JSES International 6 (2022) 763–768

Contents lists available at ScienceDirect

JSES International

journal homepage: www.jsesinternational.org

A ratio estimating glenoid bone loss

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ARTICLE INFO

Keywords:
Glenoid
Bone loss
Instability
Surgical technique
Shoulder surgery
Ratio

Level of evidence: Basic science study; Anatomical Measurement

Background: Estimating glenoid bone loss when assessing the unstable shoulder can be challenging. The aim of this article was to describe a simple derived ratio to estimate glenoid bone loss.
Methods: When the glenoid is damaged and bone is damaged because of instability, the anterior aspect of the glenoid loses its normal curvature and becomes flattened. In geometry, this represents a chord. There are 3 assumptions for the calculations: (1) the lower glenoid is a circle; (2) there is a relationship between the glenoid height and the diameter of the glenoid circle; and (3) the length of the measured bone loss of the glenoid is a chord. Two measurements are required: glenoid height and length of the glenoid defect. The calculations involved in the ratio are reviewed.
Results: If the ratio of the length of the bone defect to the glenoid height is 0.5 (otherwise, 50% of the height), the estimated bone loss is 12%.
Conclusion: Glenoid bone loss can be estimated by measuring the length of the glenoid and the length of the defect.

Evaluation of glenoid bone loss is important in decision-making when treating patients with glenohumeral joint instability. Several measurements and estimates have been recommended to assist in determining the amount of glenoid bone loss. Calculating the critical amount of bone loss that would warrant a bone reconstructive procedure can be challenging and requires advanced imaging and special software.[13,16] Considering these recent studies, the authors propose a reproducible method to estimate critical and/or subcritical bone loss from computed tomography (CT) or magnetic resonance imaging (MRI) that would be valuable to a surgeon in the decision-making process when assessing shoulder instability, albeit without the software. The described novel ratio allows a consistent, repeatable measurement method for estimating the surface area of glenoid bone loss based on the height of the glenoid and the length of the bone loss defect. The purpose of this article was to describe the mathematical method of calculation behind this glenoid bone loss estimate technique providing the practicing clinician a simple method to assess glenoid bone loss. The hypothesis is that percentage bone loss can be estimated from simple linear measurements without complex software or calculations. This value proposition mitigates the need for further imaging and costly software when determining the surgical procedure for a glenoid bone loss patient.

Materials and methods

Glenoid anatomy has been well described. The lower glenoid has been accepted to closely resemble a circle.[7,14] The height of the glenoid has been shown to have a constant relationship with the diameter of the glenoid circle of 0.65 as described by Lenart et al. The height of the glenoid can be easily measured on CT or MRI images. This length is measured from the most inferior aspect of the glenoid to the most superior aspect posterior to the coracoid on the sagittal cut.

When the glenoid is damaged and bone is lost because of instability, the anterior aspect of the glenoid loses its normal curvature and becomes flattened and/or displaced medially. Traditionally, bone loss has been estimated by taking the diameter of the defect and dividing by the diameter of the glenoid, which is a linear calculation. Sophisticated software can be used to calculate the surface area and more accurately calculate the total bone loss.

The defect of the anterior glenoid can be measured as a straight line. In geometry, this anterior straight line (ASL) is called a chord, and the portion of the circle defined by the chord is a segment of the circle. The area of the segment can be calculated if the length of the chord (ASL) and radius of the circle are known. The challenge is

Institutional review board approval was not required for this short communication.

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https://doi.org/10.1016/j.jseint.2022.05.001

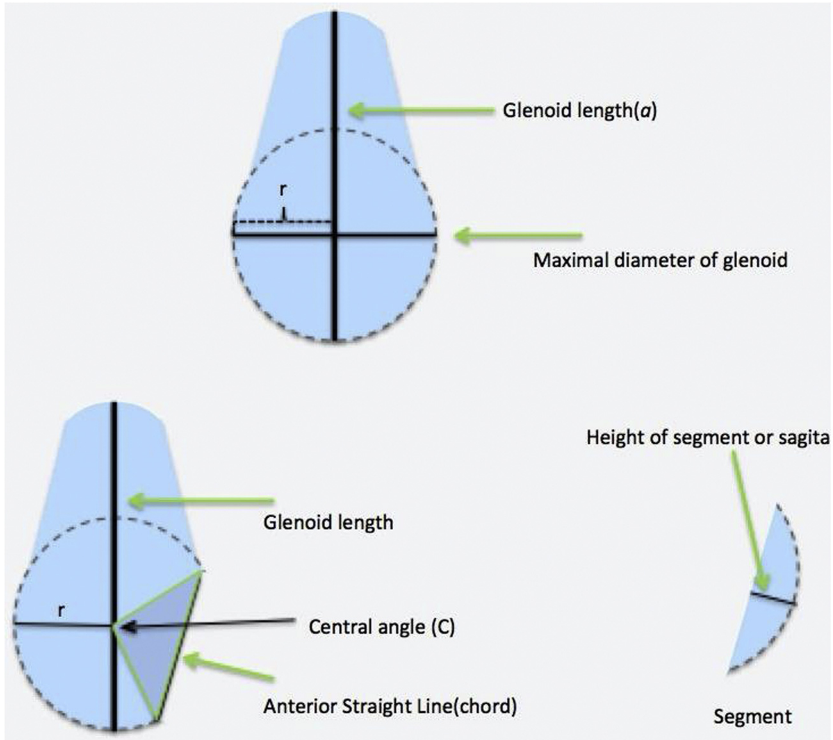


Figure 1 Glenoid with lower glenoid as a circle. Two measurements are the glenoid length and the length of the bone defect. Relationship between glenoid length and maximal diameter is 0.65.[3] Radius of the lower glenoid circle is 0.325 of glenoid length.

in identifying the radius of the lower glenoid. Other definitions of a segment include the segment height (h) or sagita and the distance from the midpoint of the segment to the center of the circle (l). These relationships can define the percentage of bone loss and aid the clinician in decision-making and adequately reconstructing the glenoid.

There are 3 assumptions for these calculations:

1. The lower glenoid is a circle.
2. The relationship between the glenoid height and the diameter of the glenoid circle is 0.65.
3. The ASL(c) of the glenoid is a chord of the circle.

The calculations require 2 measurements: the height of the glenoid (a) and the length of the ASL (Fig. 1). If both measurements are taken from the same series of images, calibration is not necessary, and the % bone loss is calculated from a ratio.

The following series of calculations are required to define the ratio but not required by the clinician.

1. Calculate the radius of the lower glenoid:

$$\frac{0.65(Measurement\ a)}{2} = radius(r) \quad 1$$

2. Calculate the central angle (C) of the segment of the circle

This requires several steps. The radius (r) has been calculated and defines 2 sides of an equilateral triangle. The third side (ASL) is the base of the triangle (c). The sum of the angles in a triangle is 180. The angles can now be solved by the Sin rule. The central angle (C) is the angle opposite the ASL and is solved with the Cosine rule (Fig. 2).

3. Calculate the area of the circle:

$$\pi r^2 = area \quad 2$$

4. Calculate the area of the segment. This formula calculates the area of the sector defined by the central angle (C) and then subtracts the area of the triangle. This solves for the area of the segment, which represents the lost bone of the glenoid. Percent bone loss is calculated by the ratio of area of the segment:area of the circle.

Bone loss is expressed as a percentage of the lower glenoid circle and based on the area of a segment calculation. This is a direct calculation of bone loss (Fig. 3).

Additional Calculations

If accurate measurements are obtained with calibrated imaging software, the height (sagita) of the lost segment of bone can be determined. This value represents the thickness of the lost segment of bone.

$$sagita = r \pm \sqrt{r^2 - c^2} \quad 3$$

Results

Given a measurable glenoid height and measurable glenoid defect, the percent bone lost can be directly calculated.

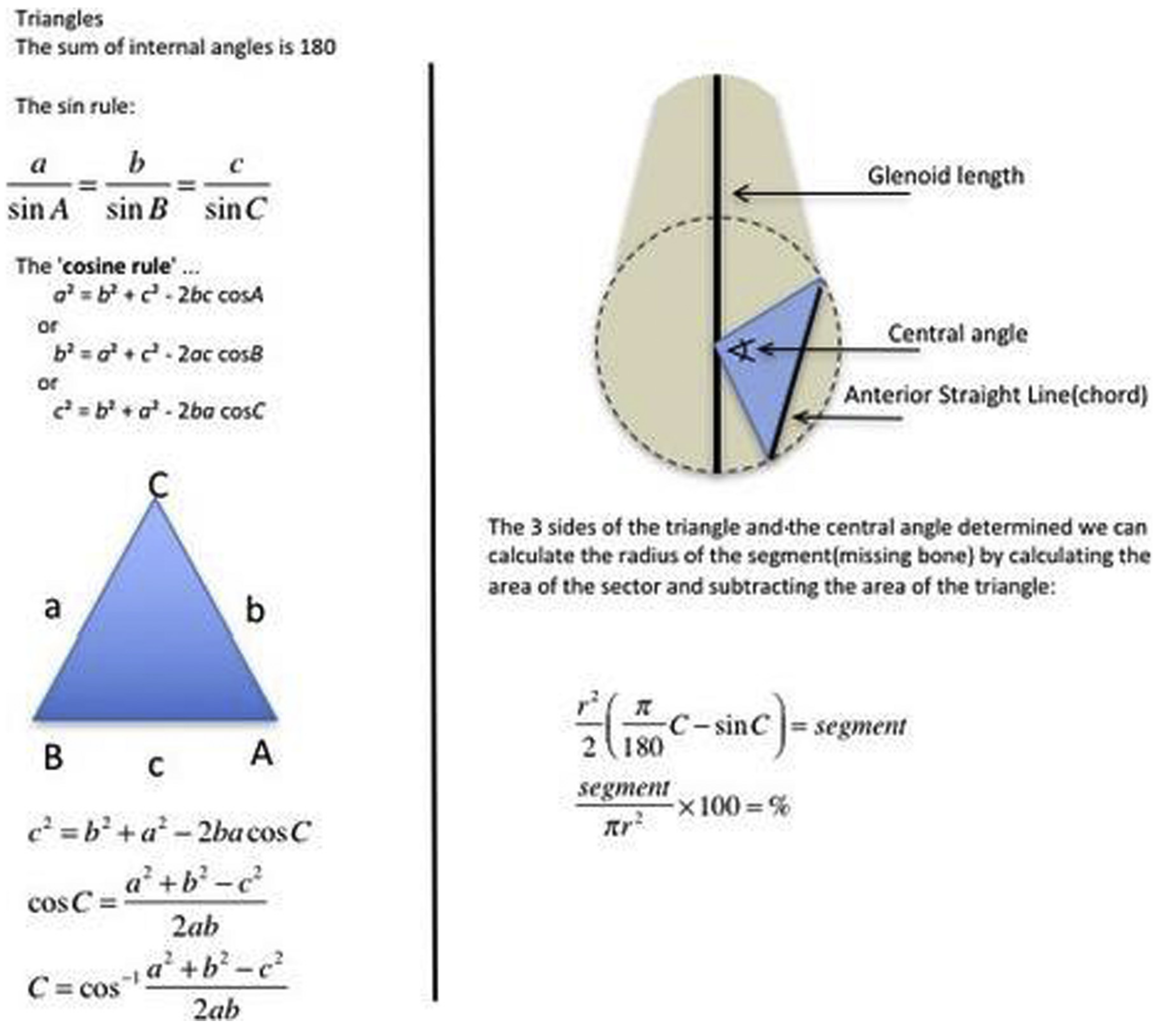


Figure 2 The triangle has the 3 sides known. Sides a and b are the radius of the circle, and side c is the chord. The central angle (*C*) is calculated with the *sin rule*. Calculate the area of the segment. The ratio of area of the segment/area of the circle = % bone loss.

Figure 3 shows the ratio of ASL to glenoid height compared with % bone loss. At a ratio of 0.50, the calculated bone loss is approximately 12%. A ratio of 0.57 represents approximately 20% bone loss.

Discussion

Glenoid bone loss can be calculated by direct measurement using sophisticated imaging software on CT and MRI (surface area bone loss) or estimated by radiographic or intraoperative measurements (estimated linear bone loss). There are 3 general methods in which bone loss is assessed or measured. The linear technique involves measuring the expected diameter of the glenoid by a variety of techniques at its maximal width and measuring the actual glenoid width and calculating the percent of bone lost. The linear technique can be done by direct measurement or intraoperative visualization. The surface area technique assumes the lower glenoid is a circle and calculates the lost segment of bone. The most common method is to overlay a best-fit circle on CT scan and either calculate the defect area or draw an outline, and the radiology software can calculate the area. As several methods have been in clinical use for calculating bone loss, it is important that the methodology for calculation be considered when comparing recommendations for treatment and outcome.

Bhatia et al discussed the different percent bone loss calculated by linear vs. the circle surface area method.[2] The authors showed that bone loss calculated varied by technique with maximal variability at 20% by the linear method that was equal to 14.2% by the surface area method. As many prior studies have made recommendations for treatment based on percent bone loss, the methodology used by the author is important, as the true critical bone loss is probably less than the original 20%-25%, which would influence a soft tissue vs. bone reconstruction of the glenoid.

Lo provided clinical outcome based on an estimation and calculation of bone loss using a linear method.[9] The center of the glenoid is determined, and the distance from the back of the glenoid(r) to the center and to the edge of the defect (a) is used in the calculation:

$$\frac{r-a}{2r} \times 100 = \%\ bone\ loss \qquad 4$$

In this study, the authors suggest the critical value for higher risk of recurrent instability is 20%. This method is also described for arthroscopic measurement of bone loss using the bare spot of the glenoid.[3] Whether the bare spot represents the center of the glenoid has come into question.[12] This equation assumes the glenoid is

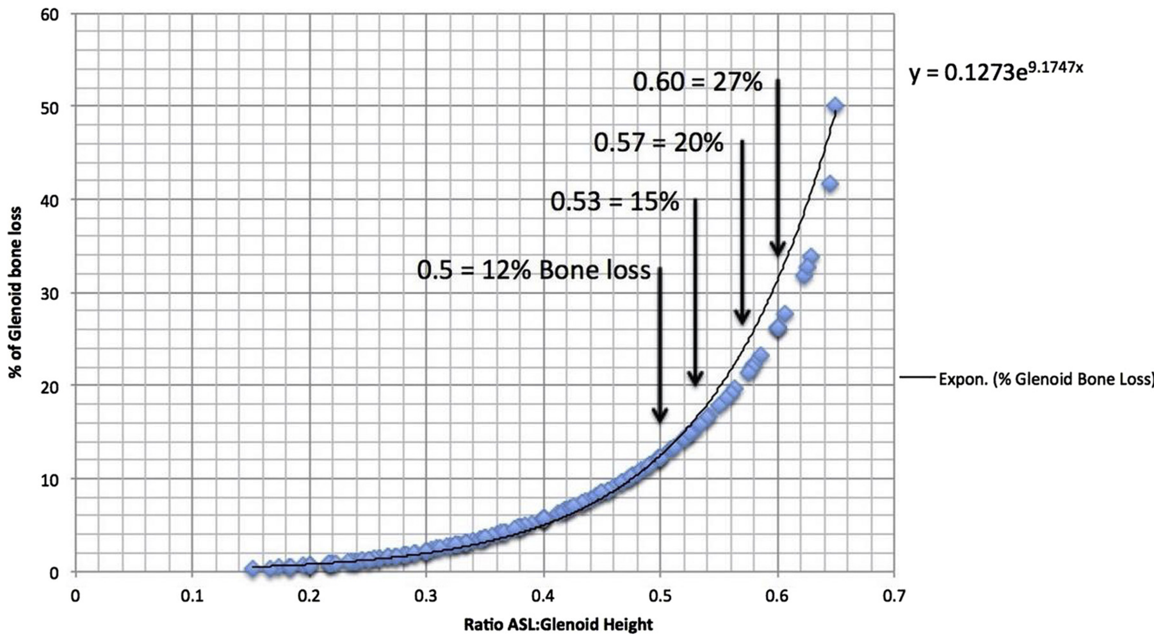


Figure 3 The ratio of anterior glenoid bone loss to glenoid height vs. the percent of glenoid bone loss.

linear and therefore will overestimate percent bone loss when compared with an equation that assumes the glenoid is a circle.

Provencher has described the secant method to determine more accurate measurements of the edge of the defect to the center of the circle and then uses the formula as above.[11] This is another linear calculation and will overestimate bone loss compared with the surface area method.

Direct measurement using software on CT and MRI can more accurately measure bone loss by the surface area technique. Sugaya, using 3D CT, used a best-fit circle method to directly measure glenoid bone loss.[15] Barchilon, using CT, determined the center of the lower glenoid as a best-fit circle.[1] The radius of the glenoid was measured, and the distance from the defect edge to the radius was measured. Using similar calculations as used in this article, the bone loss was directly calculated (surface area). The authors determined that when the ratio of the height of the defect from the center was 0.5 of the radii that bone loss was 20%.

Dumont et al described a method using a best-fit circle for the lower glenoid.[5] The center of the circle was defined, and lines are drawn to the upper and lower aspects of the defect. This defines the central angle, otherwise known as the glenoid arc angle, and the percent bone loss was calculated. The calculation of a central angle of 120 equals 19.6% bone loss by calculated surface area method. This method is consistent with our calculations as well. At a ratio of 0.56, the central angle is 119, and the bone loss is 19.1%. These methods require software that may not be available to the practicing orthopedic surgeon.

Finally, Detterline et al described the secant chord theory that also used the circular geometry of the inferior glenoid; however, this was done in an arthroscopic model.[4] Mathematical calculations are necessary, and it was determined that there is an error of 4% when arthroscopically determining bone loss. This can be significant when assessing the critical bone loss in clinical decision-making.

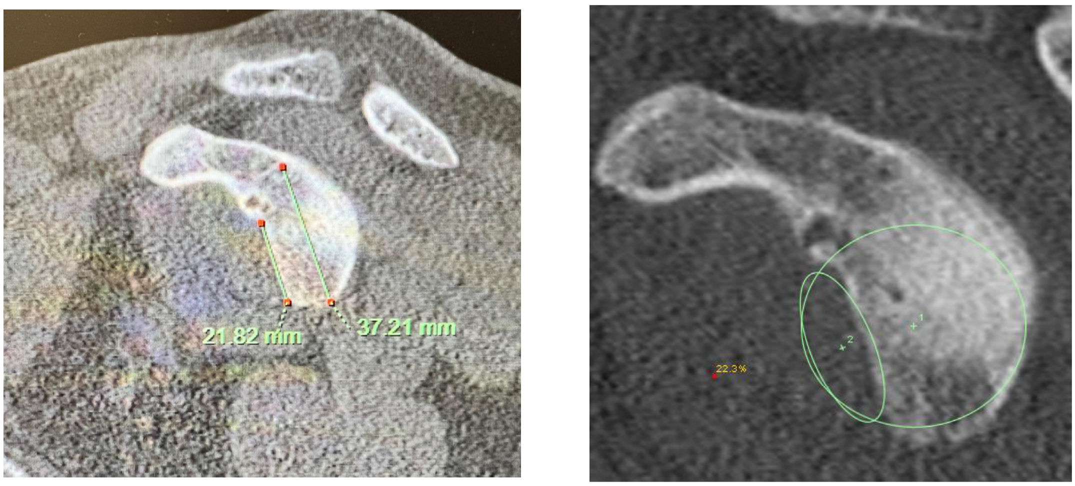
The calculation and ratio as presented in this article describe a method for calculation of bone loss on CT or MRI. The mathematical formulas have been previously reported, but the challenge has been in defining the radius of the lower glenoid. By using the relationship between the glenoid height and diameter of the lower glenoid, the clinician can simply measure the glenoid height and glenoid defect length of the defect directly. As this calculation involves a ratio, calibration of actual length is not needed to calculate percent bone loss. The clinician can complete the calculation or use the ratio that has been determined. This method is an estimate of bone loss and not an exact measurement. The main assumption for this calculation that has potential error is the glenoid height-to-width ratio, and other authors have identified other formulas. If the ratio approaches the definition of potential critical bone loss, the author recommends considering additional direct surface area calculation by 3D CT and advanced software. The value of this estimate is that the bone loss can be immediately calculated from CT or MRI and can provide the surgeon with satisfactory information to determine an operative plan. In certain cases, advanced software and repeat imaging may not be possible.

All techniques described in the literature require an assumption or estimation. Whether it is the size of the best-fit circle placed on an image by the radiologist or orthopedist, the center of the glenoid or bare spot, the outlining of the defect, or direct measurement of the defect, there may be error or interobserver variability.

The author chose to base this estimate on the work of Lenart et al.[8] They described the relationship between the length of the glenoid and maximal width or diameter as measured by MRI to be 0.65. In clinical use, MRI is commonly ordered to assess the injured patient after dislocation, and patients will frequently present to the clinician with MRIs in hand. Owens has also looked at the relationship between the glenoid and width on MRI and determined the glenoid width = 1/3 height + 15 mm.[10] Giles looked at CT scans and calculated the formula glenoid width = 2/3 glenoid height + 5 mm for men and +3 mm for women.[6] Both authors then used this calculation to measure bone loss by the linear method by estimating the expected width of the glenoid vs. the measured width.

Presented is a simple ratio for the clinicians to use that can determine bone loss by the surface area method of calculation and estimates the percent bone loss of the glenoid as represented as a circle. Using this method, the angle and location of the damaged bone do not affect the calculation. However, larger defects in the a

ASL	Glenoid Length	Ratio ASL:Glenoid Length	% BONE LOSS	Defect Height(mm)	Rad
21.8	37.2	0.586021505	23.34	6.86	12.09



b

ASL	Glenoid Length	Ratio ASL:Glenoid Length	% BONE LOSS	Defect Height(mm)	Rad
25.2	43.3	0.581986143	22.62	7.81	14.0725

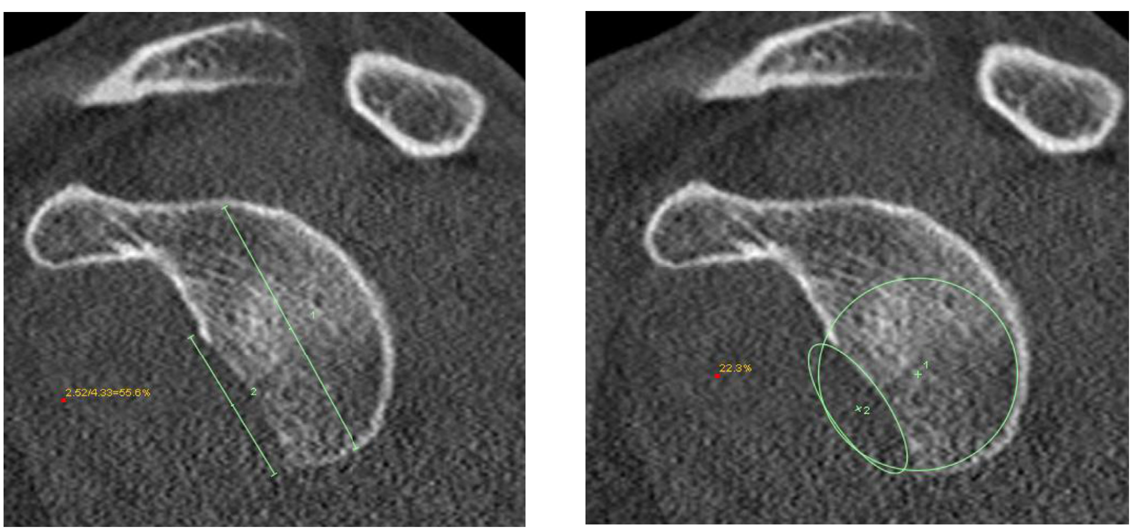


Figure 4 Glenoid bone loss calculation.

anterior location may extend beyond the circle of the lower glenoid. In this circumstance, the clinician should evaluate these calculations with caution, as this method may overestimate bone loss.

If calibrated measurements are performed, the height of the segment or thickness of the lost bone can also be calculated. This may aid the clinician in determining the best option of bony reconstruction of the glenoid. Currently, there is no guidance in the published studies recommending the thickness of a bone graft on the anterior glenoid. For instance, Lenart measured the average glenoid height at 37.5 mm. If the anterior glenoid defect is measured at 21.4 mm on calibrated images, the ratio is 0.57 or 20% bone loss, and the height of the lost segment can be calculated to 6.4 mm. This calculation may assist the surgeon in choosing a bone reconstructive option and in graft preparation. The authors also present an app that can immediately determine the surface area of glenoid bone loss based on these 2 straightforward measurements.

Once the glenoid height and length of the defect are measured, these are placed into the app and the percent bone loss is calculated. Figure 4 demonstrates 2 examples of these measurements with the estimated bone loss using the ratio in an excel format. In Figure 4, *A* and *B*, both heights (defect height and maximal glenoid height) were measured on the sagittal cuts of the CT scan and inserted into the excel table. The first image on the left is an estimate of the lengths of the defect and maximal height of the glenoid. The second image on the right is the bone loss calculation using the best-fit circle method with software by the radiologist. As is seen, the percent bone loss is nearly identical with both methods. As mentioned earlier, limitations do include variation in the measurement of the length of the defect and maximal height of the glenoid. The formulas were inserted into the appropriate cells, allowing for immediate calculation of the percent bone loss. It is the authors' belief that this is the value proposition of this method.

Advanced software calculations and 3D reconstructions are not necessary to assist with preoperative planning. The cost-effectiveness and immediate knowledge of pathology provide the clinician and patient with value without compromising quality.

Conclusion

The percent bone loss of the glenoid can be estimated by direct measurement of the glenoid height and the length of the glenoid defect. The mathematical proofs have been corroborated by multiple authors, and surgeons do need not the sophisticated software to determine bone loss. In this article, it has been shown if the length of the glenoid bony defect to the length of the glenoid is 0.5, then there is an estimated 12% bone loss, and if the ratio is 0.57, there is an estimated 20% bone loss by surface area. With these references and an app for more precise measurements, the glenoid loss can be estimated. Given the current climate of health care with a focus on value, cost, and patient satisfaction, this simple ratio can assist the clinician in timely decision-making in potentially complex shoulder instability cases.

Disclaimers:

Funding: No funding was disclosed by the authors.
Conflicts of interest: The authors, their immediate families, and any research foundation with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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