Technical Note

Assessment and Evaluation of Glenoid Bone Loss

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Abstract: The preoperative assessment of anterior glenoid bone loss is a critical step in surgical planning for patients with recurrent anterior glenohumeral instability. The structural integrity of the glenoid has been identified as one of the most important factors influencing the success of operative repair. The currently accepted gold standard for glenoid structural assessment among most orthopaedic surgeons is the use of 3-dimensional reconstructed computed tomography images with the humeral head digitally subtracted, yielding an en face sagittal oblique view of the glenoid. This view allows for evaluation of glenoid morphology and quantitative assessment of glenoid bone loss. In this article, we describe the practical application of ImageJ software (National Institutes of Health, Bethesda, MD) to quantify the amount of glenoid bone loss reported as a percentage of either total surface area or diameter. The following equations are used in this technical note for the diameter-based method and surface area method, respectively: Percent bone loss = (Defect width/Diameter of inferior glenoid circle) × 100% and Percent bone loss = (Defect surface area/Surface area of inferior glenoid circle) × 100%.

Glenoid bone deficiency with recurrent shoulder instability constitutes one of the key components to assess in cases of failed shoulder stabilization surgery.[1] Preoperative history taking and physical examination, as well as quantifying anterior glenoid bone deficiency, are critical for successful surgical treatment because the anterior glenoid has been identified as the primary location of bone loss.[2] The osseous structure, as well as integrity, has been identified as one of the most critical factors that influences surgical outcomes.[3] Glenoid bone defects related to recurrent anterior shoulder instability typically occur in 2 possible forms including a fracture fragment or attritional loss.[3]

History taking can elicit important clinical clues that point toward the diagnosis of glenoid bone loss, including a history of a high-energy mechanism of injury, specifically if the arm was abducted 70° or more and extended 30° or more during the initial dislocation event.[1] In addition, in patients who have multiple dislocations, instability in the midranges of motion, and instability at night, bone deficiency pathology should be considered. Physical examination can provide meaningful clues, which strongly suggest glenoid bone loss, particularly in patients with a positive apprehension test in the range of motion between 30° and 90° of shoulder abduction with a minimal amount of external rotation.[1] The examination should also include an evaluation of anterior translation of the humeral head over the glenoid border because, when reproducible, this is suggestive of bone loss.[1] Preoperative imaging can help determine the extent and type of glenoid deficiency.

Besides commonly ordered radiographs, other indices can contribute to enhanced sensitivity of diagnosis,[1]

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such as the apical oblique view,[4] the West Point view,[5] and the Didiee view.[6] However, to quantify the extent of the deficiency, a computed tomography (CT) scan with 3-dimensional (3D) reconstruction should be performed.[7] This imaging modality allows for digital subtraction of the humeral head, providing an unobstructed view of the glenoid.[1] It is vital to determine if a bone procedure will be required or should be expected for preoperative planning and proper informed consent of the patient.

Several methods have been reported to quantify the amount of glenoid bone loss. One of the most commonly used concepts described in the literature uses the diameter of the "best-fit circle" circumscribed around the inferior glenoid.[8,9]

The ImageJ program was developed by the National Institutes of Health (Bethesda, MD) and is publicly available for download and use. The program is able to display, edit, and analyze images with applications within the field of orthopaedic surgery. It can evaluate the area and pixel value measurements of user-defined selections using an assortment of drawing functions. The purpose of this article was to describe the practical applications of the ImageJ program in the assessment and evaluation of glenoid bone loss using 3D CT imaging.

Technique

We used reformatted 3D CT patient images of the right shoulder of a 21-year-old male with the humeral head digitally subtracted (Fig 1) acquired with 1.25-mm slices using the BrightSpeed CT scanner (GE Healthcare, Little Chalfont, England). A screenshot of these 3D CT images was taken in the routine picture archive and communication system (Opal Viztech, Garner, NC) and imported into Microsoft PowerPoint (Microsoft, Redmond, WA). Within Microsoft PowerPoint, a perfect circle was drawn using the circle-drawing function within the Shape menu under the Insert option on the menu bar. This circle was drawn around the inferior portion of the glenoid (Video 1) based on previous studies showing that the inferior glenoid can be modeled as a true circle.[8,9] This patient image, with the perfect circle drawn, was saved as a picture file (JPEG) and then imported into the ImageJ program for analysis of glenoid bone loss.

The ImageJ program was designed with multiple drawing functions that allow for calculation of pixel values and area measurements that include a rectangular function, oval/elliptical function, polygonal function, freehand function, and straight-line function. The toolbar also contains a status bar that displays the x- and y-coordinates of the cursor relative to the imported image, the length of any line drawn, and the dimensions of any shape drawn. When the user is drawing an ellipse, the height and width dimensions are displayed; therefore, the user must use this readout to draw a perfect circle by ensuring these dimensions are equal.

Diameter-Based Method

To calculate the percentage of glenoid bone loss using the diameter-based method, the user selects the straight-line drawing function and then measures the anterior-to-posterior diameter by drawing a line

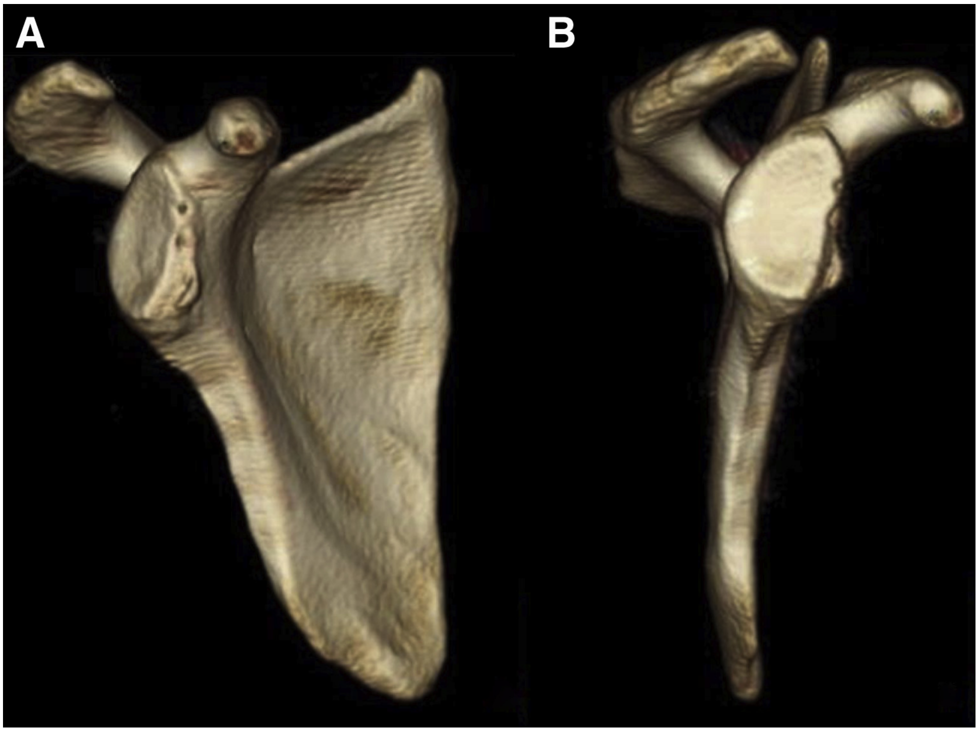

Fig 1. Preoperative 3-dimensional reconstructed computed tomography images of the glenoid with the humeral head digitally subtracted showing (A) an oblique view and (B) en face view of the right shoulder of a 21-year-old male patient. These images were acquired using 1.25-mm-thick slices using the BrightSpeed computed tomography scanner with the patient lying in the supine position. The significant amount of anterior glenoid bone loss should be noted.

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through the center of the previously drawn circle from Microsoft PowerPoint (Fig 2A). Once this line is drawn, the user selects the Measure function from the Analyze drop-down menu. ImageJ will then calculate the diameter of the circle in a pixel value displayed in a readout data sheet that will save all measurements. This value will be used as the denominator in the glenoid bone loss calculation. The user will then select the straight-line function to measure the width of the defect along the same axis previously used for the diameter measurement (Fig 2B). Again, the user selects the Measure function to determine the width of the defect. This value will be the numerator used in the calculation. These values can then be plugged into the following equation: Percent bone loss = (Defect width/Diameter of inferior glenoid circle) × 100%.

Surface Area Method

To calculate the percentage of glenoid bone loss using the surface area method, the user selects the oval/ellipse drawing function and uses the previously drawn perfect circle from PowerPoint as a guide to draw a circle within ImageJ (Fig 3A). The user should draw the ellipse with the same height and width dimensions, which are displayed on the status bar located below the toolbar, to ensure a perfect circle is drawn. The area of this circle can then be calculated by selecting the Measure function once again from the Analyze drop-down menu. The user will select the freehand function and outline the glenoid defect border, incorporating the circumference of the perfect circle to calculate the surface area of the defect (Fig 3B). Again, the user selects the Measure function from the Analyze drop-down menu. These 2 measurements will then be plugged into the following equation: Percent bone loss = (Defect surface area/Surface area of inferior glenoid circle) × 100%.

Discussion

In this technical note, we describe the use of the surface area method and diameter method for quantification of glenoid bone loss as a percentage using the ImageJ program. Currently, 3D CT imaging is the most reliable imaging modality to evaluate glenoid bone loss and morphology for preoperative surgical planning in cases of anterior stabilization procedures.[7] Sugaya et al.[10] first described the use of the circle method to quantify the percentage of bone loss by modeling the inferior glenoid as a perfect circle. The technique we present uses the same concept with the publicly available ImageJ program. ImageJ has previously been applied in the evaluation of the reproducibility of unilateral CT measurements of glenoid surface area.[11] The authors found that the normal inferior glenoid surface is very similar to a perfect circle and can be modeled as such for preoperative assessment of glenoid bone loss. The diameter

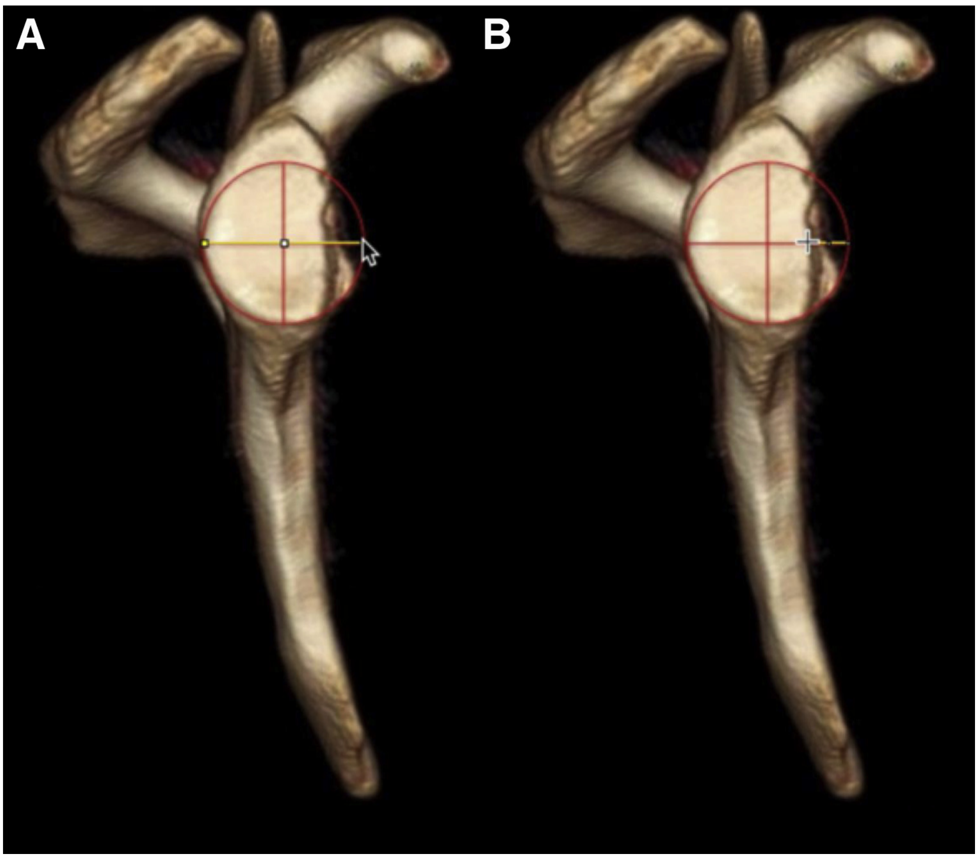

Fig 2. Diameter method of glenoid bone loss quantification showing the user interface when using the straight-line drawing function of ImageJ. (A) A straight line (yellow) has been drawn representing the diameter of the perfect circle that can be used to calculate the length of the diameter in a pixel value. (B) A straight line (yellow) has been drawn representing the width of the glenoid defect. The measurements of the lines shown in A and B can be plugged into the following equation to calculate the percentage of glenoid bone loss: Percent bone loss = (Defect width/Diameter of inferior glenoid circle) × 100%. These images were acquired from the right shoulder of a 21-year-old male patient.

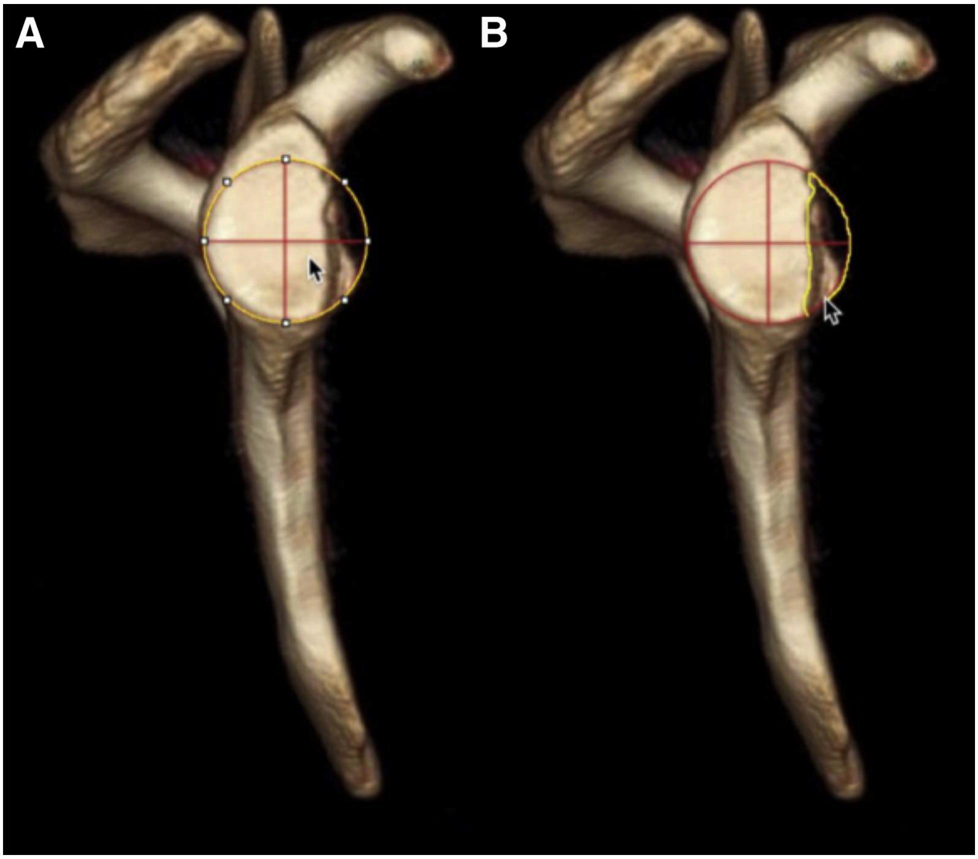

Fig 3. Surface area method of glenoid bone loss quantification showing the user interface when using the oval/ellipse drawing function of ImageJ. (A) A perfect circle (yellow) has been drawn over the previously drawn perfect circle (red) that can be used to calculate the surface area in a pixel value. (B) The freehand drawing function is used to outline the anterior glenoid defect border (yellow) and circumference of the perfect circle for determination of the surface area of the defect. The surface area measurements of the circle and freehand drawing shown in A and B, respectively, can be plugged into the following equation to calculate the percentage of glenoid bone loss: Percent bone loss = (Defect surface area/Surface area of inferior glenoid circle) × 100%. These images were acquired from the right shoulder of a 21-year-old male patient.

method is another commonly used method to evaluate glenoid bone loss, which we also demonstrate in this technical note. The line drawn within ImageJ that represents the diameter of the circle was drawn perpendicular to the defect border according to similar findings by Altan et al.[12] The diameter method is frequently used because of its ease of use; however, Bhatia et al.[13] reported that determining the percentage of glenoid bone loss based on the glenoid diameter is inconsistent with a surface area—based method. They found that the diameter method calculation overestimated glenoid bone loss by approximately 4% when compared with the geometric calculation of surface area of a circular segment. The maximum error occurred when the glenoid defect width was 20% of the diameter of the glenoid/circle. Understanding the measurement differences between the surface area method and diameter-based method of bone loss (Tables 1 and 2) is critical when describing indications for bone reconstruction procedures. When authors or surgeons are providing recommendations regarding the amount of bone loss, which indicates bone reconstruction, they must specify which measurement method is being used for the calculation.

There exist other methods using different imaging modalities including plain radiography, fluoroscopy, and magnetic resonance imaging, as well as intraoperative techniques, to measure bone loss. Edwards et al.[14]

Table 1. Step-by-Step Comparison of Diameter-Based Method and Surface Area Method

Diameter-Based Method	Surface Area Method
Perfect circle drawn in Microsoft PowerPoint	Perfect circle drawn in Microsoft PowerPoint
Image imported into ImageJ	Image imported into ImageJ
Select straight-line drawing function	Select oval/ellipse drawing function
Draw straight line representative of diameter of perfect circle	Draw perfect circle (use height and width dimensions in status bar) circumscribed over perfect circle previously drawn in PowerPoint
Select “Analyze” and “Measure” to calculate length of line/diameter	Select “Analyze” and “Measure” to calculate area of circle
Select straight-line drawing function	Select freehand drawing function
Draw straight line representative of glenoid defect width	Draw outline of glenoid defect incorporating glenoid border and perfect circle circumference
Select “Analyze” and “Measure” to calculate width of glenoid defect	Select “Analyze” and “Measure” to calculate area of defect
Percent bone loss = (Defect width/Diameter of inferior glenoid circle) × 100%	Percent bone loss = (Defect surface area/Surface area of inferior glenoid circle) × 100%

Table 2. Advantages and Disadvantages of Diameter-Based Method and Surface Area Method

	Advantages	Disadvantages
Diameter-based method	Easy to use with rapid clinical application[1]	May overestimate percentage of glenoid bone loss[13]
	Can be applied intraoperatively using glenoid bare spot as a reference point[17]	Represents deficit in anteroposterior width of glenoid only[13]
	Widely used and accepted in clinical practice[1]	Maximum error occurs at 20% of glenoid diameter (common threshold used to determine open bone graft procedure *v* arthroscopic stabilization)[13]
Surface area method	May be more accurate representation of percentage of glenoid bone loss[13]	More complex measurements needed for calculation[13]
	More accurate calculation allows for more informed decision making regarding treatment options[13]	Difficult to apply intraoperatively[17]

described a method using the Bernageau view and fluoroscopic control to detect anterior glenoid rim lesions. However, the limitations of this method are that the contralateral shoulder must be imaged, exposed to radiation, and healthy for comparison. In addition, their method is not able to detect inferior glenoid fractures.[15] Griffith et al.[16] proposed a technique to measure bone loss by measuring the diameter of the affected shoulder and comparing the result with the contralateral healthy shoulder. Lastly, Burkhart et al.[17] described an arthroscopic method for quantifying glenoid bone loss using the glenoid bare spot as a landmark and applying similar principles of the diameter-based method.

The publicly available ImageJ program developed by the National Institutes of Health is a user-friendly computer software program that can be efficiently and effectively used for the assessment and evaluation of the percentage of glenoid bone loss and preoperative surgical planning in cases of shoulder instability. When practicing orthopaedic surgeons use these techniques to assess glenoid bone loss, they must consider the measurement differences between the diameter-based method and surface area method when making treatment recommendations for patients.

References

1. Provencher MT, Bhatia S, Ghodadra NS, et al. Recurrent shoulder instability: Current concepts for evaluation and management of glenoid bone loss. *J Bone Joint Surg Am* 2010;92:133-151 (suppl 2).
2. Ji JH, Kwak DS, Yang PS, Kwon MJ, Han SH, Jeong JJ. Comparisons of glenoid bony defects between normal cadaveric specimens and patients with recurrent shoulder dislocation: An anatomic study. *J Shoulder Elbow Surg* 2012;21:822-827.
3. 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;17:482-493.
4. 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;66:1450-1453.
5. 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;82:84-86.
6. Pavlov H, Warren RF, Weiss CB Jr, Dines DM. The roentgenographic evaluation of anterior shoulder instability. *Clin Orthop Relat Res* 1985;194:153-158.
7. Bishop JY, Jones GL, Rerko MA, Donaldson C. 3-D CT is the most reliable imaging modality when quantifying glenoid bone loss. *Clin Orthop Relat Res* 2013;471:1251-1256.
8. Huysmans PE, Haen PS, Kidd M, Dhert WJ, Willems JW. The shape of the inferior part of the glenoid: A cadaveric study. *J Shoulder Elbow Surg* 2006;15:759-763.
9. Chuang TY, Adams CR, Burkhart SS. Use of preoperative three-dimensional computed tomography to quantify glenoid bone loss in shoulder instability. *Arthroscopy* 2008;24:376-382.
10. Sugaya H, Moriishi J, Dohi M, Kon Y, Tsuchiya A. Glenoid rim morphology in recurrent anterior glenohumeral instability. *J Bone Joint Surg Am* 2003;85:878-884.
11. Nofsinger C, Browning B, Burkhart SS, Pedowitz RA. Objective preoperative measurement of anterior glenoid bone loss: A pilot study of a computer-based method using unilateral 3-dimensional computed tomography. *Arthroscopy* 2011;27:322-329.
12. Altan E, Ozbaydar MU, Tonbul M, Yalcin L. Comparison of two different measurement methods to determine glenoid bone defects: Area or width? *J Shoulder Elbow Surg* 2014;23:1215-1222.
13. Bhatia S, Saigal A, Frank RM, et al. Glenoid diameter is an inaccurate method for percent glenoid bone loss quantification: Analysis and techniques for improved accuracy. *Arthroscopy* 2015;31:608-614.e1.
14. Edwards TB, Boulahia A, Walch G. Radiographic analysis of bone defects in chronic anterior shoulder instability. *Arthroscopy* 2003;19:732-739.
15. Pansard E, Klouche S, Billot N, et al. Reliability and validity assessment of a glenoid bone loss measurement using the Bernageau profile view in chronic anterior shoulder instability. *J Shoulder Elbow Surg* 2013;22:1193-1198.
16. Griffith JF, Antonio GE, Tong CW, Ming CK. Anterior shoulder dislocation: Quantification of glenoid bone loss with CT. *AJR Am J Roentgenol* 2003;180:1423-1430.
17. Burkhart SS, Debeer JF, Tehrany AM, Parten PM. Quantifying glenoid bone loss arthroscopically in shoulder instability. *Arthroscopy* 2002;18:488-491.

Video 1. Steps for calculating the percentage of bone loss in a case of right shoulder instability in a 21-year-old male patient. Important steps highlighted in this video include the importation of the 3-dimensional reconstructed computed tomography screenshot image of the en face view of the glenoid into Microsoft PowerPoint from our picture archive and communication system. A perfect best-fit circle is drawn over the inferior glenoid within PowerPoint, and the image is subsequently saved as a picture file (JPEG) and imported into ImageJ for analysis of bone loss using the following equations: Percent bone loss = (Defect width/Diameter of Inferior glenoid circle) $\times$ 100% and Percent bone loss = (Defect surface area/Surface area of inferior glenoid circle) $\times$ 100%.