

Simple Linear Calculating Method of Glenoid Bone Defects Using 3-Dimensional Computed Tomography Based on an East Asian Population in China

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Background: The evaluation of glenoid bone defects in the preoperative stage for patients with anterior shoulder instability is critical for surgical decision making. A novel method that predicts the intact glenoid width based purely on the measurement of the glenoid height has been advocated. Despite the convenience, all studies to date have focused on the Western population, and there is no similar research based on an East Asian population.

Purpose: To determine the relationship between glenoid height and width in an East Asian population.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: Spiral computed tomography (CT) scans of both sides of the shoulder joints were obtained from 205 patients of Han nationality (China) who had no history of shoulder trauma or pain. The maximal height and width of each glenoid were measured on the en face view by 2 radiologists who were blinded to each other's results. Pearson correlation coefficients and multivariable linear regression were calculated from all data measured to evaluate the relationship between maximal glenoid height and width between the sexes.

Results: A total of 205 patients (410 shoulder CT scans) were analyzed. The mean glenoid height was 34.45 ± 2.82 mm, and the mean glenoid width was 23.35 ± 2.40 mm. There was a statistical difference between male and female patients with regard to glenoid height (36.61 vs 32.39 mm, respectively; $t = 9.76$; $P < .001$) and width (25.26 vs 21.54 mm, respectively; $t = 20.73$; $P < .001$). Analysis of the measured glenoid height and width demonstrated a strong linear correlation of 0.82 ($R^2 = 0.68$; $P < .001$) for the entire cohort and similarly strong linear correlations when each sex was analyzed separately. For male patients, the glenoid width was measured as: glenoid height $\times 0.50 + 7$ mm ($R^2 = 0.36$; $P < .001$); for female patients, the glenoid width was measured as: glenoid height $\times 0.45 + 7$ mm ($R^2 = 0.31$; $P < .001$).

Conclusion: In an East Asian population, the mean glenoid height and width were 34.45 and 23.35 mm, respectively. The formulas that represent the relationship between glenoid width and height for male and female patients are the following: glenoid width = glenoid height $\times 0.50 + 7$ mm and glenoid width = glenoid height $\times 0.45 + 7$ mm, respectively.

Keywords: shoulder instability; bone loss; CT; East Asian

Anterior shoulder instability is a common traumatic disease with an annual incidence between 0.084% and 1.7%.^{10,19} Stability of the shoulder joint requires complex musculoskeletal interactions. The osseous structure, as well as its integrity, are among the most critical components that influence clinical results. Glenoid bone defects (GBDs), which have been reported from 8% to 90% of recurrent anterior shoulder instability cases, can result in ongoing instability and recurrent dislocations due to diminished

congruency of glenohumeral contact surfaces and their concavity.^{7,11,20} Numerous biomechanical studies^{12,14} have proven that GBDs can impair shoulder stability. Clinical studies^{1,4,5,15,20,21} have also demonstrated a significant correlation between the amount of defect and the recurrence rate of instability after surgical repair. The critical threshold percentage of defect over which the risk of recurrence after surgical treatment becomes clinically relevant is considered to be about 20% to 25% of the glenoid width.[§] Bone reconstruction or augmentation surgery is recommended in such cases.

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Therefore, recognizing and precisely evaluating a GBD in the preoperative stage are critical for surgical decision making. Several methods to measure the presence and size of a GBD have been described in the literature. However, the accurate quantification of bone loss and morphology is still a significant challenge. Currently, the most widely used method is based on a study published by Sugaya et al,²⁰ which used the en face view of the glenoid with 3-dimensional (3D) computed tomography (CT). It is based on the principle that the geometry of the inferior two-thirds of the glenoid is a true circle.¹¹ By measuring the width of the osseous defect and dividing it by the diameter of the best-fit circle, the percentage of defect can be calculated. However, several studies^{1,2} have questioned the accuracy of this technique. In addition, it requires postimaging software, which is complicated and may not be available in all surgical centers.^{8,16,18}

As such, a novel method that predicted the intact glenoid width based purely on the measurement of the glenoid height was advocated, and a simple formula was created that allowed for easy calculation of the percentage of defect.^{8,16} Despite the convenience, all studies focused on the Western population.^{8,16} There is no similar research based on an East Asian population. The purpose of this study was to determine the relationship between glenoid height and width in an East Asian population. We hypothesized that the relationship between glenoid height and width would also correlate in an East Asian population and that a formula could be determined for calculating the expected glenoid width.

METHODS

This study was approved by the ethical committee of our hospital. For this study, we enlisted 205 patients from China who had no previous shoulder trauma or pain and underwent low-dose spiral CT of the chest, which showed right and left shoulder joints. All of the 205 patients were of Han nationality. Only young and skeletally mature patients were enrolled in the study to avoid the influence of arthritis or epiphysis. Patients with any signs of bone loss, fractures, arthritis, and abnormalities in the shoulder on CT were excluded from the study. Therefore, the mean patient age was 32.1 ± 5.4 years (range, 18-40 years), and there were 100 male and 105 female patients. Neither height nor weight was recorded.

All CT scans were obtained using a 320-slice scanner (Aquilion One; Canon) or a 128-section scanner (Revolution CT; GE Healthcare). The helical CT parameters included a 0.992-mm collimation, 0.625-mm reconstruction interval,

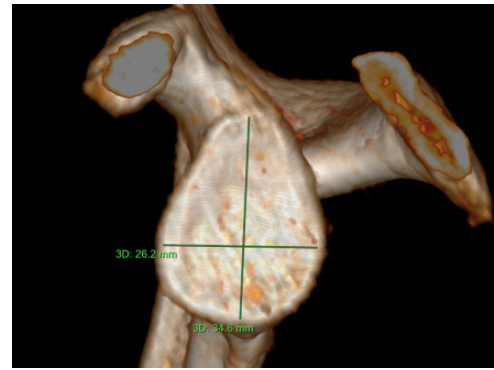


Figure 1. En face view used for measurement of the glenoid height and width.

120 kV, 50 mA, 1:1 table pitch, rotation time of 0.5 seconds, and standard reconstruction algorithm. The scans were analyzed by Carestream Vue PACS software. Three-dimensional CT reconstructions of the bilateral glenoid with subtraction of the humeral head were obtained. The en face view was obtained via a 2-step process: alignment of the axial plane to account for the scapular angle followed by alignment of the coronal plane to adjust for glenoid inclination.

The height and width of each glenoid were measured using the same methodology as Giles et al.⁸ The minimum glenoid height was determined to be the minimum length possible from the superior pole (12-o'clock position) to the inferior pole (6-o'clock position) of the glenoid. The minimum width was the maximum length possible in an orthogonal orientation to the measured height line (Figure 1). All measurements, including right and left sides of the shoulder, were performed on the en face view by 2 radiologists (L.D. and W-F. L.) who were blinded to each other's results.

Statistical Analysis

All measurements were displayed to a tenth of a millimeter. For interobserver reliability, the intraclass correlation coefficient (ICC) was calculated for measurements between the observers. Confidence intervals were calculated at the 95% level for reliability coefficients. ICC values ranging from 0.81 to 1.00 indicated very good reliability.

The mean values of the 2 observers were used for further data analysis. An independent 2-tailed *t* test was used to examine the difference in glenoid height and width measurements between male and female patients. A paired 2-tailed *t* test was performed to determine whether there was a statistically significant difference between the left

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Ethical approval for this study was obtained from the China-Japan Friendship Hospital (2019-84-K55).

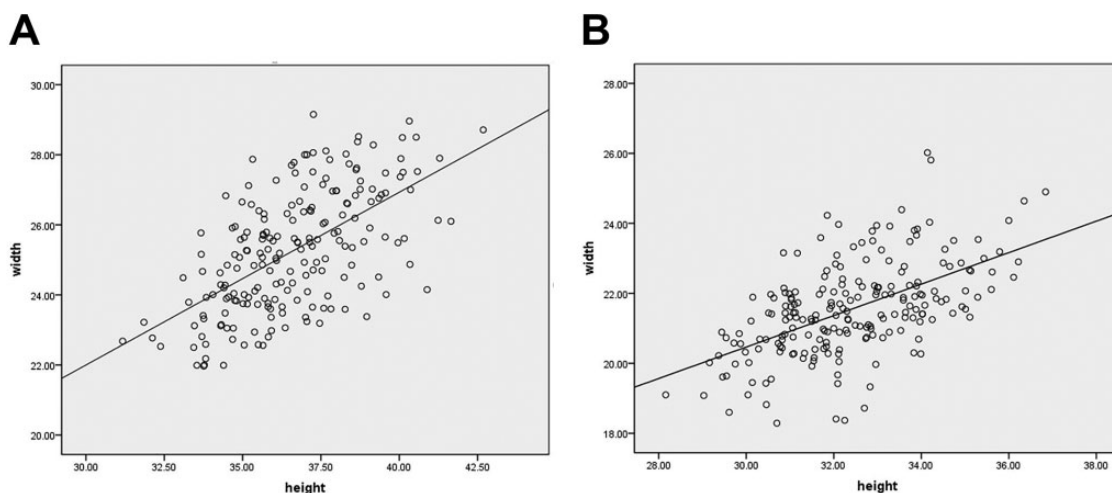


Figure 2. Regression analysis between glenoid height and width for (A) male and (B) female patients.

TABLE 1
Hypothetical GBD Measurements^a

Patient	Sex	Measured Glenoid Height, mm	Predicted Glenoid Width, ^b mm	Measured Glenoid Width, mm	Percent Defect	Recommended Surgical Procedure
1	Male	40.72	27.36	25.45	7	Soft tissue repair
2	Female	34.87	22.69	17.19	24	Bone augmentation
3	Male	38.44	26.22	27.72	-6 ^c	Soft tissue repair
4	Female	32.95	21.82	17.47	20	Need more information
5	Male	36.90	25.45	17.75	30	Bone augmentation

^aGBD, glenoid bone defect.

^bMeasured using the following formula: for male patients, glenoid width = glenoid height × 0.50 + 7 mm; for female patients, glenoid width = glenoid height × 0.45 + 7 mm.

^cMeasured glenoid width may be larger than predicted glenoid width; indicates no GBDs in this patient.

and right sides of the glenoid in maximum height and width. Pearson correlation coefficients and multivariable linear regression were calculated from all data measured to evaluate the relationship between maximum glenoid height and width between the sexes. A *P* value <.05 was considered statistically significant. All analyses were performed using SPSS 20.0 (IBM).

RESULTS

A total of 205 patients with 410 shoulder CT scans were analyzed. For the entire cohort, the mean glenoid height was 34.45 ± 2.82 mm, and the mean glenoid width was 23.35 ± 2.40 mm. For male and female patients, respectively, the mean glenoid height was 36.61 ± 2.08 and 32.39 ± 1.66 mm, and the mean glenoid width was 25.26 ± 1.70 and 21.54 ± 1.34 mm. There was a statistical difference between male and female patients regarding glenoid height (*t* = 9.76; *P* < .001) and width (*t* = 20.73; *P* < .001). Analysis of interobserver reliability showed that ICC values of the glenoid height and width were 0.91 (95% CI, 0.89-0.92) and 0.96 (95% CI, 0.95-0.97), respectively, which indicated very

good reliability. There was no statistical difference between the left and right sides in glenoid height (*t* = 1.32; *P* = .19) and width (*t* = 0.76; *P* = .45).

Analysis of the measured glenoid height and width demonstrated a strong linear correlation of 0.82 (*R*² = 0.68; *P* < .001) for the entire cohort and similarly strong linear correlations when each sex was analyzed separately. The formula that represented the relationship between glenoid width and height was also generated separately. For male patients, glenoid width = glenoid height × 0.50 + 7 mm (*R*² = 0.36; *P* < .001), and for female patients, glenoid width = glenoid height × 0.45 + 7 mm (*R*² = 0.31; *P* < .001) (Figure 2).

DISCUSSION

The most important finding of our study was that there was a strong linear correlation between glenoid height and width in an East Asian population. To the best of our knowledge, no similar studies designed for a purely East Asian population have been published, and this study is the first to evaluate the relationship between glenoid height and

width in an East Asian population. GBDs can be easily measured with the presented formulas (Table 1). Compared with a previous study⁸ that also utilized CT, the mean glenoid height was 33.3 ± 2.9 mm in a Western population and 34.45 ± 2.82 mm in an East Asian population (current study), and the mean glenoid width was 26.2 ± 2.5 mm in a Western population and 23.35 ± 2.40 mm in an East Asian population (current study). Based on our findings, the morphological characteristics of the glenoid are not quite the same in East Asian and Western populations. The shape of the glenoid in an East Asian population is longer but narrower than that in a Western population.

The osseous structure, as well as integrity, is one of the most critical components that influences the surgical treatment of anterior shoulder instability. Burkhart and De Beer⁴ analyzed 194 consecutive patients with traumatic anterior shoulder instability who all were treated with arthroscopic Bankart repair using suture anchors. Their results showed that if there was no significant GBD, the recurrence rate for subluxations or dislocations was only 4%; however, if a significant GBD existed, the recurrence rate was up to 67%. Therefore, an accurate assessment of the amount of defect is critical for surgical decision making as well as to determine whether Bankart repair is sufficient or bone augmentation surgery is necessary.

Significant variability exists in different methods of measuring GBDs, even when using the same imaging modality.¹ No gold standard has been established. One of the most common concepts described in the literature utilizes the diameter of the “best-fit circle” circumscribed around the inferior two-thirds of the glenoid, which was first proposed by Sugaya et al²⁰ using 3D CT. However, this method requires postimaging software, which may not be available at all centers. Also, the accuracy of this method has been challenged. Bhatia et al² reported that diameter-based quantification of GBDs overestimates true GBDs, with the maximum error occurring when theorized bone loss is up to 20%. Bakshi et al¹ also questioned the validity and accuracy of the best-fit circle method using linear measurements. They suggested that linear measurements of glenoid bone loss significantly overestimate bone loss compared with surface area measurements in patients with anterior GBDs.

One novel method introduced by Owens et al¹⁶ and Giles et al⁸ predicted the intact glenoid width based purely on the measurement of the glenoid height using a simple linear formula. With this, GBDs could be calculated easily. Based on our findings, the shape of the glenoid in an East Asian population was quite different from that in a Western population. The mean glenoid height was 33.3 ± 2.9 mm in the Western population and 34.45 ± 2.82 mm in the East Asian population, and the mean glenoid width was 26.2 ± 2.5 mm in the Western population and 23.35 ± 2.40 mm in the East Asian population. Therefore, we conducted linear regression analyses for the East Asian population: for male patients, glenoid width = glenoid height $\times 0.50 + 7$ mm, and for female patients, glenoid width = glenoid height $\times 0.45 + 7$ mm. In comparison, Giles et al utilized the following formulas for the Western population: for male patients, glenoid width = glenoid height $\times 2/3 + 5$

mm, and for female patients, glenoid width = glenoid height $\times 2/3 + 3$ mm.

Bone augmentation surgery, such as the Latarjet procedure, has been recommended but is still controversial. In a classic biomechanical study, Itoi et al¹² found that stability of the shoulder decreases progressively as the amount of defect increases, dropping off notably with defects greater than 21%. Another classic study by Lo et al¹⁴ recommended a loss of 25% to 27% of the inferior glenoid width with the appearance of an inverted pear-shaped glenoid, which needed bone augmentation surgery. Various clinical studies^{3,15} have also suggested that the threshold for bone augmentation surgery in anterior shoulder instability is between 20% and 25% of the glenoid width. However, bone resorption of the transferred coracoid is a complex phenomenon after a Latarjet procedure.²¹ The concept of the glenoid track, which can predict engagement between glenoid and humeral head defects, is dependent on the size of the GBD as well as on the size and location of the Hill-Sachs lesion.⁶

This study has several limitations. First, sometimes, the shape of the GBD was irregular, and the measurement of the maximal width could be ambiguous. Combining multiple measurement methods was necessary for those patients. In addition, only an East Asian population (Mongolian) was included in this study; hence, it may not be suitable for other areas in Asia. Furthermore, the study did not include people older than 40 years, therefore the accuracy of the formula in a geriatric population may have been compromised. However, a previous study⁸ explained that the measurement of the glenoid width and height is not directly influenced by age. Therefore, the evaluated glenoid morphological characteristics should represent the population of interest. Finally, this method has not been used in patients with shoulder instability, nor has it been compared with other methods such as that of Sugaya et al.²⁰ Further studies could focus on these areas.

CONCLUSION

The mean glenoid height was 34.45 mm, and the mean glenoid width was 23.35 mm for an East Asian population. The formulas that represent the relationship between glenoid width and height are as follows: for male patients, glenoid width = glenoid height $\times 0.50 + 7$ mm, and for female patients, glenoid width = glenoid height $\times 0.45 + 7$ mm.

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