



# Bipolar bone loss and distance to dislocation

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**Abstract:** Studies have shown that glenoid- and humeral-sided bone loss may be present in up to 73–93% of individuals with recurrent anterior shoulder instability. As such, bone loss must be addressed appropriately, as the amount of bone loss drives surgical decision making and influences outcomes. Methods to describe and measure bone loss have changed over time. Originally, glenoid and humeral bone loss were viewed separately. However, the concepts of bipolar bone loss, the glenoid track (GT), and “on/off-track” lesions arose, highlighting the interplay between the two entities in contributing to recurrent instability. Classically, “off-track” lesions have been described as those Hill-Sachs interval (HSI) greater than the GT, and have been shown to result in higher rates of re-instability when addressed nonoperatively or with Bankart repair alone. More recently, further attention has been given to “on-track” lesions (HSI < GT). The new concept of “distance to dislocation” (DTD) has gained popularity. DTD is calculated as the difference between the GT and HSI, and literature evaluating DTD suggests that not all “on-track” lesions should be treated in the same manner. The purpose of this concept review article is twofold: (I) describe glenoid, humeral, and bipolar bone loss in the setting of anterior shoulder instability; and (II) elaborate on the new concept of “DTD” and its use in guidance of management.

**Keywords:** Anterior shoulder instability; glenoid bone loss; Hill-Sachs lesion; bipolar bone loss; “distance to dislocation” (DTD)

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## Introduction

As the glenohumeral joint is the most commonly dislocated joint in the human body, anterior shoulder instability is a familiar orthopedic problem, particularly affecting young, hyper-lax contact athletes and military personnel at a rate as high as 3% per year (1-4). Research has shown that a single dislocation decreases the force needed for subsequent dislocations and increases the risk of future instability episodes (5,6). Repeated dislocations often result in glenoid- and humeral-sided bone loss in the forms of bony Bankart and Hill-Sachs lesions, respectively. This bone loss perpetuates further instability and potential failure after

initial stabilization (2,5,7). Studies have shown that glenoid- and humeral-sided bone loss may be present in up to 73–93% of individuals with recurrent instability. As such, it must be addressed appropriately, as the amount of bone loss drives surgical decision making and influences outcomes (8-11). Methods to describe and measure bone loss have changed over time. Originally, glenoid and humeral bone loss were viewed separately. However, the concepts of bipolar bone loss, the glenoid track (GT), and “on/off-track” lesions arose, highlighting the interplay between the two entities in contributing to recurrent instability (12-15). More recently, further attention has been given to “on-track” lesions. The new concept of “distance to dislocation”

(DTD) has gained popularity and suggests that not all “on-track” lesions should be treated in the same manner (16).

Whether bone loss is glenoid-sided, humeral-sided, or bipolar, the assessment of bone loss plays a crucial role in the treatment of anterior shoulder instability. Meticulous review of the current available literature was assessed, and the purpose of this article is twofold: (I) describe glenoid, humeral, and bipolar bone loss in the setting of anterior shoulder instability; and (II) elaborate on the new concept of “DTD” and its use in guidance of management.

## Bone loss in shoulder instability

### *Glenoid bone loss*

Successful treatment of both primary and recurrent anterior shoulder instability requires careful consideration of glenoid bone loss, as failure to address underlying bony deficiency confers an increased risk of recurrent instability (17). Treatment algorithms for glenoid bone loss focus on defining “critical” versus “subcritical” thresholds, although the precise definitions of each remain debated (18). While critical anterior bone loss is typically defined as 20–25% of the glenoid diameter (19), studies have found increased failure rates with capsulolabral repair in patients with as little as 13.5% glenoid bone loss (18). Thus, thorough preoperative planning with accurate image-based measurements is critical in the management of patients with glenohumeral instability and underlying glenoid bone loss.

### Assessment of glenoid bone loss

Following a thorough history and physical examination, imaging evaluation of the patient with suspected glenoid bone loss should begin with dedicated shoulder radiographs. A standard series includes anteroposterior (AP), true AP or Grashey, scapular Y, and axillary lateral views. AP views may demonstrate coronal plane translation of the humeral head as well as loss of the sclerotic margin of the anterior glenoid, while the axillary view can reveal axial subluxation and anterior glenoid deficiency (20). Glenoid bone loss is best elicited radiographically with a West Point view, a modification of the axillary lateral (21). However, as the sensitivity of such projections is limited, advanced imaging is recommended for further evaluation and preoperative planning (22).

Computed tomography (CT) scans enable more complete evaluation of osseous anatomy in acute injury and chronic bone loss. Characterization of anterior glenoid rim fractures (“bony Bankart” lesions) is important, as attritional

bone loss may develop if such injuries are not appropriately addressed, increasing the size of the glenoid defect (23). In chronic bone loss, CT scan is indicated to determine the size and location of osseous deficiency. Multiple measurement techniques exist, including linear and area-based measurements.

Most area-based, as well as some linear-based, techniques employ a best-fit circle to measure glenoid bone loss. Two types of glenoid best-fit circle have been described: the “inner circle” (24) and the “outer circle” (25). The inner circle is defined as a circle fitting the inferior glenoid face, while the outer circle is defined as a circle connecting the most superior and inferior portions of the glenoid. While the inner, or inferior, circle is more commonly used, in the setting of glenoid bone loss the outer circle method may be technically easier and more reproducible. A recent study noted a high correlation between the inner and outer circle measurements, with a ratio of 0.74 (26). Although future studies are needed to confirm the validity of this ratio, it may serve as a useful technique to mitigate variations in measurement attributable to the presence of bone loss.

Popular area-based techniques for measuring glenoid bone loss, such as the “Pico” (27) and Sugaya (24) methods, typically derive from inner circle measurements. In the Pico method described by Baudi *et al.*, a sagittal two-dimensional (2D) CT image is selected, providing an *en face* view of the glenoid. A circle of best fit is placed along the posteroinferior curvature of the contralateral (uninjured) glenoid, and its area measured. The circle is then superimposed on the injured side. The area of bone loss anteriorly is measured and digitally subtracted from the overall area, giving a percentage area of deficiency. In the presence of a bony Bankart lesion, the best fit circle is drawn on the injured side, while the area of the bony fragment is similarly measured and subtracted to determine the degree of deficiency (27). The Sugaya method is comparable yet uses a sagittal three-dimensional (3D) CT image. The circle of best fit is drawn based on the inferior portion of the glenoid from the 3 o'clock to 9 o'clock positions, while the size of the osseous fragment or defect is calculated using CT-based software. The area of the defect is then divided by the area of the best fit circle, yielding the percentage of bone loss (24).

Numerous linear-based measurements have also been described (28–31). Griffith *et al.* described the “Griffith Index”, which involves drawing a line from the supraglenoid tubercle to the infraglenoid tubercle on the uninjured side (line B), followed by a perpendicular line spanning the widest portion of the glenoid (line A). This is repeated on

the injured side, and the ratio of B/A is compared between the two. A ratio of 0.7 is considered normal, while a smaller ratio is noted on the injured side (28). However, while this technique enables easy and reliable identification of anterior glenoid bone loss, its utility in guiding prognosis and treatment is limited (32). A more recent and commonly performed linear-based measurement was described by Sugaya (31). A circle of best fit is drawn on the injured glenoid, and the diameter measured. The maximum width of the anterior defect is then measured and divided by the diameter to yield a percentage of bone loss (31). Finally, the “AP distance to the bare area” method uses the center of an inferiorly based circle of best fit as its primary landmark. The horizontal distances from the center of the glenoid to the anterior edge (A) and the posterior edge (B) are measured, and bone loss is calculated according to the formula:  $(B - A)/2B \times 100\%$  (30). While linear-based measurements are advantageous in their convenience and reproducibility, recent studies have demonstrated that such measurements may overestimate glenoid bone loss by as much as 7% compared to area-based and arthroscopic measurements (33,34). Furthermore, maximum error is present when theorized bone loss is 20%, a commonly accepted threshold for critical bone loss, with subsequent implications for treatment (33). For these reasons, the authors prefer the use of area-based measurements such as the Pico method when calculating anterior glenoid bone loss.

When comparing 2D versus 3D CT, studies indicate that 3D CT provides more reproducible measurements than 2D with the use of a standardized *en face* view (32,35). Furthermore, 2D CT is highly dependent on formatting of cuts in the plane of the body versus the scapula, which may lead to under- or overestimation of glenoid bone loss based on the level of the cut (36). Thus, when available, 3D CT is the preferred modality for calculating glenoid bone loss. The relationship between CT and magnetic resonance imaging (MRI) is less well-defined. CT is widely considered the “gold standard” imaging modality due to superior bony resolution and availability (32), yet recent studies suggest that 2D and 3D MRI is equivalent to 3D CT in evaluating bone loss (37-40). Thus, when determining the optimal study, the risk of ionizing radiation characteristic of CT must be weighed against the cost and limited availability of MRI (2D or 3D). It is also important to note that MRI is useful in evaluating for soft tissue or chondral injuries that may occur concomitantly with glenohumeral dislocation, including rotator cuff tears, humeral avulsions

of the glenohumeral ligament (HAGL) lesions, or glenoid articular cartilage defects (20).

### Defining glenoid bone loss

While surgery is often indicated in patients with glenohumeral instability and associated bone loss, treatment is guided by the degree and pattern of bony deficiency. However, determining clinically significant thresholds of glenoid bone loss remains difficult due to a lack of consensus throughout the literature. In general, treatment algorithms for glenoid bone loss focus on defining “critical” versus “subcritical” limits of bony deficiency, both of which will be discussed.

### Critical bone loss

One of the earliest descriptions of “critical” bone loss was by Itoi *et al.* in 2000 (25). In a cadaveric study, the authors demonstrated that an anterior osseous defect with a width measuring at least 21% of the glenoid length was associated with instability and limitations in range of motion following isolated Bankart repair (25). This work was expanded upon by Lo *et al.*, who found the presence of 25–27% bone loss to produce an inverted pear glenoid, and correlated this morphology with the need for a bony augmentation procedure (19). Since that time, glenoid bone loss >20–25% has consistently been defined as critical, as numerous studies have shown high rates of recurrent instability following isolated capsulolabral repair in such patients (41,42). A recent scoping review found that 60.5% of included studies used this threshold as the determining factor when deciding to perform a soft tissue or bony augmentation procedure such as a Latarjet or bone block allograft (43). However, the authors also highlighted the emerging significance of subcritical bone loss, with increased failure rates following soft-tissue stabilization in patients with anterior glenoid bone loss of 15% or less (18).

### Subcritical bone loss

Studies within the last decade have challenged the notion that patients with anterior glenoid bone loss measuring less than 20% may be successfully treated with soft tissue stabilization. In 2014, Shaha *et al.* reported increased rates of recurrent instability following primary arthroscopic repair in patients with >17% bone loss (44); the following year, the same group demonstrated inferior patient-reported outcomes following capsulolabral repair in patients with bone loss above 13.5% (18). Since that time, numerous studies have reported similar findings, with some calling

for the redefinition of critical bone loss as anywhere from 15% (45) to 17% (46). Even more recently, a 2018 study reported the glenoid bone loss as low as >10% may be a threshold for bony augmentation procedures (47). In a 2022 scoping review of the assessment and management of glenohumeral bone loss, Gouveia *et al.* found that 34% of included studies used a threshold of 15% or less when deciding the appropriate amount of bone loss to perform an isolated soft tissue procedure. Notably, the authors also reported a trend based on the year of publication, with more recent studies reporting lower thresholds for the consideration of bony augmentation procedures (43).

### Authors' preferred treatment

Despite recent literature that directs the treatment of recurrent glenohumeral instability based on glenoid bone loss, it is important to note that this factor cannot be considered in isolation. Numerous other morphologic and patient-specific factors contribute to the risk of recurrent instability and should be weighed when deciding on the optimal treatment for a specific patient. Such factors include age, participation in competitive, contact, or overhead sports, the presence of hyperlaxity (48), and concomitant Hill-Sachs lesions or bipolar bone loss (49). However, stratification of degrees of glenoid bone loss can be helpful in determining a basic algorithm to help guide treatment.

After obtaining appropriate preoperative imaging using 3D CT, the authors prefer to divide patients into four categories based on the following degrees of glenoid bone loss: >40%, 20–40%, 13.5–<20%, <13.5%. Patients with >40% glenoid bone loss often require a larger graft and are indicated for free bone block augmentation using either distal tibia allograft (DTA) or autograft or iliac crest bone graft (ICBG) allograft or autograft. In patients with 20–40% glenoid bone loss, the authors perform Latarjet due to the combined sling effect of the conjoint tendon and bony reconstruction of the coracoid (50).

Patients with <20% glenoid bone loss are managed differently according to risk factors including age and status as a contact athlete, as well as morphologic features such as the presence of bipolar bone loss. In such patients, treatment is guided by the accurate assessment of humeral-sided bone loss, as well as the interplay between the GT and any existing Hill-Sachs lesion.

### Humeral bone loss

While evaluating glenoid bone loss is a critical component

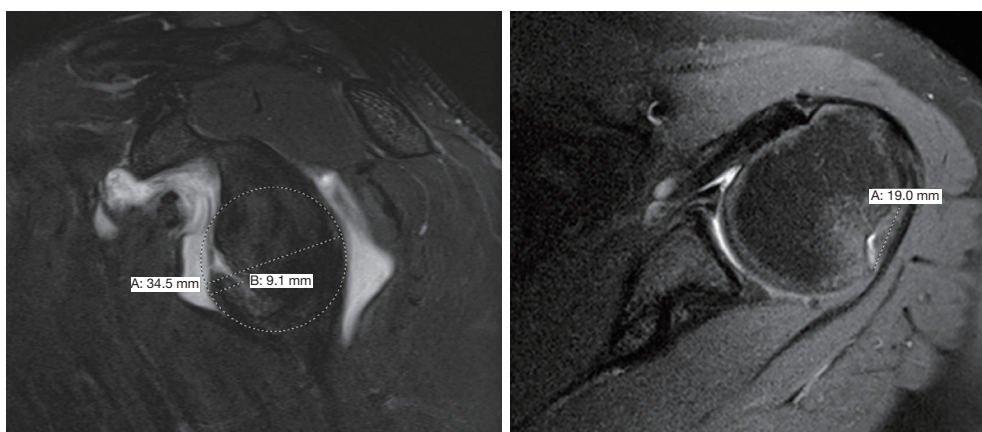
of determining the extent of injury after dislocation, it is also key to evaluate humeral-sided bone loss. The Hill-Sachs lesion is an important independent risk factor of anterior shoulder instability and is often indicative of high energy dislocation events (51). Hill-Sachs lesions are present in an estimated 40–90% of cases of anterior shoulder dislocation events, and as high as 100% of cases of recurrent anterior shoulder instability (51).

Like glenoid-sided defects, the location and size of humeral bone loss is an important component of the algorithm for treatment of shoulder instability. However, determining the extent of humeral sided defects is limited by a lack of universal and consistent preoperative measurement criteria (52).

### Measuring humeral bone loss

A variety of methods for measuring humeral bone loss exist. While radiography has historically been a modality for measuring the extent of humeral defects (53,54), advanced imaging modalities (i.e., CT and MRI) have been widely recognized as more accurate and reliable (22). Regardless of the method, the goal is to determine both the dimensions of the Hill-Sachs lesion as well as the Hill-Sachs interval (HSI), which measures the distance from the medial edge of the Hill-Sachs lesion to the articular rotator cuff insertion (55).

In 2011, Cho *et al.* used CT with 3D reconstruction to predict which Hill-Sachs lesions had the highest rate of recurrent anterior shoulder instability. The Hill-Sachs lesion was found by identifying the cut with the greatest width in both the axial and coronal planes, which provided both the length and the depth of the lesion (56). In 2014, Ozaki *et al.* used 3D CT and found that CT was able to detect almost two-thirds of Hill-Sachs lesions; however, while CT was appropriate for osseous lesions, it did not reliably detect cartilaginous lesions (57). Meanwhile, the use of MRI, while more recent, has proven useful in the characterization of humeral bone loss in patients with glenohumeral instability. In an early feasibility study, Gyftopoulos *et al.* evaluated both glenoid and humeral bone loss using MRI, resulting in an 84.2% accuracy rate (58). Additionally, magnetic resonance arthrography (MRA) has been especially useful in the determination of not only Hill-Sachs length and width, but also the volume of the defect, resulting in a sensitivity and specificity ranging from 69% to 100% and 0% to 100%, respectively (59). While there are many methods and modalities of characterizing humeral bone loss, no consensus exists on the best, easiest, and most reliable method. Additionally, because of the low interobserver



**Figure 1** Bipolar bone loss. MRI sagittal cut on left showing glenoid bone loss with glenoid track calculated as  $0.83 \times (34.5 \text{ mm}) - 9.1 \text{ mm} = 19.5 \text{ mm}$ ; axial cut on right showing Hill-Sachs interval measured at 19.0 mm. MRI, magnetic resonance imaging.

reliability and high variability in measurements of Hill-Sachs lesions seen with various methods of measurement (52,60,61), developing treatment strategies solely based on the Hill-Sachs lesion is not recommended.

#### Authors' preferred method of measurement

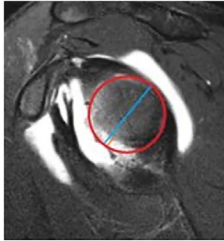
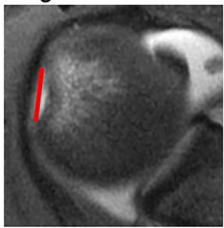
The authors prefer the use of MRA for the characterization of Hill-Sachs lesions. Patients with anterior shoulder instability will routinely receive magnetic resonance (MR)-arthrograms as a diagnostic and preoperative planning tool. On MRA, we prefer the use of the T1-weighted sequence on axial imaging to determine the width and depth of the Hill-Sachs lesion. Each patient's Hill-Sachs lesion is then characterized as either absent, mild, moderate, and severe, based on the Rowe classification (62). However, as the Hill-Sachs lesion is just one element of the treatment algorithm, it is essential to consider both glenoid- and humeral-sided defects to understand the severity of injury and how to best address glenohumeral instability after traumatic anterior shoulder dislocations.

#### Assessing bipolar bone loss

It is well described that the interplay between humeral- and glenoid-sided bone loss contributes to failure of soft tissue shoulder stabilization. In 2000, Burkhart and De Beer first recognized the importance of bipolar bone loss as they found that inverted-pear glenoid morphology in combination with engaging Hill-Sachs lesions were risk factors for recurrence after isolated arthroscopic Bankart repair (13). In 2007, Yamamoto *et al.* developed the GT

concept, determining that a Hill-Sachs lesion had risk of engagement and dislocation if it extended over the medial margin of the GT (12). The GT can be calculated with the formula “ $0.83D - d$ ”, where “ $D$ ” is the diameter of the glenoid fit to a perfect circle on a sagittal CT or MRI image (mm) and “ $d$ ” is the amount of glenoid bone loss, measured from the edge of the glenoid to the rim of the perfect circle (mm) (12,14,63). The HSI should be measured on axial CT or MRI imaging and represents the width of the Hill-Sachs lesion (mm) plus the width of the intact bone bridge (mm) between the rotator cuff attachment and the lateral margin of the Hill-Sachs lesion (*Figure 1*) (12,14,64). Di Giacomo *et al.* classified Hill-Sachs lesions as “on-” or “off-track”, and subsequent analyses have validated this method, showing that the risk of recurrent instability is higher when “off-track” lesions (HSI > GT) are treated nonoperatively or with Bankart repair in isolation (14,65,66).

Rather than relying solely on glenoid- or humeral-sided measurements, addressing bone loss as a bipolar concept continues to gain popularity and aids in better understanding the dynamic nature of the unstable shoulder. MRI, 3D CT scans, and standard CT scans have all proven acceptable imaging modalities for assessing the nature of a Hill Sachs lesions as “on-” or “off-track” (14,58,63). A 2022 scoping review published by Gouveia *et al.* compiled recent findings related to methods for assessment of bone loss in anterior shoulder instability. They included 113 studies in their review. Of these studies, 23.9% (27/113) utilized the GT concept in addressing bipolar bone loss by 3D CT (13 studies), standard CT (7 studies), or MRI imaging (5 studies). Interestingly, the authors also found that the

Steps for Calculating “Distance to Dislocation” (DTD)	
1. Identify sagittal MRI cut that shows entire glenoid face ( <b>Image A</b> )	<b>Image A.</b> 
2. Place circle that matches posterior inferior glenoid from 5 o'clock to 9 o'clock position ( <b>red circle</b> )	
3. Measure diameter ( <b>D</b> ) of glenoid ( <b>light blue line</b> )	
4. Measure width ( <b>d</b> ) of glenoid bone loss ( <b>orange line</b> )	
5. Calculate the width of the glenoid track ( <b>GT</b> ). <b>GT = (0.83*D) - d</b>	<b>Image B.</b> 
6. Identify axial MRI cut with widest length of Hill-Sachs lesion ( <b>Image B</b> )	
7. Measure the Hill-Sachs Interval width from medial edge of lesion to cuff insertion ( <b>HSI</b> ) ( <b>red line</b> )	
8. Calculate DTD. <b>DTD = GT - HSI.</b> *if $DTD < 0$ , the Hill-Sachs lesion is “off-track”	

**Figure 2** Steps for calculating “DTD”. Reformatted from Barrow *et al.* (49) with permissions. DTD, distance to dislocation; MRI, magnetic resonance imaging; GT, glenoid track; HSI, Hill-Sachs interval.

use of the GT concept grew in popularity over the search period. In the earlier half of the search period [2017–2019], the GT was reported in <15% of studies (7 of 47), while in the latter half [2020–2022], 30% of studies (20 of 66) utilized the concept to examine the bipolar nature of bone loss (43). While the GT concept has been monumental in assessing and quantifying bipolar bone loss, current research has further classified “on-track” lesions, as these lesions should not all be viewed equally.

### “DTD”

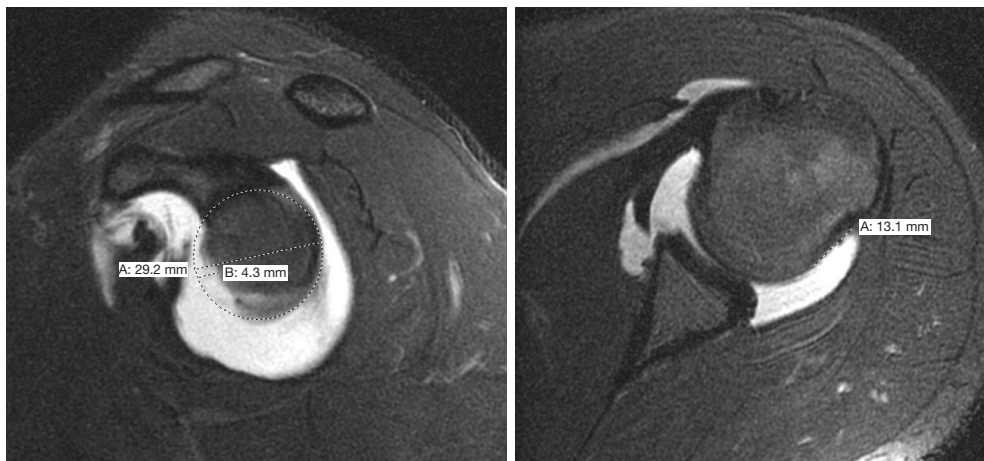
The presence of “off-track” Hill-Sachs lesions greatly increases the risk for recurrent instability, even after isolated Bankart repair (65). However, not all “on-track” lesions should be viewed in the same manner (64). In 2021, Li *et al.* introduced the new concept of “DTD” in the setting of “on-track” Hill-Sachs lesions. The authors defined DTD as the distance from the medial edge of the Hill-Sachs lesion to the medial edge of the GT (calculated as  $DTD = GT - HSI$ ; *Figure 2*) and concluded “on-track” lesions with DTD less than 8 mm (“near-track” lesions) increased the rate of failure after arthroscopic Bankart repair (*Figure 3*) (16). Research on “near-track” lesions and DTD continues to evolve. In 2022, Barrow *et al.* reported on 188

individuals with “on-track” lesions undergoing arthroscopic Bankart repair with minimum 2-year follow-up. Amongst other predictors of failure, the authors concluded that as DTD approached 0 mm (“off-track” threshold), the risk of recurrent dislocation after arthroscopic Bankart repair significantly increased. Furthermore, below a DTD threshold of 10 mm, the risk of failure increased exponentially across the study population. In collision sports athletes, recurrent dislocation risk remained elevated at higher DTD values (24 mm) than for noncollision athletes (49).

Currently, research involving the DTD concept continues to grow. Studies examining rates of failure after arthroscopic labral repair compared to arthroscopic labral repair plus remplissage in patients with “near-track” lesions are underway. Furthermore, research currently examining the effects of hyperlaxity, Hill-Sachs’s lesion location, and DTD in patients with subcritical bone loss and those who’ve experienced recurrent instability after Latarjet procedure is underway.

### Authors’ preferred assessment and treatment of bipolar bone loss

In cases of suspected bone loss based on history, examination, and radiographs, advanced imaging is obtained including both CT and MRI. These studies are performed



**Figure 3** “Near-track” lesion. Glenoid track calculated on sagittal MRI cut on left as  $0.83 \times (29.2 \text{ mm}) - 4.3 \text{ mm} = 19.9 \text{ mm}$ ; Hill-Sachs interval measured at 13.1 mm on the axial MRI cut on right. “DTD” calculated as (glenoid track) – (Hill-Sachs interval);  $19.9 \text{ mm} - 13.1 \text{ mm} = 6.8 \text{ mm}$  DTD. DTD <8 mm = “near-track” lesion. MRI, magnetic resonance imaging; DTD, distance to dislocation.

to evaluate the magnitude and location of osseous deficiency, anchors from prior capsulolabral repair, and the integrity of surrounding soft tissue structures.

In the presence of an off-track Hill-Sachs lesion, a remplissage is performed. For contact athletes, consideration is also given to performing an open Bankart repair or a Latarjet, as studies have demonstrated decreased rates of recurrence with the use of these procedures in athletes compared to arthroscopic repair (67,68). For on-track lesions, as the DTD approaches 0 mm, the risk of recurrent dislocation increases exponentially, particularly in contact athletes (34). Thus, in contact athletes demonstrating “near-track” lesions with subcritical bone loss and a DTD  $\leq 10$  mm, consideration is given to combined Bankart repair and remplissage, or Latarjet (16,49).

## Conclusions

Bone loss in shoulder instability drives treatment algorithms and patient outcomes. Humeral- and glenoid-sided bone loss must be measured and addressed in the unstable shoulder to promote the most successful outcomes. The new concept of DTD introduces an additional dimension to the GT concept and has been proven as a predictor of failure after arthroscopic stabilization. As the body of literature continues to grow on DTD, the concept will provide necessary information for surgeons, offering support for specific management options following anterior shoulder instability.

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procedures described in this study were performed in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from the patients for the publication of this article and accompanying images.

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