Curr Rev Musculoskelet Med (2017) 10:452–462
DOI 10.1007/s12178-017-9439-y

Management of Glenoid Bone Loss with Anterior Shoulder Instability: Indications and Outcomes

Justin Rabinowitz [1] · **Richard Friedman** [1] · **Josef K. Eichinger** [1]

Published online: 9 October 2017

Abstract
Purpose of Review Glenoid Bone Loss is a commonly encountered problem in anterior shoulder instability. In this article, we review current techniques for diagnosis, indications and management of glenoid bone loss.
Recent Findings Multiple bone grafting techniques are available depending on the glenoid defect size including the coracoid, distal clavicle, iliac crest, and allograft distal tibia. Advancement in imaging methods allows for more accurate quantification of bone loss. Indications and techniques are continuing to evolve, and emerging evidence suggests that smaller degrees of bone loss "subcritical" may be best treated with bone grafting.
Summary Future directions for innovation and investigation include improved arthroscopic techniques and a refinement of indications for the type of bone grafts and when to indicate a patient of arthroscopic repair versus glenoid bone grafting for smaller degrees of bone loss to ensure successful outcome.

Keywords Glenoid bone loss · Shoulder instability · Latarjet · Distal tibia allograft

Introduction

Anterior shoulder instability is a commonly diagnosed and treated shoulder disorder [1]. The most common underlying pathology is an injury to the anterior glenoid labrum or Bankart lesion; however, there is often an associated osseous defect in the glenoid and/or humeral head [2]. Following an initial shoulder dislocation, an osseous defect is present in up to 22% of patients, and up to 88% of patients with recurrent instability [3, 4]. Glenoid bone deficiency leads to recurrent glenohumeral instability by altering its function as a static restraint of the shoulder [5]. Historically, research in anterior shoulder instability was focused on the importance of the soft tissue envelope surrounding the glenohumeral joint. Glenoid bone loss is now a recognized cause of recurrent shoulder dislocations or poorer functional outcomes following an arthroscopic or open soft tissue repair for glenohumeral instability [6–9]. In the past 10–15 years, more attention is being paid to the role of glenoid bone deficiency and its management for patients with recurrent anterior shoulder instability. Advances in imaging, quantification of bone loss and evolution in bone grafting techniques continue to emerge. This article reviews new and established techniques for imaging and calculating glenoid bone loss, as well as evolving indications for intervention and current options available for surgical management.

Diagnosis of Glenoid Bone Loss

History and Physical Exam

An accurate and detailed history is helpful for making the diagnosis of glenoid bone deficiency. Acute bone loss in the primary dislocator's initial dislocation event often involves a high energy injury with an axial load placed on the glenoid [7]. Patients with bone loss experience subsequent instability episodes with increasing frequency even with lower energy episodes. A comprehensive shoulder exam should be

This article is part of the Topical Collection on *Management of Anterior Shoulder Instability*

✉ Josef K. Eichinger
joe.eichinger@gmail.com

1 Department of Orthopaedic Surgery, Medical University of South Carolina, Charleston, SC, USA

performed taking note of axillary nerve dysfunction and distal arm paresthesias. Axillary nerve dysfunction can manifest as sensory alterations, deltoid weakness, and atrophy. Following a dislocation event, axillary nerve palsy is present in up to 48% of patients (range 13.5–48%) [10–12]. However, even complete axillary nerve injuries should receive surgery as reasonable function can be attained in the setting of a permanent injury [13•]. Instability apprehension is apparent with early to midrange abduction and external rotation and worsens with increasing severity of glenoid bone deficiency [14–16]. Patients who describe instability and apprehension with daily activities coupled with night-time instability will frequently have substantial glenoid and humeral bone loss. Risk factors for recurrent instability such as younger age, athletes (particularly those participating in contact and overhead sports), and generalized ligamentous laxity lower the threshold at which bone loss is tolerated [16].

Imaging

Standard AP, axillary lateral, and scapular Y radiographs of the shoulder should initially be obtained. In addition, specific projections with the beam angled obliquely to the glenoid face may provide more detail, including the Bernageau profile view (Fig. 1), Didiee, West Point, and apical oblique views [17–20]. Radiography, while helpful in identifying bone loss, is not as accurate as computed tomography (CT) and magnetic resonance imaging (MRI) for quantifying bone loss [21•].

CT imaging is helpful to understand bone loss; however, standard 2-dimensional (2D) CT imaging of the glenoid can over or underestimate glenoid bone loss if the patient is not accurately oriented in the CT gantry [22•]. Three-dimensional (3D) CT is the current gold standard imaging modality for accurately demonstrating glenoid bone loss [23]. It removes the effect of gantry angles and allows the user to orient the glenohumeral joint with the scapula plane [22•]. It provides the ability to subtract the humeral head from the image of the glenohumeral joint, leaving an en face view of the glenoid surface (Fig. 2) [23–25]. The isolated view of the glenoid surface gives a more precise image to accurately quantify the amount of glenoid bone loss and its location. Similarly, 3D CT allows for accurate quantification of humeral head bone loss with scapular subtraction [26]. While CT is generally considered to be superior to radiography for measuring glenoid bone loss, one study found no statistical difference in measurements taken from the radiographic Bernageau profile view and 3D CT in a small sample of patients with glenoid bone loss [27]. It is unknown if the Bernageau view can accurately distinguish between critical and subcritical bone loss, so 3D CT is still the gold standard for evaluating glenoid bone loss.

MRI is the gold standard imaging modality for assessing soft tissue shoulder pathology with the addition of contrast arthrography for further soft tissue assessment [28]. As a result, MRIs are frequently obtained for patients with shoulder instability; however, similar to 2D CT scans, quantification of glenoid bone loss can potentially be misleading. A recent cadaveric study comparing bone loss measurements revealed that 3D CT is more accurate than 2D CT, 2D MRI, and plain radiography for quantifying glenoid bone loss [25]. Recently, interest has developed in the use of three-dimensional magnetic resonance imaging (3D-MRI) for the assessment of glenoid bone loss as a potential alternative to 3D CT [28, 29•, 30•]. Gyftopoulos et al. performed a clinical study to evaluate the accuracy of 3D-MRI for measuring glenoid bone

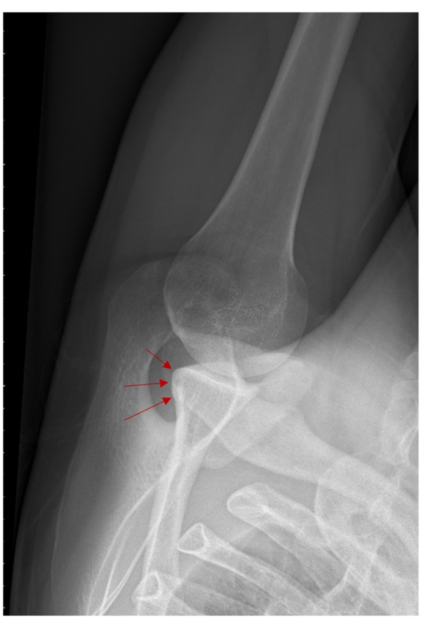

Fig. 1 Bernageau view of the left shoulder. The anterior glenoid, indicated with red arrows, is easily visualized in profile

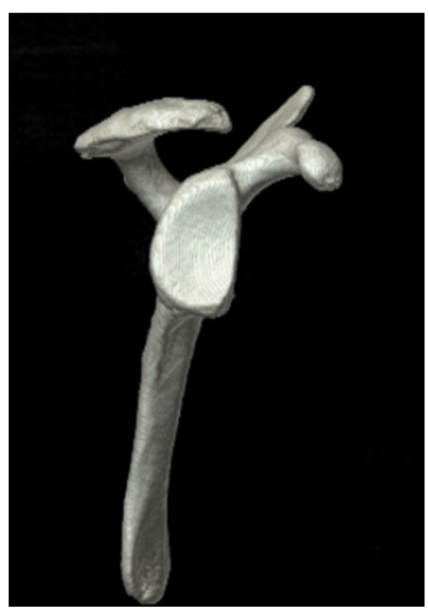

Fig. 2 CT-generated scapula, en face view of glenoid

loss using arthroscopy as the gold standard. Glenoid bone loss was quantified using the best-fit circle method for 3D-MRI reconstructions and the bare spot method for intraoperative measurements. The findings show that 3D-MRI reconstructions may be used to accurately quantify glenoid bone loss [29•]. Stillwater et al. conducted a prospective study comparing the use of 3D-MRI to 3D-CT for the quantification of glenoid and/or humeral head bone loss in patients with glenohumeral instability [30•]. A total of 11 patients (mean age 29) with glenohumeral instability or recurrent shoulder dislocations were included in the study. Each patient underwent CT and MRI imaging of their shoulder (3-T MRI scanner and 64-multidetector row CT scanner). The images were post processed to create 3D reconstructions, and measurements were taken of the glenoid and humeral head. There was no statistically significant difference between measurements taken from the 3D-MRI or 3D-CT reconstructions, and percent bone loss was equivalent. Advantages of 3D-MRI include elimination of the radiation dose associated with a CT scan and the need for only one examination (Fig. 3) [30•].

Quantification of Glenoid Bone Loss

It is clear that 3D imaging is required to more accurately quantify bone loss, but the optimal method for doing so has not been identified [21•, 31]. There are multiple described methods for quantifying glenoid bone deficiency; however, there is no universally accepted method for measuring defects. The most accurate methods utilize a CT-generated en face view of the glenoid to make either linear or surface area

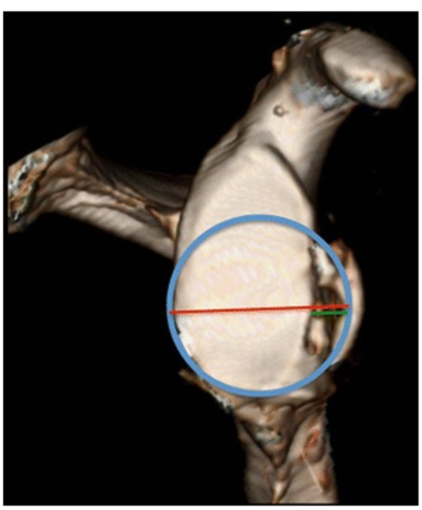

Fig. 3 3D-MRI of glenoid, en face view, demonstrating the best-fit circle method of quantifying glenoid bone loss. (Reproduced, with permission, from Gyftopoulos S, Beltran LS, et al. use of 3D MR reconstructions in the evaluation of glenoid bone loss: a clinical study. Skeletal Radiol. 2014 Feb;43(2):213–8)

measurements of the inferior glenoid. Commonly used linear and ratio measurements include the Glenoid Index method (Fig. 4a) and Gerber x-ratio, while the most common surface area measurement studied is the Pico method (Fig. 4b) [29•, 32–34]. A recent review of imaging methods for quantifying bone loss found the Glenoid Index and Pico methods to be the most accurate and reliable forms of measurement [21•]. Automated computer-generated calculation software is now being used at some centers. While this software provides an accurate measurement of bone loss, it is not widely available for use by most surgeons.

There is recent evidence suggesting that attritional loss of the bone fragment displaced from the glenoid may play an important role in management. McNeil et al. performed a study which analyzed the degree of attritional bone loss and found that duration of shoulder instability was significantly associated with percentage of attrition of the displaced fragment [35•]. It is important to consider the duration of symptoms during surgical planning, because small bony Bankart lesions when repaired may not reconstitute the glenoid.

The glenoid track concept was developed to account for the dynamic relationship of glenoid and humeral bone defects in shoulder instability [36]. It is recognized that both humeral bone loss and glenoid bone loss must be accounted for when assessing shoulder instability, as increasing size of the Hill-Sachs lesion is an independent risk factor for recurrent instability and potentiates the severity of glenoid bone loss [16]. Di Giacomo et al. further defined calculation based on the degree of humeral and glenoid bone loss to determine whether the interaction is "on-track" or "off-track" [37•]. Independent 3D CT of the humeral head and scapula are required to perform the measurements and calculations if the width of the Hill-Sachs lesions matches that of the glenoid lesion then the Hill-Sachs glenoid loss combined lesion is considered "off-track" and warrants consideration for bony augmentation of the glenoid (Fig. 5). Shaha et al. evaluated patients undergoing arthroscopic Bankart reconstructions and found a significant increase in recurrent postoperative shoulder instability in "off-track" patients [38•].

Management

Non-operative

Non-surgical management for recurrent anterior shoulder instability in the setting of glenoid bone loss is not a recommended treatment option for young, active patients, as recurrent instability will result in further damage to the soft tissue or cartilage within the glenohumeral joint that may end up progressing to symptomatic glenohumeral arthritis. Treatment is limited to physiotherapy and is based on the important role that the periscapular and rotator cuff

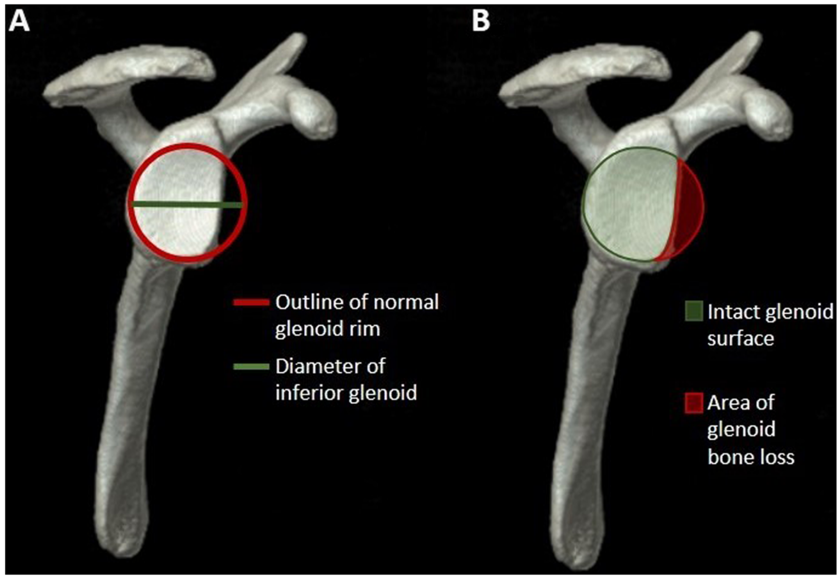

Fig. 4 (**a**) Glenoid index method for quantifying glenoid bone deficiency, linear measurements. (**b**) PICO method for quantifying bone loss, surface area measurements

musculature plays in dynamic shoulder stabilization. This principle is used to create a protocol focused on strengthening these muscle groups. However, non-surgical management is limited to lower demand older patients with minor glenoid deficiencies [5].

Operative

There are several strategies for the surgical management of glenoid bone loss, including the Latarjet or coracoid transfer as well as other osseous and osteoarticular autografts and allografts (Fig. 6) [39•]. Common grafts used for reconstruction of glenoid bone deficiency include iliac crest and distal tibia [40•, 41]. All of the currently described techniques share the same goal: to restore the osseous defect in a manner that most closely resembles the native glenoid. Traditionally, bone loss of greater than 20–25% is considered a contraindication for soft tissue repairs alone due to the poor biomechanical environment and high clinical failure [7, 42].

Recent research has identified the concept of "subcritical" bone loss, in which a lower percentage of bone loss after arthroscopic Bankart repair does not necessarily result in a recurrence of dislocation events, but results in poorer patient reported clinical outcomes (WOSI scores) when comparing a soft tissue repair to those patients treated with bone augmentation [38•, 43•]. Shin et al. identified 17.3% glenoid bone loss as the critical value that leads to recurrent instability following arthroscopic Bankart repair. In their study, 43% of patients with greater than 17.3% bone loss had surgical failure, which was defined as need for revision surgery or subjective feelings of instability, compared to 3.7% of patients with less than 17.3% glenoid bone loss [44•]. This research suggests that, particularly for higher demand individuals, such as contact athletes, bone augmentation may result in better outcomes and lower failure rates for patients with this subcritical bone loss between 13.5 and 17.3%.

Some authors suggest that shoulder instability should be treated with a primary Latarjet procedure independent of glenoid bone loss [45•, 46•]. Conversely, however, DiGiacomo et al. showed a coracoid graft resorption of 39.6% at 1 year follow-up in patients with less than 15% glenoid bone loss [47•], which suggests that an unloaded

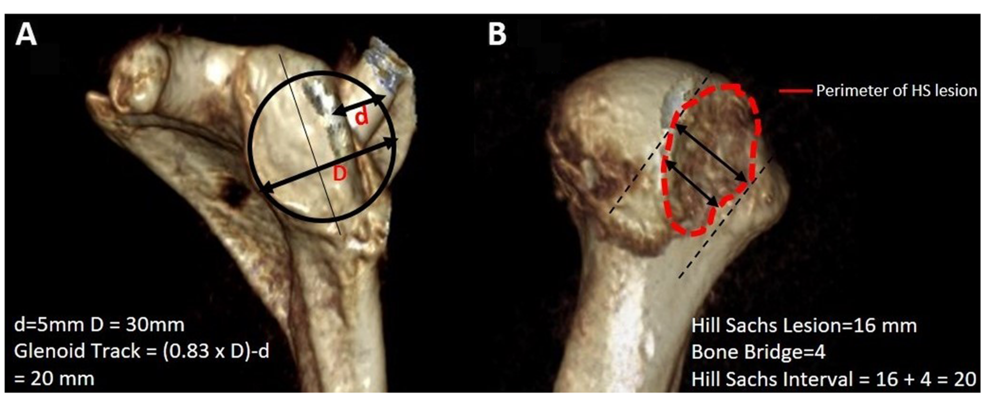

Fig. 5 (**a**) Glenoid track (GT) formula where D = diameter of the inferior glenoid and d = the width of the anterior glenoid bone loss. (**b**) Hill-Sachs interval (HSI) formula, the sum of the width of the HS lesion and the width of the bone bridge between the rotator cuff attachments and the lateral aspect of the HS lesion. If HSI > GT, the HS is off-track or engaging. If HSI < GT, the HS is on track, or non-engaging

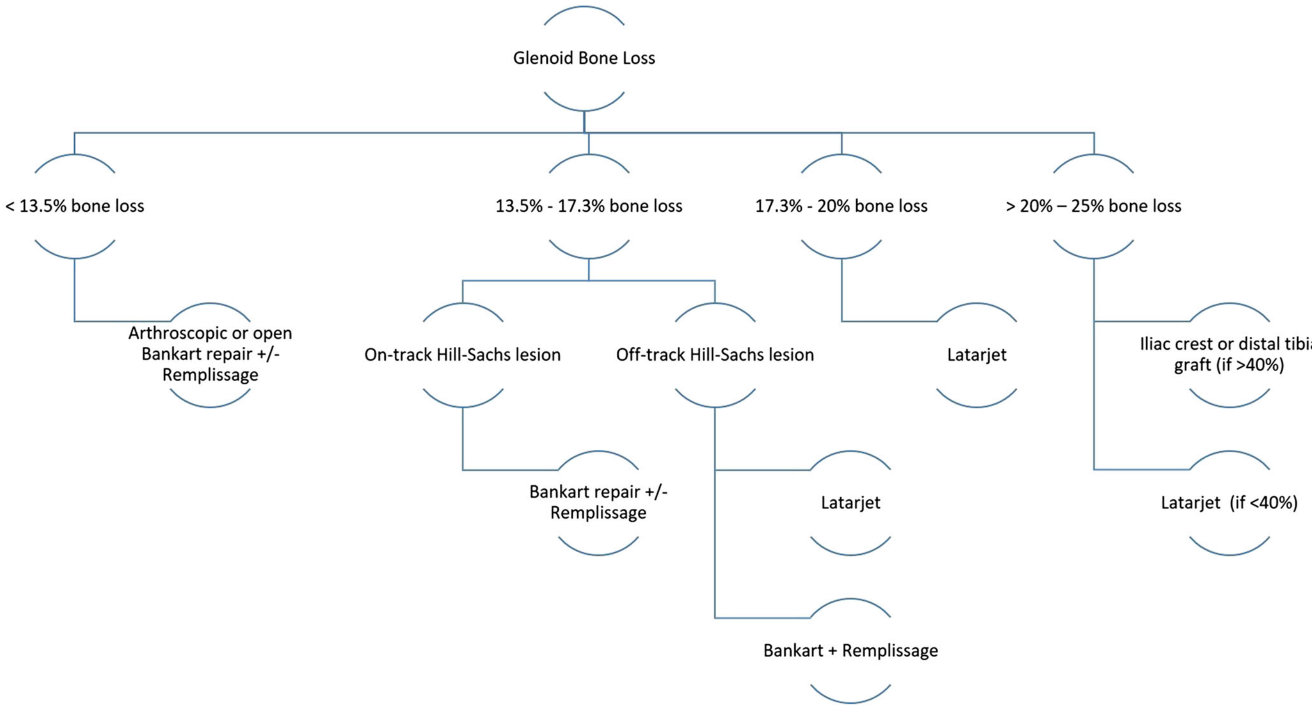

Fig. 6 Flowchart demonstrating surgical treatment options based on percent of glenoid bone loss

graft will ultimately resorb according to Wolff's law. The high rate of graft osteolysis may be a risk factor for recurrent instability and subsequent development of early glenohumeral arthritis [48].

Latarjet

The Latarjet procedure was originally described by Michael Latarjet in 1954 and later modified to the Latarjet-Bristow procedure by Arthur Helfet in 1958 [49, 50]. There are multiple described variations of the procedure, but the general technique involves transecting the coracoid at its base and transferring the graft intra-articular to the glenoid neck (Fig. 7) with one or two screw fixation. The pectoralis minor is detached from the coracoid, and a portion of the coracoacromial ligament is maintained for capsular repair.

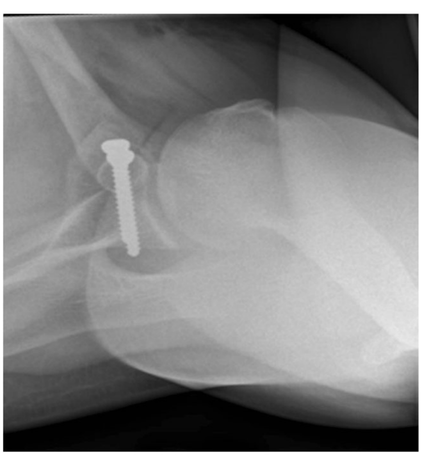

Fig. 7 General technique for Latarjet, graft of coracoid intra-articularly transferred to the glenoid neck

There are currently two commonly used techniques for a coracoid transfer: traditional Latarjet and congruent arc. The traditional Latarjet involves fixation of the inferior surface of the coracoid to the anterior surface of the glenoid [51•]. This technique provides a large surface area for fixation and bone healing, but leaves less anterior to posterior distance to fill the glenoid defect and restore glenoid width [51•]. The congruent arc technique involves fixation of the medial aspect of the coracoid to the glenoid and is accomplished by rotating the coracoid 90°. This creates a congruent surface between the inferior surface of the coracoid and the articular surface of the glenoid [52]. The congruent arc technique provides more anterior to posterior distance to restore glenoid width and can be used to fill larger glenoid defects [51•]. Furthermore, it more closely matches the radius of curvature of the native glenoid [39•]. However, this comes at the cost of less surface area for fixation between the glenoid and coracoid [51•, 53].

The Latarjet procedure remains the gold standard technique for addressing anterior glenoid bone loss, and its success is evidenced by its low long-term failure rate [54–56]. Several studies show excellent outcomes for both traditional and congruent arc techniques; however, there have been no clinical studies comparing the two methods [52, 54, 57•].

Cowling et al. recently published a systematic review of the described techniques and outcomes of the Latarjet procedure [58•]. In the review, the authors discuss variations for the coracoid osteotomy site, subscapularis approach, fixation site of the coracoid, orientation of the coracoid graft, and fixation method. There were several described methods for determining the osteotomy site, including 1–2 cm of coracoid length, junction between the horizontal and vertical parts of the coracoid, junction between the superior two-thirds and inferior one-third, immediately distal to the pectoralis minor or just anterior to the coracoclavicular ligaments, but rate of recurrent dislocation and nonunion did not differ. The subscapularis approach was mainly performed through a horizontal split in line with muscle fibers or a vertical tenotomy. Five of the seven studies performing a vertical tenotomy split only two-thirds of the tendon and reflected the upper half into an L-shape. Although a statistical analysis was not performed, the subscapularis split seems to preserve postoperative external rotation compared with a vertical tenotomy. The coracoid graft was most commonly placed flush with glenoid rim and less commonly placed medial to the glenoid rim. Unfortunately, a comparative analysis of recurrent dislocations based on fixation site could not be accurately completed due to biased study results. Only a few studies reported on graft position and orientation, making analysis difficult.

Iliac crest

Iliac crest autograft is usually reserved for patients with significant glenoid bone loss greater than 25 to 30%. Warner et al. described the technique in a case series of 11 patients in which a tri cortical iliac crest autograft is used to reconstruct large glenoid defects in patients with recurrent anterior shoulder instability. The authors use the inner table of the iliac due to its ability to closely match the concave articular surface of the glenoid. At a mean follow-up of 33 months, there were no episodes of recurrent instability, and at 4–6 months after surgery, there was no evidence of graft osteolysis [41]. Auffarth et al. described a variation of this procedure in which an autologous bicortical iliac crest graft is fashioned into a J-shape and secured to the glenoid in a press fit method with the keel of the graft impacted into a preformed crevice medial to the glenoid rim. In their series of 46 patients, there were no episodes of recurrent instability at a mean follow-up of 7.5 years [59]. The lack of hardware in the J-bone technique offers a theoretical benefit by eliminating the risk of prominent hardware and the need for additional surgery in the event of graft resorption.

Distal Tibia Allograft

The use of a fresh osteochondral distal tibia allograft (DTA) is a relatively new approach for the reconstruction of anterior glenoid bone deficiency (Fig. 8). Provencher et al. originally described the technique in a small case series in which the lateral aspect of the distal tibia was used to reconstruct the glenoid in patients with greater than 30% glenoid bone loss [60]. The lateral aspect of the distal tibia is used, because its curvature is similar to the curvature of the native glenoid, thus providing a more anatomical reconstruction. Further, the graft contains a cartilaginous service with a radius of curvature that is highly congruent with the area of glenoid bone loss. The DTA can accommodate large glenoid defects that are unable to be reconstructed using the Latarjet technique. A recent case series of 27 patients who underwent reconstruction with a DTA for recurrent anterior shoulder instability in the setting of greater than 15% glenoid bone loss found significantly improved clinical outcome scores and no episodes of recurrent instability at an average follow-up of 45 months. There was an average allograft healing rate of 89% and average allograft osteolysis of 3% seen on CT scans 1.4 years post operatively. This early data is promising, although more studies and long-term data are needed.

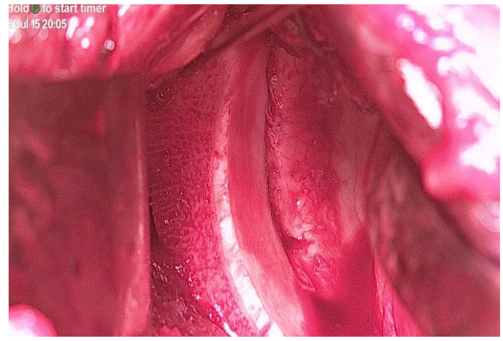

Fig. 8 Intraoperative photograph of a distal tibia allograft secured to the glenoid rim

Distal Clavicle Autograft

The distal clavicle osteochondral autograft is a new arthroscopic technique for addressing glenohumeral instability secondary to glenoid bone loss. The technique was originally described by Tokish et al., and it is performed by harvesting the distal 6 to 8 mm of clavicle and securing it to the glenoid with suture anchors or a 3.75-mm cannulated screw [61•]. The graft provides an articular surface that is congruent with the glenoid, and it has a large surface area for fixation and bony union [61•]. In a biomechanical study evaluating glenohumeral contact area and pressures, an articular-sided distal clavicle bone graft and a coracoid bone graft were comparable when used for restoration of an anterior glenoid bone defect [62•]. Tokish et al. reported positive early outcomes for a small sample of patients in their initial pilot study, but clinical studies are needed to evaluate the effectiveness and safety of this new technique for the management of recurrent shoulder instability due to glenoid bone loss [61•].

Future Directions

Determining the optimal treatment for so-called "subcritical" bone loss (13.5% or more) remains an unanswered question as balancing recurrent instability risk with graft osteolysis is important. Additional research to identify the optimal technique for graft fixation is necessary as multiple screw types and materials exist. It is unknown if osteolyisis is related to graft fixation strength.

Growing interest and research in the management of glenoid bone loss has led to the development of new surgical techniques and graft options. The arthroscopic Latarjet procedure was first reported in the literature 10 years ago [63]. Athwal et al. found a 24% adverse event rate in their recently published study on short-term complications of the arthroscopic Latarjet procedure [64•], which is similar to the short-term adverse event rate found by Shah et al. in their series of open Latarjet procedures [65]. Nourissat et al. performed a recently published prospective study comparing open Latarjet procedures to arthroscopic Latarjet procedures and found a reduction in immediate postoperative pain scores in the arthroscopic group, but no difference in pain or function at 1 year [66•]. There is a lack of prospective studies or long-term follow-up in the current literature to adequately assess the efficacy of arthroscopic Latarjet procedures compared to the traditional open techniques.

Conclusions

Glenoid bone loss is well established in the literature as an important cause of recurrent anterior shoulder instability. Advanced imaging technology has led to improved methods for diagnosing and accurately quantifying glenoid bone loss for surgical planning. Surgical management has evolved from the historical Latarjet procedure to new techniques and graft options that may better anatomically match the native glenoid and reduce the risk of recurrent instability and early glenohumeral arthritis. While the Latarjet procedure remains the gold standard, a growing body of literature provides good evidence for the use of new techniques. In the subset of patients with failed Latarjet or large amount of bone loss, either the classic iliac crest bone grafting or distal tibia allograft can be used as reconstruction options. Despite the significant graft resorption rates seen with the Latarjet procedure and bone grafting, functional outcome and recurrence rate is good to excellent in majority of patients after glenoid bone grafting. Continued research is required to identify a universally accepted method for quantifying glenoid bone loss, and to identify surgical techniques and grafts that best reconstruct the glenoid rim.

Compliance with Ethical Standards

Conflict of Interest All authors declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance

1. Lynch JR, Clinton JM, Dewing CB, Warme WJ, Matsen FA 3rd. Treatment of osseous defects associated with anterior shoulder instability. J Shoulder Elbow Surg. 2009;18(2):317–28. https://doi.org/10.1016/j.jse.2008.10.013.
2. Provencher MT, Bhatia S, Ghodadra NS, Grumet RC, Bach BR Jr, Dewing CB, et al. Recurrent shoulder instability: current concepts for evaluation and management of glenoid bone loss. J Bone Joint Surg Am. 2010;92(Suppl 2):133–51. https://doi.org/10.2106/JBJS.J.00906.
3. Edwards TB, Boulahia A, Walch G. Radiographic analysis of bone defects in chronic anterior shoulder instability. Arthroscopy. 2003;19(7):732–9.
4. Taylor DC, Arciero RA. Pathologic changes associated with shoulder dislocations: arthroscopic and physical examination findings in first-time, traumatic anterior dislocations. Am J Sports Med. 1997;25(3):306–11. https://doi.org/10.1177/036354659702500306.
5. Piasecki DP, Verma NN, Romeo AA, Levine WN, Bach BR Jr, Provencher MT. Glenoid bone deficiency in recurrent anterior shoulder instability: diagnosis and management. J Am Acad Orthop Surg. 2009;17(8):482–93.
6. Bigliani LU, Newton PM, Steinmann SP, Connor PM, McLlveen SJ. Glenoid rim lesions associated with recurrent anterior dislocation of the shoulder. Am J Sports Med. 1998;26(1):41–5. https://doi.org/10.1177/03635465980260012301.
7. Burkhart SS, De Beer JF. Traumatic glenohumeral bone defects and their relationship to failure of arthroscopic Bankart repairs: significance of the inverted-pear glenoid and the humeral engaging Hill-Sachs lesion. Arthroscopy. 2000;16(7):677–94.
8. Mologne TS, Provencher MT, Menzel KA, Vachon TA, Dewing CB. Arthroscopic stabilization in patients with an inverted pear glenoid: results in patients with bone loss of the anterior glenoid. Am J Sports Med. 2007;35(8):1276–83. https://doi.org/10.1177/0363546507300262.
9. 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(5):878–84.
10. Visser CP, Coene LN, Brand R, Tavy DL. The incidence of nerve injury in anterior dislocation of the shoulder and its influence on functional recovery. A prospective clinical and EMG study. J Bone Joint Surg Br Vol. 1999;81(4):679–85.
11. de Laat EA, Visser CP, Coene LN, Pahlplatz PV, Tavy DL. Nerve lesions in primary shoulder dislocations and humeral neck fractures.

A prospective clinical and EMG study. J Bone Joint Surg British Vol. 1994;76(3):381–3.

12. Robinson CM, Shur N, Sharpe T, Ray A, Murray IR. Injuries associated with traumatic anterior glenohumeral dislocations. J Bone Joint Surg Am. 2012;94(1):18–26. https://doi.org/10.2106/JBJS.J.01795.
13.• Galvin JW, Eichinger JK. Outcomes following closed axillary nerve injury: a case report and review of the literature. Mil Med. 2016;181(3):e291–7. https://doi.org/10.7205/milmed-d-15-00205 **This is a case report of a 43-year-old male who developed permanent axillary nerve palsy after a left anterior glenohumeral joint dislocation at the age of 18. He enlisted and served over 20 years in the military with near normal shoulder function, suggesting the potential for high functioning after permanent loss of axillary nerve function in young, athletic patients.**
14. Lazarus MD, Sidles JA, Harryman DT 2nd, Matsen FA 3rd. Effect of a chondral-labral defect on glenoid concavity and glenohumeral stability. A cadaveric model. J Bone Joint Surg Am. 1996;78(1):94–102.
15. Howell SM, Galinat BJ. The glenoid-labral socket. A constrained articular surface. Clin Orthop Relat Res. 1989;243:122–5.
16. Balg F, Boileau P. The instability severity index score. A simple pre-operative score to select patients for arthroscopic or open shoulder stabilisation. J Bone Joint Surg Br Vol. 2007;89(11):1470–7. https://doi.org/10.1302/0301-620x.89b11.18962.
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(9):1450–3.
18. Pansard E, Klouche S, Billot N, Rousselin B, Kraus TM, Bauer T, et al. Reliability and validity assessment of a glenoid bone loss measurement using the Bernageau profile view in chronic anterior shoulder instability. J Shoulder Elb Surg. 2013;22(9):1193–8. https://doi.org/10.1016/j.jse.2012.12.032.
19. Pavlov H, Warren RF, Weiss CB Jr, Dines DM. The roentgenographic evaluation of anterior shoulder instability. Clin Orthop Relat Res. 1985;194:153–8.
20. Rokous JR, Feagin JA, Abbott HG. Modified axillary roentgenogram. A useful adjunct in the diagnosis of recurrent instability of the shoulder. Clin Orthop Relat Res. 1972;82:84–6.
21.• Saliken DJ, Bornes TD, Bouliane MJ, Sheps DM, Beaupre LA. Imaging methods for quantifying glenoid and Hill-Sachs bone loss in traumatic instability of the shoulder: a scoping review. BMC Musculoskelet Disord. 2015;16:164. https://doi.org/10.1186/s12891-015-0607-1. **This systematic review identified and analyzed imaging methods for quantifying glenohumeral bone loss. Forty-one studies were included in the review and 32 of the studies evaluated glenoid bone loss. The review found that radiography is a useful screening tool for patients with significant bone loss, but it is not useful for quantifying bone loss. The Pico Method and Glenoid Index Method applied to three dimensional CT scans were the most accurate and reliable methods for quantifying glenoid bone loss.**
22.• Gross DJ, Golijanin P, Dumont GD, Parada SA, Vopat BG, Reinert SE, et al. The effect of sagittal rotation of the glenoid on axial glenoid width and glenoid version in computed tomography scan imaging. J Shoulder Elb Surg. 2016;25(1):61–8. https://doi.org/10.1016/j.jse.2015.06.017. **Imaging software was used to reconstruct CT scans of the shoulder to measure the effect of sagittal rotation of the glenoid on axial measurements of glenoid width and glenoid version. Thirty CT scans of the shoulder were reformatted and images corrected for sagittal rotation were compared to images uncorrected for sagittal rotation. There was a 2.6% average difference in glenoid version and 5.2% average difference in glenoid width between corrected and uncorrected images. Standard uncorrected CT scans of the shoulder may under or overestimate the degree of glenoid bone loss.**
23. Kwon YW, Powell Ka Fau-Yum JK, Yum Jk Fau-Brems JJ, Brems Jj Fau-Iannotti JP, Iannotti JP. Use of three-dimensional computed tomography for the analysis of the glenoid anatomy. J Shoulder Elb Surg. 2005;14(1):85–90.
24. Bishop JY, Jones Gl Fau-Rerko MA, Rerko Ma Fau-Donaldson C, Donaldson C. 3-D CT is the most reliable imaging modality when quantifying glenoid bone loss. Clin Orthop Relat Res. 2013;471(4):1251–6. https://doi.org/10.1007/s11999-012-2607.
25. Rerko MA, Pan X, Fau-Donaldson C, Fau-Jones GL, Bishop JY. Comparison of various imaging techniques to quantify glenoid bone loss in shoulder instability. J Shoulder Elb Surg. 2013;22(4):528–34. https://doi.org/10.1016/j.jse.2012.05.034.
26. 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(11):2389–95. https://doi.org/10.1177/0363546511398644.
27. Murachovsky J, Bueno RS, Nascimento LG, Almeida LH, Strose E, Castiglia MT, et al. Calculating anterior glenoid bone loss using the Bernageau profile view. Skelet Radiol. 2012;41(10):1231–7. https://doi.org/10.1007/s00256-012-1439-9.
28. Gyftopoulos S, Yemin A, Mulholland T, Bloom M, Storey P, Geppert C, et al. 3DMR osseous reconstructions of the shoulder using a gradient-echo based two-point Dixon reconstruction: a feasibility study. Skelet Radiol. 2013;42(3):347–52. https://doi.org/10.1007/s00256-012-1489-z.
29.• Gyftopoulos S, Beltran LS, Yemin A, Strauss E, Meislin R, Jazrawi L, et al. Use of 3D MR reconstructions in the evaluation of glenoid bone loss: a clinical study. Skelet Radiol. 2014;43(2):213–8. https://doi.org/10.1007/s00256-013-1774-5. **This retrospective study assessed the ability of 3D MRI shoulder reconstructions to accurately quantify glenoid bone loss using arthroscopy as the gold standard. The study included 15 patients who underwent shoulder arthroscopy and bone loss was measured using the bare spot method. Imaging software was used to create 3D MRI reconstructions of the shoulder and the best-fit circle method was used to measure bone loss. There was a less than 2.21% mean absolute error of the MRI measurements compared to arthroscopy measurements, suggesting that 3D MR reconstructions may be used to accurately measure glenoid bone loss.**
30.• Stillwater L, Koenig J, Maycher B, Davidson M. 3D-MR vs. 3D-CT of the shoulder in patients with glenohumeral instability. Skelet Radiol. 2017;46(3):325–31. https://doi.org/10.1007/s00256-016-2559-4. **This prospective study measured glenoid bone loss on 3D CT and 3D MRI reconstructions of the shoulder. Twelve patients underwent CT scans and MRI scans of their injured shoulder. Imaging software was used to create 3D CT reconstructions and 3D MRI reconstructions and there were no statistically significant differences in measurements between 3D CT and 3D MRI.**
31. Bois AJ, Fening SD, Polster J, Jones MH, Miniaci A. Quantifying glenoid bone loss in anterior shoulder instability: reliability and accuracy of 2-dimensional and 3-dimensional computed tomography measurement techniques. Am J Sports Med. 2012;40(11):2569–77. https://doi.org/10.1177/0363546512458247.
32. Baudi P, Campochiaro G, Rebuzzi M, Matino G, Catani F. Assessment of bone defects in anterior shoulder instability. Joints. 2013;1(1):40–8.
33. Chuang TY, Adams CR, Burkhart SS. Use of preoperative three-dimensional computed tomography to quantify glenoid bone loss in shoulder instability. Arthroscopy. 2008;24(4):376–82. https://doi.org/10.1016/j.arthro.2007.10.008.

34. Gerber C, Nyffeler RW. Classification of glenohumeral joint instability. Clin Orthop Relat Res. 2002;400:65–76.

35.• JW MN, Beaulieu-Jones BR, Bernhardson AS, LE LC, Dewing CB, Lynch JR, et al. Classification and analysis of attritional glenoid bone loss in recurrent anterior shoulder instability. Am J Sports Med. 2016; https://doi.org/10.1177/0363546516677736. **This retrospective review included 265 patients and measured glenoid bone loss using 3D CT reconstructions of the shoulder. In addition, they measured attritional bone loss of the displaced bone fragment. Total time of instability prior to the CT scan was significantly associated with the degree of attritional bone loss of the displaced fragment. Therefore, in patient with a long history of instability the remaining bone fragment may not be able to fully reconstruct the glenoid.**

36. Yamamoto N, Itoi E, Abe H, Minagawa H, Seki N, Shimada Y, 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 Elb Surg. 2007;16(5):649–56. https://doi.org/10.1016/j.jse.2006.12.012.

37.• 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(1):90–8. https://doi.org/10.1016/j.arthro.2013.10.004. **Using radiographic and arthroscopic methods, the authors developed a technique for evaluating whether a Hill-Sachs lesion will engage the anterior glenoid rim, with or without associated anterior glenoid bone loss. A Hill-Sachs lesion is considered to be "off track" if it engages, and "on track" if it does not engage. This technique was used to development a surgical treatment algorithm for patients with anterior shoulder instability.**

38.• Shaha JS, Cook JB, Rowles DJ, Bottoni CR, Shaha SH, Tokish JM. Clinical validation of the glenoid track concept in anterior glenohumeral instability. J Bone Joint Surg Am. 2016;98(22):1918–23. https://doi.org/10.2106/JBJS.15.01099. **This study identified 57 patients that underwent primary arthroscopic Bankart reconstructions and used pre-operative MRI to measure glenoid bone loss, as well as the glenoid track concept to classify shoulders as on-track or off-track. There was a statistically significant increase in recurrent instability in the off-track patients compared to on-track patients. The application of the glenoid track was superior to glenoid bone loss alone for predicting post-operative stability.**

39.• Noonan B, Hollister SJ, Sekiya JK, Bedi A. Comparison of reconstructive procedures for glenoid bone loss associated with recurrent anterior shoulder instability. J Shoulder Elb Surg. 2014;23(8):1113–9. https://doi.org/10.1016/j.jse.2013.11.011. **This study evaluated the ability of a tibial plafond allograft, iliac crest allograft, and standard and congruent arc Latarjet grafts to match the radius of curvature and restore the glenoid depth of an injured glenoid. Virtual surgery was performed using CT scans from 15 patients. They found that the congruent arc latarjet reconstruction most closely restored the radius of curvature, and the tibial plafond and iliac crest allografts more effectively restored glenoid depth.**

40.• Provencher MT, Frank RM, Golijanin P, Gross D, Cole BJ, Verma NN, et al. Distal tibia allograft glenoid reconstruction in recurrent anterior shoulder instability: clinical and radiographic outcomes. Arthroscopy. 2016; https://doi.org/10.1016/j.arthro.2016.09.029. **This is a retrospective review that evaluated post-operative clinical and radiographic outcomes at a minimum of two years in 27 patients who were treated with a fresh distal tibia allograft (DTA). Inclusion criteria included recurrent anterior shoulder instability and a minimum of 15% glenoid bone loss. There were significant improvements in post-operative clinical outcome measures, no episodes of recurrent instability, and an allograft healing rate of 89% with average lysis of 3%.**

41. Warner JJ, Gill TJ, O'Hollerhan JD, Pathare N, Millett PJ. Anatomical glenoid reconstruction for recurrent anterior glenohumeral instability with glenoid deficiency using an autogenous tricortical iliac crest bone graft. Am J Sports Med. 2006;34(2):205–12. https://doi.org/10.1177/0363546505281798.

42. 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;82:35–46.

43.• Shaha JS, Cook JB, Song DJ, Rowles DJ, Bottoni CR, Shaha SH, et al. Redefining "critical" bone loss in shoulder instability: functional outcomes worsen with "subcritical" bone loss. Am J Sports Med. 2015;43(7):1719–25. https://doi.org/10.1177/0363546515578250. **This cohort study evaluated the effect of subcritical bone loss (below 20%-25%) on outcomes following arthroscopic Bankart repair for anterior shoulder instability. Patients were divided into quartiles based on preoperative bone loss (Q1: 2.8%, Q2: 10.4%, Q3:16.1%, Q4: 24.5%). Within each quartile, increasing bone loss was predictive of worse functional outcome scores. There were significant differences in functional outcome scores between each quartile. Results suggest that "critical" bone loss should be considered lower than the current cutoff of 20% to 25%.**

44.• Shin SJ, Kim RG, Jeon YS, Kwon TH. Critical value of anterior glenoid bone loss that leads to recurrent glenohumeral instability after arthroscopic bankart repair. Am J Sports Med. 2017;45(9):1975–81. https://doi.org/10.1177/0363546517697963. **This is a retrospective review of 169 patients with recurrent anterior shoulder instability who underwent arthroscopic Bankart repair with at least 2 year follow up. Glenoid bone loss ranged from 2.1% to 22.1% with an average of 12.0%. Receiver operating characteristic curve analysis pointed to an optimal critical value of 17.3%, the cutoff point of glenoid bone loss for the prediction of surgical failure. Postoperative functional scores and SANE scores at last follow-up for patients with >17.3% bone loss were significantly lower than for those with <17.3% bone loss.**

45.• Blonna D, Bellato E, Caranzano F, Assom M, Rossi R, Castoldi F. Arthroscopic Bankart repair versus open Bristow-Latarjet for shoulder instability. Am J Sports Med. 2016;44(12):3198–205. https://doi.org/10.1177/0363546516658037. **This retrospective matched cohort study compared post-operative outcomes following arthroscopic Bankart repairs and open Bristow-Latarjet procedures in patients with recurrent anterior shoulder instability with <20% glenoid bone loss. They found that a mean follow up of 5.3 years, patients who underwent arthroscopic Bankart repairs had better clinical outcomes including return to sport, ROM in the throwing position, and subjective perception of the shoulder.**

46.• Zimmermann SM, Scheyerer MJ, Farshad M, Catanzaro S, Rahm S, Gerber C. Long-term restoration of anterior shoulder stability: a retrospective analysis of arthroscopic Bankart repair versus open latarjet procedure. JBJS. 2016;98(23):1954–61. https://doi.org/10.2106/jbjs.15.01398. **This retrospective case-cohort study compared post-operative outcomes at a minimum follow up of 6 years following arthroscopic Bankart repairs and open coracoid transfers in patients with recurrent anterior shoulder instability. Ninety-three patients underwent an open latarjet procedure and 271 patients underwent an arthroscopic Bankart repair. There was a statistically significant decrease in apprehension (p<0.001), redislocation (p=0.01), and operative revision (p<0.001) in**

patients undergoing open coracoid transfers compared to patients undergoing arthroscopic Bankart repairs.

47.• Di Giacomo G, de Gasperis N, Costantini A, De Vita A, Beccaglia MA, Pouliart N. Does the presence of glenoid bone loss influence coracoid bone graft osteolysis after the Latarjet procedure? A computed tomography scan study in 2 groups of patients with and without glenoid bone loss. J Shoulder Elb Surg. 2014;23(4):514–8. https://doi.org/10.1016/j.jse.2013.10.005. **This was a prospective follow-up of 34 patients who underwent treatment with mini-plate Latarjet procedure. Coracoid bone graft osteolysis was then evaluated by CT scan with 3D reconstruction. On average, the grafts in patients with >15% glenoid bone loss showed significantly less osteolysis than those in patients with no glenoid bone loss.**

48. Di Giacomo G, Costantini A, de Gasperis N, De Vita A, Lin BK, Francone M, et al. Coracoid graft osteolysis after the Latarjet procedure for anteroinferior shoulder instability: a computed tomography scan study of twenty-six patients. J Shoulder Elb Surg. 2011;20(6):989–95. https://doi.org/10.1016/j.jse.2010.11.016.

49. Latarjet M. Treatment of recurrent dislocation of the shoulder. Lyon Chir. 1954;49(8):994–7.

50. Helfet AJ. Coracoid transplantation for recurring dislocation of the shoulder. J Bone Joint Surg Br Vol. 1958;40-B(2):198–202.

51.• Montgomery SR, Katthagen JC, Mikula JD, Marchetti DC, Tahal DS, Dornan GJ, et al. Anatomic and biomechanical comparison of the classic and congruent-arc techniques of the Latarjet procedure. Am J Sports Med. 2017;45(6):1252–60. https://doi.org/10.1177/0363546516685318. **In this cadaveric study, a 30% anterior glenoid defect was created in 20 pairs of shoulders which were then randomized to treatment with either a classic or congruent-arc technique of the Latarjet procedure. Biomechanical testing revealed that classic technique provides a broader surface for bone healing and demonstrates a higher load to failure for coracoid fixation, while the congruent-arc technique allowed for restoration of a larger glenoid defect.**

52. de Beer JF, Roberts C. Glenoid bone defects–open latarjet with congruent arc modification. Orthop Clin N Am. 2010;41(3):407–15. https://doi.org/10.1016/j.ocl.2010.02.008.

53. Giles JW, Puskas G, Welsh M, Johnson JA, Athwal GS. Do the traditional and modified Latarjet techniques produce equivalent reconstruction stability and strength? Am J Sports Med. 2012;40(12):2801–7. https://doi.org/10.1177/0363546512460835.

54. Burkhart SS, De Beer JF, Barth JR, Cresswell T, Roberts C, Richards DP. Results of modified Latarjet reconstruction in patients with anteroinferior instability and significant bone loss. Arthroscopy. 2007;23(10):1033–41. https://doi.org/10.1016/j.arthro.2007.08.009.

55. Hovelius L, Sandstrom B, Sundgren K, Saebo M. One hundred eighteen Bristow-Latarjet repairs for recurrent anterior dislocation of the shoulder prospectively followed for fifteen years: study I—clinical results. J Shoulder Elb Surg. 2004;13(5):509–16. https://doi.org/10.1016/S1058274604000916.

56. Matton D, Van Looy F, Geens S. Recurrent anterior dislocations of the shoulder joint treated by the Bristow-Latarjet procedure. Historical review, operative technique and results. Acta Orthop Belg. 1992;58(1):16–22.

57.• Mook WR, Petri M, Greenspoon JA, Horan MP, Dornan GJ, Millett PJ. Clinical and anatomic predictors of outcomes after the latarjet procedure for the treatment of anterior glenohumeral instability with combined glenoid and humeral bone defects. Am J Sports Med. 2016;44(6):1407–16. https://doi.org/10.1177/0363546516634089. **This is a retrospective review of 38 patients who underwent the Latarjet procedure for shoulder instability. Anatomic characteristics such as width of the coracoid and the on-track or off-track classification of the glenoid track were measured radiographically. Patients with off-track lesions were four times more likely to experience postoperative instability, and greater width of the coracoid was associated with greater stability after surgery. Findings indicate native coracoid size, glenoid width, and the width of the Hill-Sachs lesion may impact surgical outcomes and should be considered in planning.**

58.• Cowling PD, Akhtar MA, Liow RY. What is a Bristow-Latarjet procedure? A review of the described operative techniques and outcomes. Bone Joint J. 2016;98-B(9):1208–14. https://doi.org/10.1302/0301-620X.98B9.37948. **This systematic review compared various operative techniques of the Latarjet procedure (coracoid osteotomy site, subscapularis approach, orientation and position of coracoid graft and fixation method, and additional labral and capsular repair) and their effect on post-operative outcomes. There were no significant changes in post-operative outcomes with variations of the coracoid osteotomy site, fixation site on the scapular neck, fixation method, or whether a capsular repair was performed. External rotation may be better preserved when performing a horizontal split in the subscapularis tendon versus a tenotomy.**

59. Auffarth A, Schauer J, Matis N, Kofler B, Hitzl W, Resch H. The J-bone graft for anatomical glenoid reconstruction in recurrent posttraumatic anterior shoulder dislocation. Am J Sports Med. 2008;36(4):638–47. https://doi.org/10.1177/0363546507309672.

60. Provencher MT, Ghodadra N, LeClere L, Solomon DJ, Romeo AA. Anatomic osteochondral glenoid reconstruction for recurrent glenohumeral instability with glenoid deficiency using a distal tibia allograft. Arthroscopy. 2009;25(4):446–52. https://doi.org/10.1016/j.arthro.2008.10.017.

61.• Tokish JM, Fitzpatrick K, Cook JB, Mallon WJ. Arthroscopic distal clavicular autograft for treating shoulder instability with glenoid bone loss. Arthrosc Tech. 2014;3(4):e475–81. https://doi.org/10.1016/j.eats.2014.05.006. **The authors present the advantages of utilizing the distal clavicle osteochondral autograft for bony augmentation in the case of significant anterior or posterior glenoid bone loss. This paper describes the surgical technique for the procedure and points to the need for long-term follow-up and clinical studies.**

62.• Petersen SA, Bernard JA, Langdale ER, Belkoff SM. Autologous distal clavicle versus autologous coracoid bone grafts for restoration of anterior-inferior glenoid bone loss: a biomechanical comparison. J Shoulder Elb Surg. 2016;25(6):960–6. https://doi.org/10.1016/j.jse.2015.10.023. **This is a comparative biomechanical study conducted in 13 frozen cadaveric shoulders with a vertical anterior glenoid defect approximately 25% that was experimentally created. One centimeter of both distal clavicle and coracoid were harvested and utilized to reconstruct the glenoid. While the coracoid graft provided the greater contact area for all testing positions, the differences did not reach statistical significance.**

63. Lafosse L, Lejeune E, Bouchard A, Kakuda C, Gobezie R, Kochhar T. The arthroscopic Latarjet procedure for the treatment of anterior shoulder instability. Arthroscopy. 2007;23(11):1242 e1–5. https://doi.org/10.1016/j.arthro.2007.06.008.

64.• Athwal GS, Meislin R, Getz C, Weinstein D, Favorito P. Short-term complications of the arthroscopic Latarjet procedure: a North American experience. Arthroscopy. 2016;32(10):1965–70. https://doi.org/10.1016/j.arthro.2016.02.022. **This case series reported intraoperative and early postoperative complications and problems in 83 patients who underwent arthroscopic Latarjet procedures with a mean follow up of 17**

months (range, 3 to 43 months). A problem was defined as a perioperative event that will not affect the outcome and a complication was defined as an event that will negatively affect outcome. In their series, 18% of patients experienced a problem and 10% of patients experienced a complication. Intraoperative fracture of the coracoid graft was the most common negative event (7%). Seven cases required secondary procedures. The overall adverse event rate was similar to the traditional open Latarjet procedure.

65. Shah AA, Butler RB, Romanowski J, Goel D, Karadagli D, Warner JJ. Short-term complications of the Latarjet procedure. J Bone Joint Surg Am. 2012;94(6):495–501. https://doi.org/10.2106/JBJS.J.01830.

66.• Nourissat G, Neyton L, Metais P, Clavert P, Villain B, Haeni D, et al. Functional outcomes after open versus arthroscopic Latarjet procedure: a prospective comparative study. Orthop Traumatol Surg Res. 2016;102(8S):S277–S9. https://doi.org/10.1016/j.otsr.2016.08.004. **This prospective study compared post-operative clinical outcomes in patients undergoing arthroscopic Latarjet procedures and open Latarjet procedures. The study included a total of 184 patients (85 in the open group, 99 in the arthroscopy group). The arthroscopy group had higher functional outcome scores at 3 months, but both groups had similar functional outcome scores at 1 year. Both procedures significantly improve shoulder pain and function, but the arthroscopic Latarjet procedure has less immediate postoperative pain.**