

Best-fit Circle Missing Area Method Shows Good Accuracy and Inter-rater Reliability When Assessing Glenoid Bone Loss

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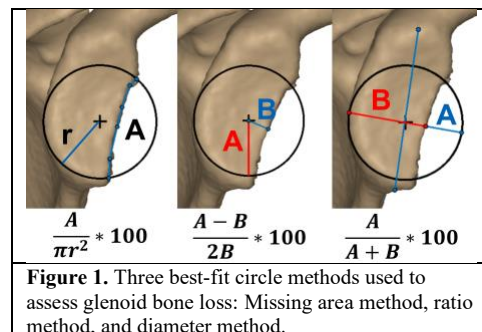
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INTRODUCTION: The incidence of anterior shoulder instability is as high as 3% in the athletic population.¹ Anterior shoulder instability typically occurs after an anterior shoulder dislocation, resulting in glenoid bone loss along the anteroinferior glenoid rim. One of the factors influencing the management of this injury is the percentage of glenoid bone loss. Current literature estimates critical bone loss to be between 10-15%.² Patients with less than the critical value are candidates for a minimally invasive procedure, while those with more than this value may require a more extensive procedure. Unfortunately, there is currently no consensus on how to accurately measure this bone loss. A variety of methods to measure bone loss have been proposed, many of which are variations of the best-fit circle to the inferior glenoid rim, such as the missing area, ratio, and diameter methods (Figure 1).³ Prior studies attempted to estimate the accuracy of these methods using cadavers and contralateral en face glenoid CT^{4,5} without knowing the true glenoid bone loss. The aim of this study was to assess the accuracy and interrater reliability of three common methods for measuring glenoid bone loss where the true glenoid bone loss was known. We hypothesized that the best fit circle missing area method would have better accuracy and interrater reliability than the ratio method and diameter method.

METHODS: In this IRB-approved study, participants were enrolled if they were between the ages of 18-30 and had no prior history of instability or prior shoulder surgery. CTs of the participants bilateral shoulders were acquired. 3D models of the scapula were made from a combination of semi-automatic and manual segmentation of the CT scans using Mimics software. Five bone loss models were created from each participant's scapula by manually removing from 5-30% of the bone from the anteroinferior region of the glenoid on the original CT volume. The native bone area was measured semi-automatically by segmenting the glenoid fossa from the intact model and aligning it using principle component analysis (pca) before fitting a circle to the inferior rim of the glenoid fossa and calculating the area of the circle. Each bone loss model was then aligned using the same pca transform, and the area between the glenoid fossa edge and the circle boundary was calculated to measure the ground-truth missing area. All bone loss models were loaded into a customized Matlab application that randomized the order of models for measurements by three reviewers (2 orthopedic residents and 1 orthopaedic sports fellow) who were blinded to the true bone loss of each model. Bone loss was measured using three common best-fit circle techniques: missing area method, ratio method, and diameter method (Figure 1). The accuracy of each method was assessed by the root mean square error (RMSE), obtained by comparing the measured to the known bone loss. Intraclass Correlation Coefficients (ICC) using a 2 way random-effects modeled with consistency were calculated to determine the inter-rater reliability of the assessments. ICC between 0.75-0.90 was classified as good, using the Portney and Watkins criteria.⁶ Bias was measured by finding the average difference between the measured and true glenoid bone loss for each model.



RESULTS: Four male, right shoulders were used to create the 20 bone loss models (average age: 22.5 ± 3.4 years old, average BMI: 24.8 ± 5.5). RMSE of the missing area method (3.8 mm^2) was better than the ratio method (7.8 mm^2) and the diameter method (6.4 mm^2) (Table 1). Inter-rater reliability of the missing area method (ICC = 0.82), ratio method (ICC = 0.88), and diameter method (ICC = 0.82) were all good⁶ (Table 1). The missing area method underestimated bone loss by 0.4%, while the ratio method and diameter method overestimated bone loss by 7% and 5.6%. Bias was unchanged over the range of bone loss (Figure 2).

DISCUSSION: To date, there is no standard method to calculate glenoid bone loss. The missing area method appears to be the most accurate of the three methods analyzed. However, this method mainly underestimated bone loss, while the other two methods overestimated bone loss. Additionally, our study shows good inter-rater reliability with all three commonly used best-fit circle methods. Having an accurate predictor of bone loss is critical when deciding between surgical options since prior studies have shown high rates of recurrent instability and revision surgeries in patients with bony Bankart lesions that were underestimated.⁴ This study is unique in that the true glenoid bone loss was known for each bone model. This allowed us to calculate the accuracy when measuring percent bone loss with each measurement technique. An additional strength of the study is that simulated bone loss encompassed the critical bone loss range of 10-15%. A limitation of the study is that bone loss was measured on 3D models and most clinical measurements are done on individual CT slices. This work will be expanded to include more graders with a wider range of experience and measurements will be made on CT slices.

SIGNIFICANCE: Using the best-fit circle missing area method may provide shoulder surgeons with an accurate and reproducible method of determining glenoid bone loss.

REFERENCES: 1) Waterman et al., *Sports Health*, 2016 2) Levy et al., *Sports Health* 2020 3) Arenas-Miquelez et al., *AJSM* 2020 4) Bakshi et al., *AJSM* 2018 5) Verweij et al., 2020 Arthroscopy 6) Portney and Watkins, *Foundations of clinical research: applications to practice* 2009

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Table 1. RMSE and ICC for all reviewers using each best-fit circle measurement.

	Missing Area Method	Ratio Method	Diameter Method
RMSE	3.8 mm ²	7.8 mm ²	6.4 mm ²
ICC	0.82	0.88	0.82

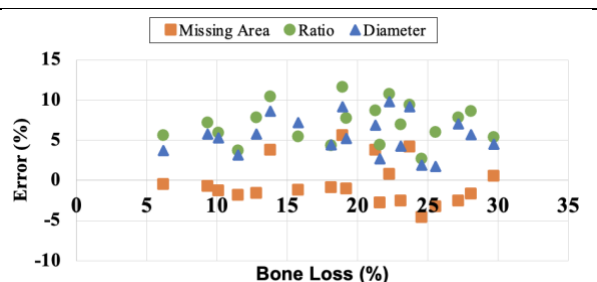


Figure 2. Average difference between known and measured bone loss with varying levels of glenoid bone loss using the Missing area method (orange squares), Ratio method (green circles), and Diameter method (blue triangles).