



# Clinical and radiological examination of bony-mediated shoulder instability

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- The coexistence of glenoid and humeral head bone defects may increase the risk of recurrence of instability after soft tissue repair.
- Revealed factors in medical history such as male gender, younger age of dislocation, an increasing number of dislocations, contact sports, and manual work or epilepsy may increase the recurrence rate of instability.
- In physical examination, positive bony apprehension test, catching and crepitations in shoulder movement may suggest osseous deficiency.
- Anteroposterior and axial views allow for the detection of particular bony lesions in patients with recurrent anterior shoulder instability.
- Computed Tomography (CT) with multiplanar reconstruction (MPR) and various types of 3D rendering in 2D (quasi-3D-CT) and 3D (true-3D-CT) space allows not only detection of glenoid and humeral bone defects but most of all their quantification and relations (engaging/not-engaging and on-track/off-track) in the context of bipolar lesion.
- Magnetic resonance imaging (MRI) is increasingly developing and can provide an equally accurate measurement tool for bone assessment, avoiding radiation exposure for the patient.

**Keywords:** shoulder instability; glenoid track; glenoid bone loss; Hill–Sachs lesion

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## Introduction

The assessment of glenoid and humeral head bone defects is important in pre-operative decision making and

planning. The presence of anterior glenoid bone loss and/or Hill–Sachs lesion (HSL) is common and may increase the risk of recurrence of instability after primary arthroscopic Bankart repair. The literature that evaluates the relationship between the bony lesions and the recurrence of the shoulder instability reports rates from 4% to 67% in shoulders without and with significant bone defects, respectively.<sup>1</sup> Tauber et al showed that 57% of 41 patients were re-operated on the recurrence of instability due to anterior glenoid bone loss.<sup>2</sup> Both glenoid and humeral side defects, but also factors such as hyperlaxity, increased the risk of recurrence.<sup>3</sup> Balg and Boileau, in 2007, formulated the Instability Severity Index Score (ISIScore) and included both glenoid and humeral head defects as two of the main risk factors of recurrence, awarding each item two points. Remaining factors are age at the time of surgery (less than 20 years old), competitive sports participation, contact sports, shoulder hyperlaxity, humeral and glenoid side defects.<sup>4</sup> The presence of just a single bony deficit with a combination of any other factor affects the decision making, suggesting coracoid transfer to address the instability. Osseous deficits are quite frequent in patients operated on for anterior shoulder instability. Boileau found bony Bankart in 37% of cases and 13% in the cohort had an attritional glenoid defect.<sup>4</sup> Sugaya et al showed that 50% of the shoulders with recurrent instability had an bony Bankart lesion and up to 40% of the glenoids demonstrated abnormal glenoid rim.<sup>5</sup> Hill–Sachs lesions have been confirmed in 65% to 93% of instability patients. It has been agreed that it is also the size of the defect that matters for the planning. However, there is no agreement on the size of glenoid lesion that may increase the risk of failed Bankart repair. Itoi et al presented that the anterior glenoid defect, which comprises at least 21% of superior–inferior glenoid length, would increase the failure rating of a Bankart procedure and limit the range of

motion.<sup>6</sup> Burkhart et al revealed that glenoid bone loss amounting to 25% or more of glenoid diameter required bone grafting.<sup>7</sup> Nowadays, the meaning of percentage bone loss is controversial in the case of anterior glenoid defect and Hill–Sachs coexistence.

The purpose of this study is to review the current literature in the context of glenoid and humeral head bone loss in patients with chronic anterior shoulder instability. We have focused on both clinical and radiological evaluation of the patient. Obtaining an adequate patient history reveals factors that would be associated with a higher risk of the presence of a defect. However, it is the imaging and accurate assessment of the size and relations of bone defects that are crucial for further treatment.

## Clinical examination

Clinical examination alone may raise a high suspicion of glenohumeral bone deficiency.<sup>8</sup> Obtaining an adequate patient history reveals factors that would be associated with a higher risk of the presence of a defect. Milano et al found that male gender and an increasing number of dislocations resulted in an increased odds ratio of glenoid defect occurrence (4.29 and 1.18, respectively). The odds ratio of critical bone defect was 9.5 times with an increasing number of dislocations and also affected the size of the defect. Other risk factors included younger age at first dislocation, contact sports and manual work.<sup>9</sup> Other conditions such as epilepsy may increase the recurrence rate of instability (69% *versus* 10% for the non-epileptic group).<sup>10</sup>

Suspicion of a bony problem may also come from physical examination of the shoulder.

In 2008, Bushnell et al,<sup>11</sup> presented the concept of a bony apprehension test in patients with significant bone lesions in shoulder instability. The apprehension was examined at 45° abduction and 45° external rotation and correlated with pre-operative radiograph assessment of bone defects. In all cases in which the arthroscopic findings confirmed bone lesions (eight of 29), the bone apprehension test was positive (100% sensitivity) as well as in another three cases where only soft tissue lesions were found (specificity of 83%, positive predictive value 73% and negative predictive value 100%). Despite some limitations such as a small study group, the authors consider that the bony apprehension test can reliably screen patients with recurrent anterior shoulder instability. Other clinical signs, e.g. mechanical symptoms, have been reported, suggesting osseous deficiency: catching or crepitation on shoulder movements.<sup>12</sup>

## Imaging of glenohumeral joint

### Radiography

Radiography is an inexpensive, easy to perform and widely available imaging modality used for the evaluation of the

glenohumeral joint. Specific views allow detection of particular bony lesions in patients with recurrent anterior shoulder instability. Anteroposterior and axial views with various modifications have been described and both can detect humeral head and glenoid defects. Humeral head compression fracture localized on the posterolateral aspect, known as Hill–Sachs defect, was first described by Malgaign in 1855.<sup>13</sup> A full description and morphology publication were performed 85 years later by Harold A. Hill and Maurice D. Sachs.<sup>14</sup> It may be well visualized in the anterior-posterior (AP) view with the arm in adduction and internal or external rotation (Fig. 1).

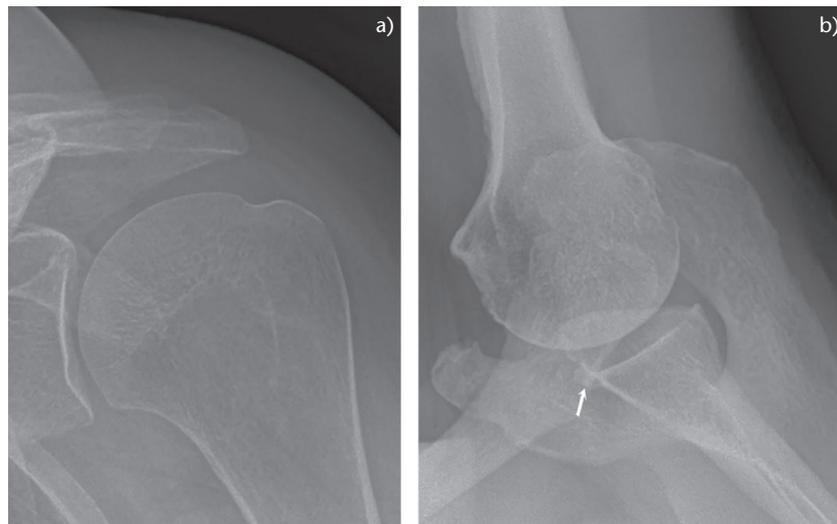
Glenoid morphology should be assessed in both the AP and axial views (Fig. 2). The AP view may show signs such as disruption of contour, anterior glenoid fracture or defect. Axial views may show osseous Bankart lesions, cliff sign or even blunted angle of anterior glenoid. In 1972, Rokous et al first described the West Point Axillary view for assessment of the anterior glenoid rim.<sup>15</sup> Some other views, such as the Bernageau view<sup>16</sup> or Stryker notch view,<sup>17</sup> were used in the diagnosis and evaluation of the Hill–Sachs defect and anterior glenoid rim.

Standard radiological evaluation has shown various levels of accuracy and diagnostic value for detection of osseous lesions. In 2003, Itoi et al presented that radiographic assessment of anterior glenoid bone loss is a good screening tool for patients after anterior shoulder dislocation. The West Point view shows the anteroinferior part of the glenoid and is consequently better than the axial view, which projects only the anterior glenoid rim.<sup>18</sup> The Instability Severity Index Score (ISIS) relies on the radiographic appearance of anterior glenoid bone loss (loss of anterior subchondral sclerotic rim, as seen in the AP view) and humeral head (Hill–Sachs visible in the AP view in maximal external rotation). The ISIS did not, however, consider the exact percentage of glenoid bone loss and was not correlated with either computed tomography (CT) or magnetic resonance (MR) scanning.<sup>4</sup> Nevertheless, it has been proven to be reliable in one multi-centre study with an excellent value at 0.933 of the Interclass Correlation Coefficient (ICC).<sup>19</sup> Compared to CT scans, the reliability was satisfying in glenoid bone loss of 15% or more. However, analysis of Hill–Sachs lesion was not consistent in the context of ISIS.<sup>20</sup> Assessment of anterior glenoid bone loss in the AP view was rated as moderately sensitive (56% to 64%) but highly specific (100%).<sup>21</sup> On the other hand, Bouliane et al showed the radiographic part of the ISIS failed to achieve a kappa score of 0.7 (mostly fair-to-moderate) for both an intra- and inter-rater reliability. The authors suggested using ISIS only with caution in preoperative planning.<sup>22</sup>

Edwards et al analysed 160 radiographs of shoulders in 156 patients with chronic anterior instability with the use of anteroposterior and Bernageau views. Glenoid bone



**Fig. 1** Radiography: shoulder in AP view with external (a) and internal (b) rotation.



**Fig. 2** Radiography: shoulder in AP view (a) and axial view (b), white arrow – displaced osseous fragment.

lesions diagnosed in the Bernageau view were found in 79% of radiographs and divided into three groups: fracture (41.3%), cliff sign (13.1%) and blunted angle (25%). Anteroposterior view with the arm in internal rotation was used to assess the presence of Hill–Sachs defect (73.1%) and fractures of the inferior glenoid rim (45.6%).<sup>23</sup>

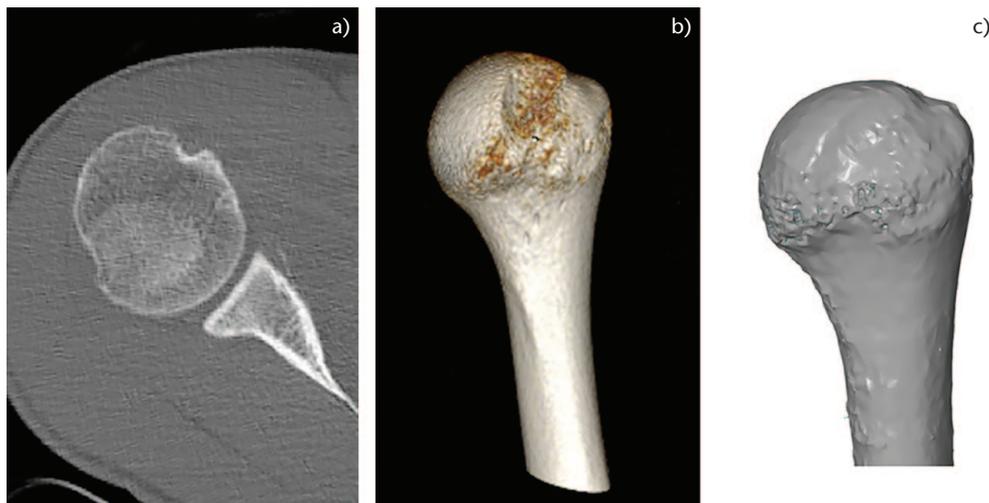
Rowe et al classified Hill–Sachs lesions based on their size in axillary view: mild (2 cm x 0.3cm), moderate (2–4 cm x 0.3–1 cm), and severe (4 cm > x > 1 cm).<sup>24</sup>

Sommaire et al proposed the Hill–Sachs measurement in AP view with internal rotation (D/R ratio; D – notch depth; R – radius of humeral head) and glenoid bone loss assessment in the Bernageau view (D1/D2; D1– glenoid surface diameter of affected shoulder, D2 – glenoid

surface diameter of healthy shoulder). These parameters were compared with the recurrence rate (15.6%) after arthroscopic Bankart repair. The authors showed that the risk of recurrence was significantly greater when the D/R ratio was higher or equal to 20%.<sup>25</sup>

#### *Computed tomography (CT)*

CT ensures high resolution, allowing for multiplanar and 3D reconstruction with good quality. For this reason, CT is now a gold standard in the assessment of bone lesions in patients with chronic anterior shoulder instability.<sup>26</sup> The method allows not only for detection of the lesions but more importantly for their quantification. One major disadvantage of a CT scan, however, is the radiation



**Fig. 3** (a) 2D-CT with multiplanar reconstruction (2D-CT-MPR); (b) quasi-3D-CT; (c) true-3D-CT.

exposure for the patient, and this may be a limitation in case of the need for repeated examinations.<sup>27</sup>

Bishop et al showed that CT is more reliable in the assessment of glenoid bone loss than magnetic resonance imaging (MRI) or radiography. Moreover, 3D-CT was the most reliable but achieved only a moderate kappa value.<sup>28</sup> Kubicka et al compared 2D and 3D-CT in the assessment of glenoid bone loss and showed that 3D-CT reliability was nearly perfect in all measurements, even if performed by an inexperienced observer.<sup>29</sup> Stefaniak et al performed a similar study and proved that 3D-CT is also more reliable in humeral head and Hill–Sachs lesion evaluation with excellent values of ICC and the Minimal Detectable Change with 95% confidence ( $MDC_{95}$ ).<sup>30</sup>

#### *2D-CT, quasi-3D-CT and true-3D-CT*

The term 3D-CT reconstruction may sometimes be misleading and has been erroneously used in papers since not all measurements are in fact done as 3D.<sup>29,31,32</sup> In true-3D-CT, measurements are set on a 3D model that can be freely rotated during the measuring process (Fig. 3c).<sup>29</sup> In this way, we minimize the error that arises during the incorrect or imprecise evaluation of the bone contour in a 2D image. This technique allows for full control in the space and highly accurate measurements.

Another method, quasi-3D is a 2D measurement based on a picture acquired from 3D reconstruction (measurements are not performed in 3D space) (Fig. 3b). Many authors use 3D reconstruction to make a 2D picture of the measuring object, for example an ‘en face’ glenoid view. In this case, we cannot rotate the object during measuring process and the risk of making a mistake can occur due to indistinct bone contour.

Another option is 2D-CT with multiplanar reconstruction (MPR) (Fig. 3a) in which we can set the 2D section of

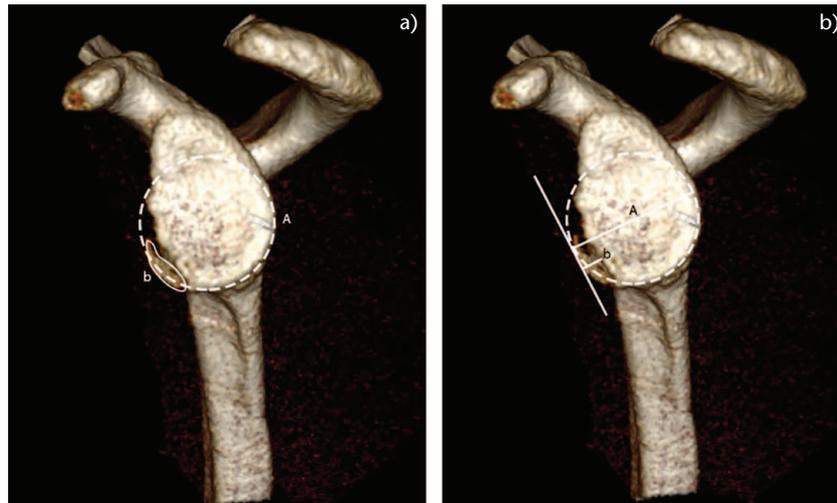
the measured object in frontal, sagittal and transverse planes.

A proper understanding of the methods used for measurement is crucial for comparative analyses. The authors urge clear definition of the measurement methods used in the studies and use of the proper nomenclature in order to avoid misunderstandings.

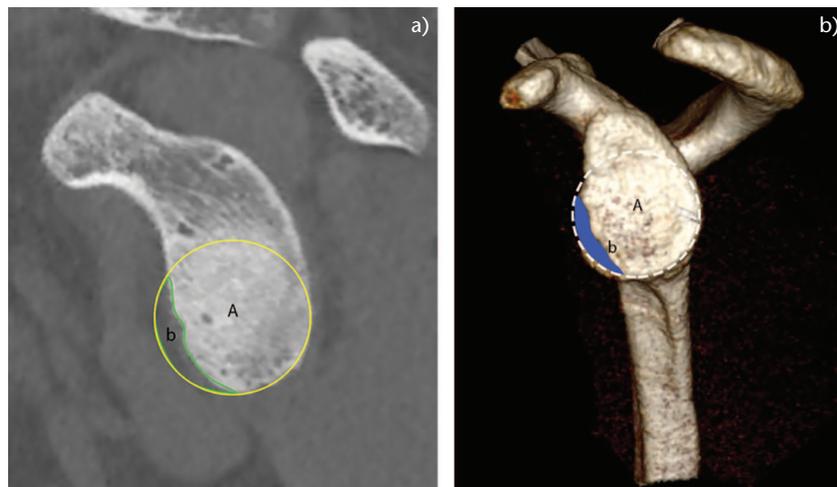
#### *Glenoid evaluation*

Glenoid bone defects in patients with recurrent anterior shoulder instability usually occur on the anterior glenoid rim between 2:30 and 4:20 on the clock face for the right glenoid. Saito et al found mean orientation of the defect at 3:01 o’clock, which is the direction with the least stability ratio<sup>33</sup>. Regarding the 38° anterior tilt of the glenoid in the sagittal plane relative to the trunk, the defect is oriented towards 4:17 in reference to the trunk. The measurements were performed on quasi-3D-CT.<sup>32</sup> Burkhart et al described the term ‘inverted pear-glenoid’ as the result of a large anterior glenoid bone defect that changes the shape of the glenoid from normal pear-shaped to inverted.<sup>1</sup> Moreover, Burkhart et al first proposed the term ‘bare spot’ as a central reference point to assess the percentage loss of anterior glenoid rim. The spot was evaluated arthroscopically as the centre of a circle that was defined by the margin of the postero-inferior glenoid contour.<sup>7</sup> The reliability of the bare spot as a central reference point of the glenoid has been questioned. Saintmard et al identified the bare spot in less than 48% of cases during arthroscopy and in only 26% with CT arthrography<sup>34</sup>. Two cadaveric studies assessed bare spot measurements and showed that the bare spot was eccentric in most of the cases, making it an unreliable landmark in glenoid assessment.<sup>35,36</sup>

Surface measurement of the glenoid is probably the most popular method in clinical use and planning. The



**Fig. 4** Best-fit circle method presented by Sugaya et al ( $b/A \times 100\%$ ); (a) A – area of best-fit circle; b – area of displaced osseous fragment; (b) A – diameter of best-fit circle; b – bone defect width.



**Fig. 5** Pico method developed by Baudi et al ( $b/A \times 100\%$ ; b – area of defect; A – area of best-fit circle (of the contralateral glenoid) on 2D-CT with multiplanar reconstruction (MPR) (a) and quasi-3D-CT (5b).

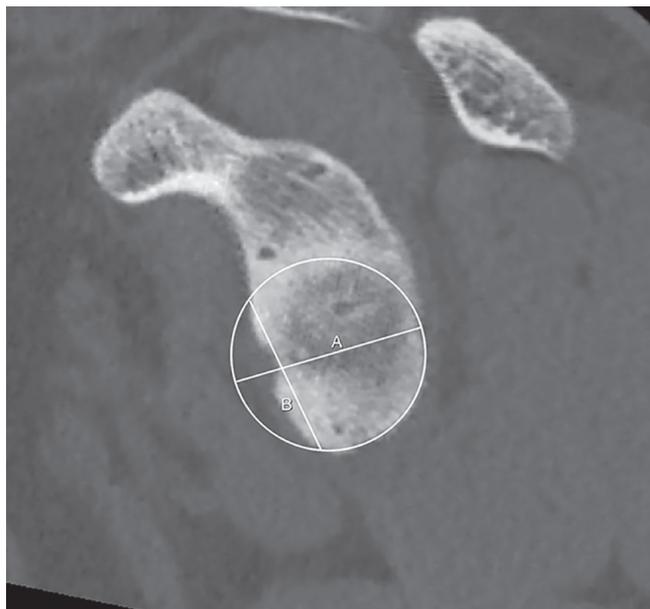
idea of a best-fit circle was developed by Sugaya et al on 3D-CT (quasi-3D-CT) to assess the percentage value of anterior glenoid bone loss. The area of the displaced osseous fragment was calculated as a percentage of the area of the best-fitting circle (Fig. 4a)<sup>5</sup> and in the other study, bone defect width calculated as a percentage of the diameter of the best-fitting circle (Fig. 4b).<sup>35</sup> Huysmans et al showed on a cadaveric study good inter- and intra-observer reliability of the Sugaya method.<sup>36</sup>

Baudi et al developed the Pico method (named in honour of Pico della Mirandola, the Italian philosopher), which is based on calculating the size of the defect in the affected shoulder as a percentage of the best-fit circle area of the contralateral glenoid on 2D-CT with MPR reconstruction

(Fig. 5).<sup>37</sup> Evaluation of this method showed very good intra- and inter-observer reliability.<sup>38</sup>

$$Pico = \frac{\text{area of defect}}{\text{area of best fit circle}} * 100\%$$

Linear indices have also been used for the quantification of glenoid deficiency. Gerber's X index, presented in 2002 by Gerber and Nyffeler, showed the ratio of anterior glenoid bone defect length to maximum AP glenoid diameter.<sup>39</sup> This measurement method was assessed as simple and reproducible in daily practice<sup>25</sup> as well as being a reliable measuring method with the use of 2D-CT-MPR (Fig. 6).<sup>40</sup> The Glenoid index similarly proposed by Griffith



**Fig. 6** Gerber's index; A – diameter of best-fit circle; B – anterior glenoid bone defect length.

et al<sup>41</sup> and Chuang et al,<sup>42</sup> is described as the ratio of the width of the injured glenoid to the width of the glenoid without bone defect. The measurements were presented on 2D-CT-MPR (Fig. 7) and quasi-3D-CT respectively and the authors proved that this CT measurement method has high sensitivity and specificity for detecting glenoid bone defects in comparison with arthroscopy.<sup>43</sup> Charousset et al found that the Griffith index showed good and excellent inter- and intra-observer reliability (ICC > 0.9).<sup>20</sup> Moreover, Griffith et al proved that parameters such as:

maximum glenoid length (width-to-length ratio), glenoid cross-sectional area or the largest axial glenoid width were not useful for glenoid bone loss assessment.<sup>41</sup>

$$\text{Gerber's } \times \text{ index} = \frac{\text{anterior glenoid bone defect length}}{\text{diameter of best fit circle}} * 100\%$$

$$\text{Glenoid index} = \frac{\text{diameter of affected glenoid}}{\text{diameter of intact glenoid}} * 100\%$$

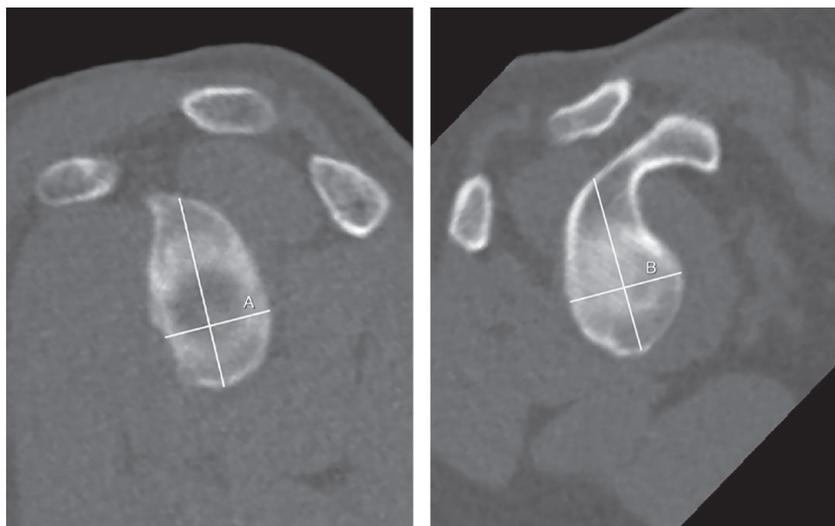
Barchilon et al presented an alternative method of assessment of the anterior glenoid rim with the use of the ratio between the depth from the centre of the best-fit circle to the edge of the glenoid defect and the radius of best-fit circle.<sup>44</sup> All measurements were performed on 3D-CT (t3D) (Fig. 8).

$$\text{Barchillon ratio} = \frac{\text{depth from the centre of the circle}}{\text{radius of the circle}}$$

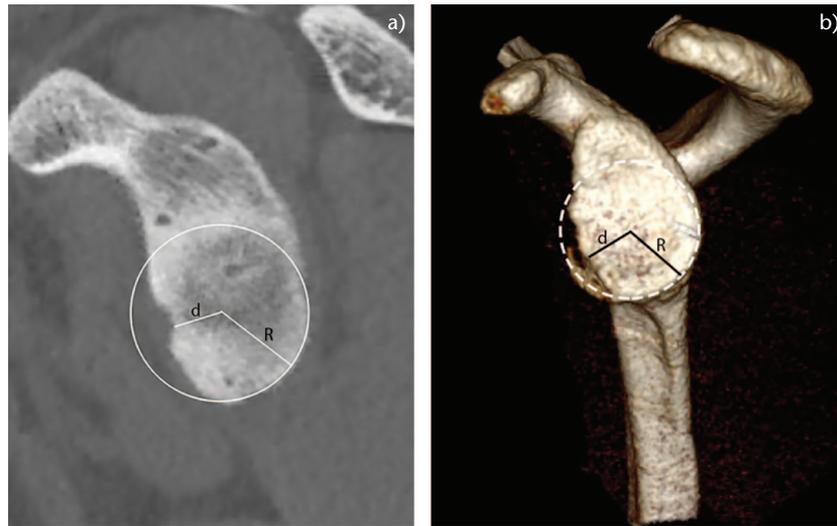
#### Humeral head evaluation

Humeral measurement focuses on evaluation of the Hill–Sachs defect. The most common measurements include length, width, depth, volume, surface area, angle and location or orientation (Fig. 9).

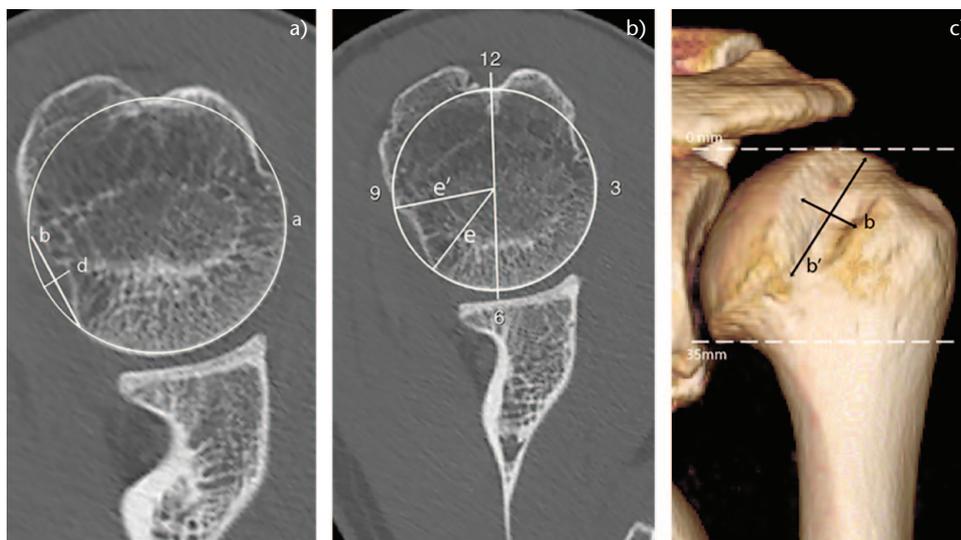
Saito et al showed that the orientation of the Hill–Sachs defect usually occurs between 6:46 and 8:56 on the clock face on the right humeral head. The mean orientation was 7:58 with the intertubercular groove at 12 o'clock. To estimate the anterior and posterior margins of the defect, the



**Fig. 7** Glenoid index (A/Bx100%) A – diameter of injured glenoid; B –diameter of intact (contralateral) glenoid; (2D-CT-MPR).



**Fig. 8** Barchillon et al.; d/R d – depth from the centre of the best-fit circle to the edge of the glenoid; R – radius of best-fit circle on 2D-CT-MPR (a) and quasi-3D-CT (b).



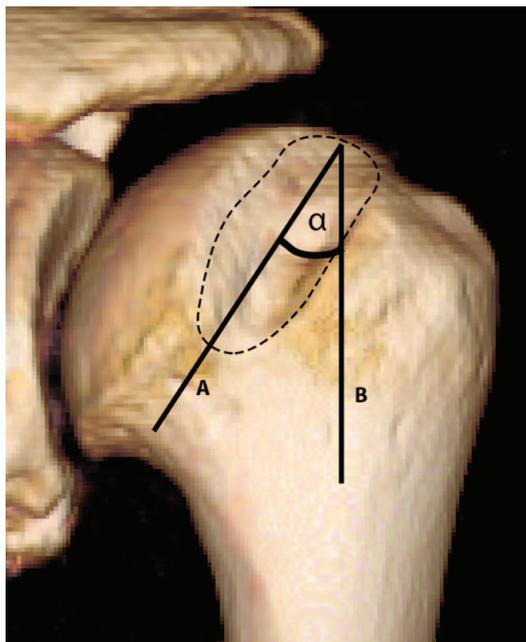
**Fig. 9** Humeral head measurements of Hill–Sachs lesion (HSL); (a) a – best-fit circle, d – HSL depth, b – HSL width; (b) HSL orientation, the clock face, e, e' – medial and lateral margins of HSL; (c) HSL location, b – HSL width, b' – HSL length.

authors used a circle that best-fitted the humeral head surface. In vertical orientation, Hill–Sachs occurred between 0 mm and 24 mm from the top of the humeral head, whereas the bare area existed below 19 mm. Authors showed how to estimate the locations of the Hill–Sachs lesion and the bare area that overlapped with each other. In other words, if Hill–Sachs lesion extends below 19 mm from the top of the humeral head, it overlaps the bare area (Fig. 9c). The measurements were performed with the use of 2D-CT-MPR.<sup>45</sup>

Kodali et al found that Hill–Sachs measurements can be reliably evaluated using a CT scan. Measurements in the

sagittal and axial views were more accurate than in the coronal view.<sup>46</sup>

Cho et al<sup>47</sup> assessed the orientation and location of the HSL with the use of the Hill–Sachs angle and bicipital and vertical angles, respectively. The Hill–Sachs angle was determined by two lines: the longitudinal axis of the humeral shaft and the axis of the deepest groove of the Hill–Sachs drawn in anteroposterior view on 3D-CT (quasi-3D-CT) (Fig. 10). To estimate the location, the bicipital angle was calculated in the axial view of 2D-CT-MPR, between the line connecting the best-fit circle centre with the bicipital groove and a line drawn from the best-fit



**Fig. 10** Hill–Sachs angle; A – axis of the deepest groove of the Hill–Sachs; B- longitudinal axis of humeral shaft.

circle to the centre of the Hill–Sachs lesion. The vertical angle was estimated in the coronal view of 2D-CT–MPR, between the centre vertical line of the humeral head and the line drawn from the centre of the HSL to the centre of the best-fit circle.

*Bipolar evaluation of glenoid and humeral defects in CT*

Recently, research focused not only on the size of a single defect but also on the interplay of both the anterior glenoid defect and HSL. Therefore, the terms engaging *versus* non-engaging or on-track *versus* off-track lesions have been introduced.

*Engaging defects.* Burkhart et al first presented the term ‘engaging’ Hill–Sachs, which means that the size and position of the Hill–Sachs cause its engagement with the anterior rim of the inverted pear glenoid in the athletic arm position (90° of abduction and 0–135° of external rotation).<sup>1</sup> They found that engaging defects had the worst prognosis when treated by arthroscopic labral stabilization.<sup>1</sup> On the other hand, different authors concluded that all defects have to engage so that the dislocation can occur, implying that the pathology may be over-diagnosed. Kurokawa et al introduced the term ‘true engaging HSL’, as one that occurs during arthroscopic examination even after Bankart repair, or when the HSL extends over the glenoid track.<sup>48</sup> The authors showed that the width and depth of the engaging Hill–Sachs were significantly

larger and located more horizontal to the humeral head shaft than non-engaging lesions.<sup>47</sup> Kurokawa et al proposed two types of engaging Hill–Sachs: wide and large and the second, narrow but medially located. In an analysis of 200 CT scans of 100 patients with unilateral shoulder instability, the engaging Hill–Sachs was found in 7% of patients (2D-CT–MPR and 2D-3D–CT).<sup>48</sup>

*Glenoid track – on-track/off-track evaluation.* Yamamoto et al presented the concept of glenoid track, which is a zone of contact between the glenoid and the articular surface of the humeral head based on a cadaver model. The width of the glenoid track was found to account for 84% of glenoid width. In the case of bone loss in the anterior glenoid rim, the glenoid track width decreases accordingly. Results were compared with 3D-CT measurements (t3D-CT) and this proved to be the same path of glenoid shift.<sup>49</sup> The calculation was clarified by Omori et al, who proposed a glenoid track width equal to 83% of glenoid width. The authors justified this with a younger group of patients with a greater range of motion in vivo than the cadaveric specimens used in the previous study.<sup>50</sup>

The concept of ‘engaging and non-engaging’ Hill–Sachs lesions was adopted by Di Giacomo et al as ‘on-track and off-track’ lesions<sup>51</sup>. In on-track lesions, HSL falls within the margins of the glenoid track, whereas in off-track, Hill–Sachs extends its medial margin beyond the track. Assessment of the on-track/off-track status of HSL may be performed during an arthroscopic procedure and based on analysis of 3D-CT (quasi-3D-CT):

1. The glenoid bone loss is evaluated in an ‘en face’ view of the glenoid (Fig. 11b).
2. The value of the glenoid track of an intact glenoid (GTint) is calculated with the use of the contralateral shoulder as a reference. The authors did not propose a way of evaluation in case of bilateral bone loss.<sup>51</sup>

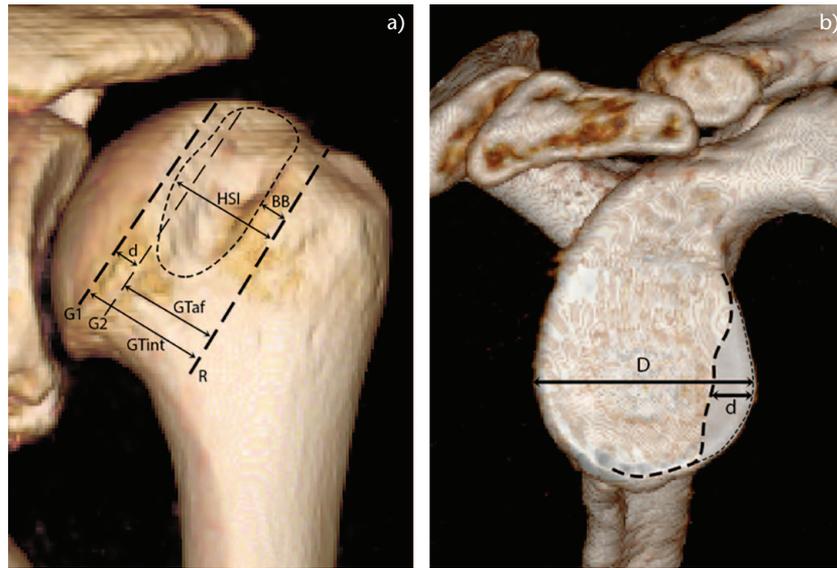
The width of the glenoid track is 83% of the width of the intact (contralateral) glenoid (D).

$$GT_{int} = 83\% * D$$

3. To calculate the glenoid track width of the affected glenoid (GTaf), the width of the defect (d) is subtracted from the glenoid track width of the intact glenoid.

$$GT_{af} = 83\% * D - d$$

4. The assessment of on-track/off-track is performed on a posterior view of the humeral head with the



**Fig. 11** On-track/off-track measurements; (a) R-line of medial margin of rotator cuff attachments; G2 – line of medial margin of glenoid track of affected shoulder; G1 – line of medial margin of glenoid track of intact shoulder; HIS – Hill–Sachs Interval; BB – bone bridge; d – width of anterior glenoid bone defect; GTaf – width of glenoid track of affected shoulder; GTint – width of glenoid track of intact shoulder; (b) D – width of intact glenoid; d – width of glenoid bone defect.

**Table 1.** Surgical treatment paradigm as suggested by Di Giacomo et al<sup>51</sup>

	On-track HSL	Off-track HSL
< 25% glenoid bone loss	Arthroscopic Bankart repair	Arthroscopic Bankart repair + HSL remplissage
≥ 25% glenoid bone loss	Latarjet procedure	Latarjet procedure + humeral-sided procedure (bone graft or remplissage)

use of two lines. The distance between the lines is the width of the glenoid track in this case (GTaf):

- a. line of the medial margin of rotator cuff attachments (R)
  - b. line that indicates the medial margin of the glenoid track of the affected shoulder (G2)
5. If the medial margin line of HSL extends beyond the glenoid track (L2), it is called ‘off-track’, otherwise, it is ‘on-track’ if it lies between the lines.

All measurements are presented in Fig. 11.

Di Giacomo et al categorized patients based on glenoid defect size and HSL engagement: 1st group, < 25% glenoid defect with on-track H-S; 2nd group, < 25% glenoid defect with off-track H-S; 3rd group, ≥ 25% glenoid lesion with on-track H-S and 4th group, ≥ 25% glenoid bone loss with off-track. Using these categories, the authors determined a surgical treatment paradigm useful in surgical planning (Table 1.).<sup>51</sup>

Yamamoto et al showed that patients with on-track lesions but with 75% or more of Hill – Sachs occupancy had a significantly worse Western Ontario Shoulder

Instability Index (WOSI) score. The Hill–Sachs occupancy was evaluated on 3D-CT and defined as Hill – Sachs interval/glenoid track width x 100% (HSL interval – distance from the medial margin of the rotator cuff attachments to the medial margin of the HSL).<sup>52</sup>

Schneider et al assessed the intra- and inter-observer reliability of glenoid track measurements on 3D-CT (2D-3D-CT). The evaluation of glenoid bone loss had good inter- and intra-observer agreement (in 90% and 94% to 96% of cases, respectively). However, measurement showed poorer inter-observer reliability for on-track/off-track classification (72%) and moderate inter-observer reliability regarding treatment classification (65%). The authors concluded that glenoid assessment is reliable and reproducible, but Hill–Sachs evaluation had a high level of variability and only moderate agreement between observers.<sup>53</sup> Stefaniak et al assessed 45 patients after failed arthroscopic Bankart repair in the context of on-track/off-track assessment. Glenoid track evaluation showed 38 patients (85%) with ‘off-track’ Hill–Sachs lesion but seven patients (15%) with ‘on-track’ lesions. The authors showed that the on-track/off-track concept was unable to

fully predict instability recurrence following isolated Bankart repair, especially in patients with less glenoid bone loss.<sup>54</sup> In 2020, Di Giacomo proposed the modification of the ISIScore with the use of on-track/off-track assessment. In the Glenoid Track Instability Management Score (GTIMS), ‘off-track’ Hill–Sachs is awarded four points, while on-track is not awarded any points at all, regardless of the size of glenoid bone loss and Hill–Sachs lesion. The authors showed the significant differences in distribution of indications following treatment, based on ISIS *versus* GTIMS.<sup>55</sup>

### Magnetic resonance imaging

MRI is widely used in the assessment of shoulder pathology. MRI has several advantages. First of all:

- it does not expose the patient to any radiation, thus allowing safer repeated examinations when necessary;
- it is the most useful modality for soft tissue evaluation and assessment of many comorbidities. It has been shown to be highly accurate for evaluation of labral tears<sup>56</sup> and cartilage lesions, especially when enhanced with arthrography.

However:

- it is much more expensive;
- it is less available;
- it takes longer to acquire and depends on technical quality;
- it is not available for every patient (claustrophobia, pacemaker, some implants);
- most of all, standard MRI has been less accurate for bone assessment in comparison to CT.<sup>57</sup>

Interestingly, more recent advancements have brought significant improvement in this area. Stillwater et al demonstrated the high accuracy of 3D-MRI (isotropic VIBE sequence), which is equivalent to 3D-CT (2D-3D-CT). The measurements of glenoid and Hill–Sachs bone loss, for example, the height and width of the humeral head and glenoid and percentage of glenoid and humeral head bone loss were compared and showed that differences were not statistically significant.<sup>58</sup>

Yanke et al compared the 3D-MRI (quasi-3D-MRI, not in 3D space) (1,5 and 3 teslas) with quasi-3D-CT in cadaveric models. The authors showed that 3D-MRI measurements correlate with CT and provide a reproducible method in the evaluation of anterior glenoid bone defects.<sup>59</sup> Fernandes de Mello et al showed similar results in glenoid assessment between 3D Zero Echo Times (ZTE) MRI and 3D-CT. However, similar to other studies, the authors compared quasi-3D-MRI with quasi-3D-CT (not in 3D

space).<sup>60</sup> ZTE MRI provides similar images to CT contrast for bone and better visualization of osseous features when compared with standard MRI.<sup>61</sup>

Metzger et al compared the glenohumeral engagement on a magnetic resonance arthrogram with multiplanar reconstruction (MRA–MPR) with clinical evaluation during shoulder arthroscopy. The mean bone loss was 7.6% and 84.5% of patients with off-track lesion showing clinical evidence of engagement too. The authors assessed that pre-operative glenohumeral measurements on MRA–MPR can be used effectively to predict the risk of engagement.<sup>62</sup>

Other results seem to support the evidence that MRI may be a reliable measure and could be used in the assessment of glenoid bone loss<sup>63</sup> and the existence of glenoid track,<sup>50</sup> nearly to a standard identical to CT.

## Conclusions

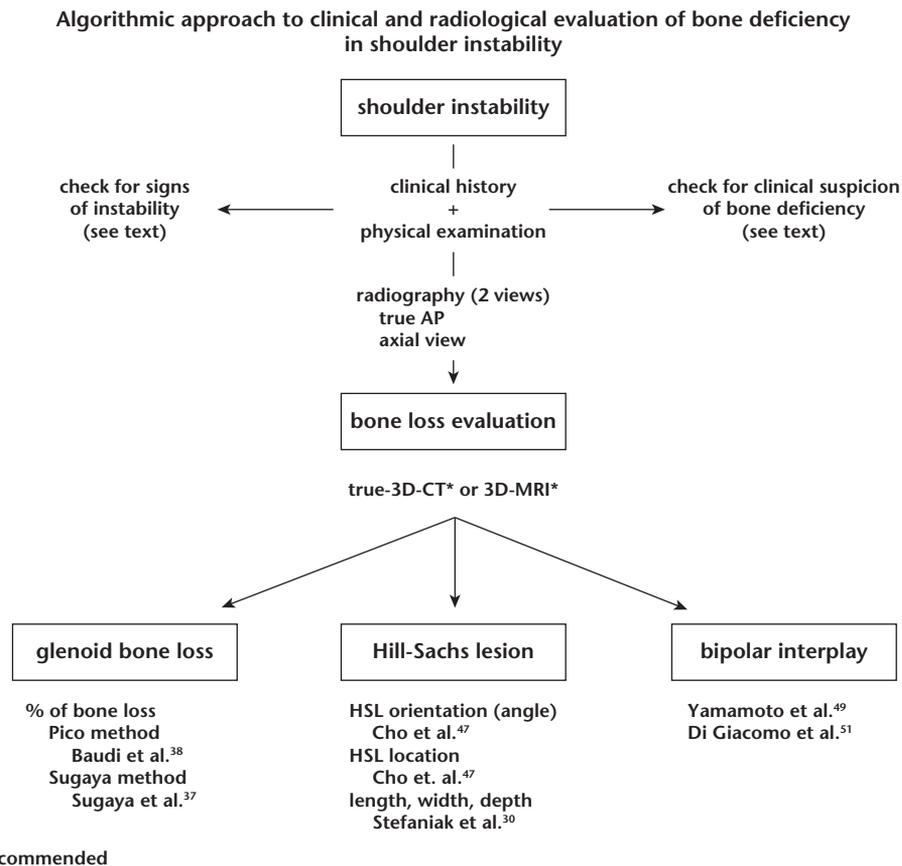
Glenoid and glenohumeral defects commonly exist in anterior shoulder instability and affect clinical results. This means every orthopaedic surgeon has to have the ability to both diagnose them and, in the case of surgical planning, also measure them. Clinical examination may raise suspicion of their presence based mostly on the identification of risk factors from the patient history. Diagnostic algorithm should start with precise clinical examination.

Basic radiography with at least two views (true AP with the arm in internal or external rotation and axial view) is helpful in the identification of osseous lesions and is required to exclude other pathologies such as fractures or humeral head dislocation.

CT, especially with true 3D reconstruction, seems to be the golden standard for identification and quantification of bony lesions of the glenoid and humeral head. It is also useful in the assessment of on-track or off-track relations between a Hill–Sachs lesion and an anterior glenoid bone defect.

The use of MR in the evaluation of glenoid and humeral head bone defects is developing increasingly and can provide an equally accurate measurement tool for bone assessment while avoiding excessive radiation exposure for the patient.

Finally, the authors propose the diagnostic algorithm for bony-mediated shoulder instability. Evaluation should start with clinical examination and basic radiography with at least two views: true AP and an axial view. For more accurate evaluation in pre-operative surgical planning, ‘true’ 3D CT is recommended. 3D reconstruction with the use of MR is also applicable, but high-resolution and good-quality images may be required for proper bone evaluation (Fig. 12).



**Fig. 12** Algorithmic approach to clinical and radiological evaluation of bone deficiency in shoulder instability.

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PL reports board membership of the Rehasport Clinic, employment by Rehasport Clinic, University of Medical Sciences, payment for lectures including service on speakers' bureaus from Smith&Nephew and Arthrex, payment for development of educational presentations from Smith&Nephew and is an Associate Editor of *EFORT Open Reviews*, all outside the submitted work.

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