaging Hill-Sachs lesion: a report of 49 cases with a minimum 2-year follow-up. *Am J Sports Med* 2011;39:1640-1647.

35. Parke CS, Yoo JH, Cho NS, Rhee YG. Arthroscopic remplissage for humeral defect in anterior shoulder instability: Is it needed? [abstract] 39th Annual Meeting of Japan Shoulder Society, 2012.

36. Yamamoto N, Itoi E, Abe H, 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;16:649-656.

37. Omori Y, Yamamoto N, Koishi H, et al. Measurement of the glenoid track in vivo as investigated by 3-dimensional motion analysis using open MRI. *Am J Sports Med* 2014;42:1290-1295.

38. Itoi E, Yamamoto N. Shoulder instability: treating bone loss. *Current Orthopaedic Practice* 2012;23:609-615.

39. Locher J, Wilken F, Beitzel K, et al. Hill-Sachs Off-track lesions as risk factor for recurrence of instability after arthroscopic Bankart repair. *Arthroscopy* 2016;32:1993-1999.

40. Shaha JS, Cook JB, Rowles DJ, et al. Clinical validation of the glenoid track concept in anterior glenohumeral instability. *J Bone Joint Surg [Am]* 2016;98:1918-1923.

41. Yamamoto N, Muraki T, An KN, et al. The stabilizing mechanism of the Latarjet procedure: a cadaveric study. *J Bone Joint Surg [Am]* 2013;95:1390-1397.

42. Neyton L, Young A, Dawidziak B, et al. Surgical treatment of anterior instability in rugby union players: clinical and radiographic results of the Latarjet-Patte procedure with minimum 5-year follow-up. *J Shoulder Elbow Surg* 2012;21:1721-1727.

43. Guity MR, Akhlaghpour S, Yousefian R. Determination of prevalence of glenoid bony lesions after recurrent anterior shoulder dislocation using the 3-D CT scan. *Med J Islam Repub Iran* 2014;28:20.

44. Nakagawa S, Ozaki R, Take Y, Mae T, Hayashida K. Bone fragment union and remodeling after arthroscopic bony Bankart repair for traumatic anterior shoulder instability with a glenoid defect: influence on postoperative recurrence of instability. *Am J Sports Med* 2015;43:1438-1447.

45. Sugaya H, Kon Y, Tsuchiya A. Arthroscopic repair of glenoid fractures using suture anchors. *Arthroscopy* 2005;21:635.

46. Kitayama S, Sugaya H, Takahashi N, et al. Clinical outcome and glenoid morphology after arthroscopic repair of chronic osseous Bankart lesions: a five to eight-year follow-up study. *J Bone Joint Surg [Am]* 2015;97:1833-1843.