The greater tuberosity radius ratio: maybe a new predictor in diagnosis of rotator cuff tear

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Research article

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Abstract

Background

The role of the greater tuberosity of humerus in subacromial impingement should be of equal important as the acromion. In this study we concerned on the morphological characteristics of the greater tuberosity of humerus and proposed the greater tuberosity radius ratio (GTRR) as a new predictor for the diagnosis of rotator cuff tear. We hypothesized that a larger value of the GTRR could increase the risk of developing rotator cuff tear.

Methods

This was a retrospective study and clinical data and preoperative computed tomography images of the patients with rotator cuff tears (defined as the RCT group, simple size: 61) or without rotator cuff tears (defined as the control group, simple size: 56) were collected. Three-dimensional models of shoulders were established by multiplanar reconstruction of computed tomography scans. In a standard anteroposterior view, the radius of the best-fit circle of the humeral head (the r) and the radius of the concentric circle passing through the most superolateral edge of the greater tuberosity (the R) were measured for each shoulder. The ratio of R and r (R/r) was defined as the greater tuberosity radius ratio (GTRR). Independent samples t tests were used to find significant differences within the r, the R and the GTRR between groups. Receiver operating characteristic (ROC) curve based on the values of GTRR was performed to determine an applied cutoff value which may be useful in clinical practice.

Results

There was no significant difference in the values of r or R. However, the mean values of GTRR were 1.339 ± 0.143 (range, 1.087–1.684) and 1.244 ± 0.172 (range, 1.040–1.706) in the two groups respectively (p = 0.002). According to the ROC curve, an optimized cutoff value of GTRR was determined as 1.262, whose sensitivity was 72% and specificity was 65% for diagnosis of rotator cuff tear.

Conclusion

The greater tuberosity of humerus contributes to the mechanisms of rotator cuff tear. The greater tuberosity radius ratio is recommended as a new predictor for diagnosis of rotator cuff tear, with an optimized cutoff value set as 1.262.

Background

Rotator cuff tear (RCT) is the most common disorder of shoulder nowadays and is characterized by shoulder pain and limitation of shoulder activity. The mechanisms contributed to RCT are mainly classified into two respects: the intrinsic factors and the extrinsic factors. The intrinsic factors including tensile overload, aging, microvascular supply, and traumatisms usually result in degeneration of the tendon itself[1]. The extrinsic factors are some anatomic variables such as acromial morphologic characteristics, acromial spurs and morphology of coracoacromial ligament, which would narrow the subacromial space and increase pressure on tendons by impingement mainly from the acromion and the greater tuberosity (GT) of humerus[1,2]. There still exist debates on which mechanism is primary or secondary, but in some patients, it seems to be an interaction between them.

Subacromial decompression with repair of teared tendons has been a very popular method to treat RCT for a long period of time, and the number of surgeries with subacromial decompression has increased significantly in the last two decades in America and the United Kingdom[3,4]. In most cases, the procedures of subacromial decompression consist of debridement of bursa, resection of anterior acromion and release of coracoacromial ligament without involvement of humeral head[5,6,7,8]. However, any impingement related with RCT is formed by both acromion and the GT of humerus, which means the GT is of equal important in the progression of subacromial impingement. Previous study has shown that RCT may occur following GT fracture and is associated with a poor outcome[9]. In another research, arthroscopic tuberoplasty yielded satisfactory outcomes during a mean eight-year follow up in the treatment of irreparable massive RCTs[10]. Therefore, we emphasize the important role of the GT in the formation of RCT and believe that the GT deserves more attention in further researches.

In this study we concerned on the morphological characteristics of the GT of humerus and aimed to find a new predictor which helps diagnose RCT in clinical practice. With the utilization of computed tomography (CT) of shoulder joint, we proposed the greater tuberosity radius ratio (GTRR) as the new predictor because this parameter associates strongly with the lateral extension of the GT. We hypothesized that a larger value of the GTRR could increase the risk of developing RCT.

Materials And Methods

Patients

The cohort consisting of patients with rotator cuff tears was defined as the RCT group. The inclusion criterion for the RCT group was (i) RCT diagnosed by magnetic resonance imaging from January 2017 to March 2020. The exclusion criteria for the RCT group were (i) tendinosis, (ii) osteoarthritis, (iii) history of fractures or dislocations around shoulder joint, and (iv) previous surgery around shoulder joint. The cohort consisting of patients without rotator cuff tears was defined as the control group. The inclusion criterion for the control group was (i) CT scans done mainly for blunt trauma at our trauma center from March 2018 to March 2020. The exclusion criteria for the control group were (i) shoulder diagnosed with RCT by magnetic resonance imaging, (ii) previous history of shoulder pathology such as symptomatic shoulder pain, tendinosis, dislocations or fractures around shoulder joint, (iii) sustaining a shoulder injury as a result of trauma, and (iv) previous surgery around shoulder joint. We retrospectively collected clinical data and preoperative CT images of all patients included in this study. Valid CT scans were performed with patients lying supine and with their arms by their side in neutral rotation. Those CT scans with patients rising their arms above their heads or crossing their arms upon abdomens were excluded. Finally, we got 61 shoulders for the RCT group and 56 shoulders for the control group.

Measurements

We used the United Imaging Medical Processing Software (uWS-CT, version R004, United Imaging, Shanghai, China) to analyze the CT images with slice thickness of 1.0·0.8 mm. Through multiplanar reconstruction we could get a complete shoulder joint in three-dimensional (3D) vision. Subsequent measurements were based on these 3D models.

A coordinate system established on scapula was necessary. We defined the center of the best-fit circle of the inferior glenoid as the origin (the point O). The line connecting the origin and the point where the scapular spine intersected the medial border of the scapula (SM) was set as Z-axis. The plane determined by the Z-axis and the most inferior point on the inferior scapular angle (SI) was defined as YZ plane. The line starting from the origin and perpendicular to the YZ plane was X-axis, and the line beginning from the origin and perpendicular to the XZ plane was Y-axis (Fig. 1A). According to Suter et al.'s and Karns et al.'s opinions[11,12], by rotating scapula around the Y-axis to correct the glenoid version, we could get a viewing perspective with an overlap of the anterior and posterior contour of the glenoid when looking perpendicular to the YZ plane, which was thought to resemble the true anteroposterior view of shoulder joint (Fig. 1B). In this view, the best-fit circle of the humeral head was defined as the smaller circle. The center of the smaller circle was set as point C and the radius of the smaller circle was defined as r. Then we drew a concentric circle with the point C as the center and made this circle pass through the most superolateral edge of the GT. The radius of this larger circle was defined as R (Fig. 1B). We measured the r and R for every shoulder and calculated the ratio of R and r (R/r), which was defined as the greater tuberosity radius ratio (GTRR). To increase the accuracy of measurement, each value was measured at two separate time points by the same person and the average value was used for the calculation.

Statistics

Statistical analysis was conducted with SPSS Statistics for Windows 24.0 software (IBM, Armonk, NY, USA). All quantitative values were reported as mean ± standard deviation (SD). Independent samples t tests were used to find significant differences within the age, the r, the R and the GTRR between the RCT group and the control group. Pearson correlation coefficient between the values of r and R was calculated. Chi-square tests were performed to compare the differences of sex and affected sides between the two groups. Reliability analysis by using the Cronbach' alpha coefficient for the measurements at two separate time points was conducted to check the reproducibility of these values. Receiver operating characteristic (ROC) curve based on the values of GTRR was performed to determine an applied cutoff value which may be useful in clinical practice. For all tests a p value of <0.05 was considered statistically significant.

Results

The demographic information and target variables were shown in Table 1. Age of the patients was described as mean ± SD (range), and no significant difference was found between the two groups, with an average age of 60.0 years versus 57.3 years ($p = 0.129$). Females were significantly more than males in the RCT group, while in the control group, males were in the majority ($p = 0.037$). Right shoulders involved in the RCT group were approximately twice as many as the left, however, in the control group the situation was just the opposite ($p = 0.002$). The values of r, R and GTRR were presented as mean ± SD (range). There were no significant differences when comparing the r or the R between the two groups, with a mean r value of 1.893 cm ± 0.232 cm (range, 1.5 cm − 2.4 cm) and a mean R value of 2.518 cm ± 0.268 cm (range, 2.0 cm − 3.2 cm) in the RCT group, and a mean r value of 1.954 cm ± 0.263 cm (range, 1.5 cm − 2.5 cm) and a mean R value of 2.420 cm ± 0.400 cm (range, 1.6 cm − 3.3 cm) in the control group respectively (r, $p = 0.191$; R, $p = 0.125$). However, we found that the values of GTRR were significantly higher in the RCT group, with a mean of 1.339 ± 0.143 (range, 1.087–1.684) compared with a mean of 1.244 ± 0.172 (range, 1.040–1.706) in the control group ($p = 0.002$).

Table 1
Demographics and target variables of two groups

Variable	RCT group (n = 61)	Control group (n = 56)	P
Age, yr	60.0 ± 9.4 (39–79)	57.3 ± 9.5 (38–81)	0.129
Sex, No.			0.037
Male	21	30	
Female	40	26	
Affected side, No.			0.002
Right	41	22	
Left	20	34	
r, cm (range)	1.893 ± 0.232 (1.5–2.4)	1.954 ± 0.263 (1.5–2.5)	0.191
R, cm (range)	2.518 ± 0.268 (2.0-3.2)	2.420 ± 0.400 (1.6–3.3)	0.125
GTRR (range)	1.339 ± 0.143 (1.087–1.684)	1.244 ± 0.172 (1.040–1.706)	0.002
Continuous data are shown as mean ± standard deviation (range) and categoric data as indicated. RCT, rotator cuff tear. GTRR, greater tuberosity radius ratio.			
List of abbreviations			
RCT, rotator cuff tear.			
GT, greater tuberosity.			
CT, computed tomography.			
GTRR, greater tuberosity radius ratio.			
3D, three-dimensional.			
SD, standard deviation.			
ROC, receiver operating characteristic.			
AUC, area under curve.			
Declarations:			

The Pearson correlation coefficient between the values of r and R was 0.557 (p = 0.000), which means a moderate positive correlation between them.

Cronbach' alpha coefficient for the measurements of r at two separate time points was 0.972, and for the measurements of R was 0.986. Scatter diagrams were shown in Fig. 2.

The ROC curve based on the values of the GTRR was pictured in Fig. 3. The area under curve (AUC) was 0.686 with 95% confidence intervals being 0.586–0.786 ($p = 0.001$). According to the ROC curve, an optimized cutoff value was determined as 1.262, whose sensitivity was 72% and specificity was 65% for diagnosis of RCT.

Discussion

The debate for the primary mechanism contributed to RCT has been discussed for many years but the answer is still not clear. From an extrinsic point of view, the impingement formed by both acromion and humeral head is a key procedure to increase pressure on tendons. Therefore, the role of humeral head in the progression of the illness should be the same important as that of acromion. A superior humeral translation relative to glenoid was observed in patients with subacromial impingement syndrome in previous kinematic study[13]. As the superolateral humeral bony projection, the GT is very likely to compromise the subacromial space when abducting or elevating arm. It is very necessary and urgent to discover the relationship between the morphological characteristics of the GT and the formation of RCT for a better understanding of the whole pathological process.

In our study, significant differences were found in the values of GTRR between the two groups, however, no significant differences were observed when comparing the r or the R. This was a dramatic result and had not been discussed in any other researches before. Previous studies indicated that geometric parameters of humeral head, such as the radius of curvature, the articular surface diameter, the articular surface thickness and so on, could be different according to the differences of race, sex, age, height and weight[14,15,16]. So the values of r or R could differ from person to person as a result of demographic diversity. The Pearson correlation analysis indicated that there was a moderate positive correlation between the values of r and R, which meant the R could change according to the variation of the r. In most cases, a larger value of r usually correlates to a larger value of R. Based on these backgrounds, it is reasonable to realize that a normal person who is higher and heavier could even have a larger humeral head (namely a higher value of r or R) than a patient who is diagnosed with subacromial impingement syndrome but is shorter and thinner. Taking into account the differences of age (though not significant in this study), sexual ratio, height and weight of our cohort, we believed that the results involved with the values of r or R were not sufficient to reflect the truth, and the bias did exist. In order to get a more accurate result, we need a cohort whose demographic characteristics are almost the same, which is hard to achieve in reality.

As a highlight of our research, the design of the GTRR may be a solution for the bias produced by demographic diversity. According to the backgrounds mentioned above, we know that the values of r and R are associated with not only the illness itself, but also the individual differences. With the utilization of division method, we could reduce the influence brought by individual differences and make the results present more information about the illness. The value of R is a direct parameter to measure superolateral extension of the GT, whereas the value of GTRR, which is calculated by division of the values of R and r, is indirect measurement for the extension. For two persons with the same values of r, the one who has larger superolateral extension of the GT will have a higher value of R, resulting in a larger GTRR when comparing with the other. No significant differences found in the R was a conflicting result compared to the significant differences found in the GTRR. This contradiction revealed a fact that the GT indeed contributes to the mechanism of RCT and, at the same time, confirmed the effectiveness of the GTRR on reducing the bias produced by demographic diversity. The indirect measurement was proved to be more effective and practicable than the direct measurement in assessment of superolateral extension of the GT.

In the last decades, many researches about radiographic image have been conducted to reveal the geometric characteristics of shoulders with RCTs. The three subtypes of acromion shapes (flat, curved or hooked) described by Bigliani et al. in 1986[17], the lateral acromion angle proposed by Banas et al. in 1995[18], and the critical shoulder angle introduced by Moor et al. in 2013[19], were all some parameters focusing on the aspect of acromion. In contrast, the researches concentrating on proximal humerus were relatively fewer. The acromion index presented by Nyffeler et al. in 2006 was a parameter involved with lateral border of humeral head[20]. In 2018, Cunningham et al. designed the greater tuberosity angle (GTA) to evaluate the superolateral extension of the GT, and announced that a GTA value ≥70° was strongly associated with RCT[21]. For most measurements performed on radiographs, a standard anteroposterior view of shoulder is necessary. In our study, we used 3D models established by reconstruction of CT scans to accomplish measurements. Though adequate positional adjustment of shoulder mentioned above, we could get an ideal standard anteroposterior view and ensure the accuracy and reproducibility of measurements. The Cronbach’s alpha coefficients for both r and R were satisfactory and proved good reliability and repeatability of our methods. Disadvantages of analysis by CT scans compared with X-ray images are high costs and complicated manipulating procedures. Therefore, simple X-ray examination should be preferred in clinical practice, and we aimed to verify our findings by radiographs in further researches.

Although tuberoplasty is not as popular as acromioplasty in treatment of RCT, its satisfactory clinical outcomes have been reported in several studies. Obvious improvement in clinical symptoms and range of motions in patients with massive irreparable RCTs after tuberoplasty combined with subacromial decompression within a two-year follow up was confirmed in some previous work[22,23]. In another follow up lasting for at least seven years after surgeries with isolated tuberoplasty in patients with massive irreparable RCTs, the researchers also observed good outcomes and regarded tuberoplasty as a good option for relieving pain and improving functionality[24]. With the discovery of this study, we recommended the GTRR as a postoperative control marker to assess surgical procedures. Decortication and bone removal of the GT should be performed to make the value of GTRR lower than 1.262. However, surgeons must take care not to cause excessive medialization of the GT because it may decrease the deltoid wrapping effect and increase the load of tendons[21]. More biomechanical researches and clinical observations were needed to reveal the relationship between the GT and the RCTs.

There are some limitations in this study. First, the AUC calculated from the ROC curve of the GTRR was 0.686, and the sensitivity and specificity of the optimized cutoff value (namely 1.262) were 72% and 65%, respectively. These results indicated that the power of the GTRR to discriminate the RCT and control groups was not so excellent. A larger simple size could be helpful to improve the quality of analysis and make the results more accurate. Remembering that the impingement is based on both the GT and acromion, we advise a combined diagnosis by using the GTRR united with an index presenting the geometric characteristics of acromion, such as the critical shoulder angle, to increase the diagnostic sensitivity and specificity. The clinical practicability of the combined diagnosis will be checked in our next work.

The second limitation is that we did not assess the stability of measurements according to different rotation of humerus. In Cunningham et al.'s research about the GTA[21], they concluded that the GTA variation remained within a stable range of 1° between − 20° and + 40° of rotation in the axial plane and between − 10° and + 20° of rotation in the sagittal plane. In our study, the humerus was placed in neutral rotation and excellent stability and reproducibility of the values of GTRR were confirmed. However, if a stable measurement range of GTRR according to different rotation of humerus could be defined, it would be helpful to expand the application scope in clinical practice. More efforts are needed to explore the practical effectiveness of the GTRR in clinical diagnosis of RCTs.

The third limitation is that the GTRR was measured in coronal plane and did not take into account the anteroposterior relationship between the GT and the humeral head, whose potential influence may cause bias to the practicability of GTRR.

The last limitation is that we did not perform multivariable analysis because of the lack of data about height and weight of the cohort. Although the significance was not clear, we believed the differences of height and weight existed and contributed to the demographic diversity more or less.

Conclusion

There exist significant differences in the values of GTRR between the RCT and the control groups, indicating that the GT contributes to the mechanisms of RCTs. An optimized cutoff value of 1.262 is recommended for diagnosis of RCTs.

Abbreviations

RCT, rotator cuff tear.

GT, greater tuberosity.

CT, computed tomography.

GTRR, greater tuberosity radius ratio.

3D, three-dimensional.

SD, standard deviation.

ROC, receiver operating characteristic.

AUC, area under curve.

Declarations

Ethics approval and consent to participate:

IRB of Beijing Tsinghua Changgung Hospital gave the approval for the study. The consent to participate was not applicable because this was a retrospective research. But we did not divulge any private information of the patients in the manuscript.

Consent for publication:

Not applicable.

Availability of data and materials:

The datasets used and analysed during the current study are available from the corresponding author on reasonable request.

Competing interests:

The authors declare that they have no competing interests.

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Authors' contributions:

QM contributed to collection of data, analysis of results, and writing of manuscript. QM, CS, PL, SW and XC contributed to the design of the work. All authors read and approved the final manuscript.

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Figures

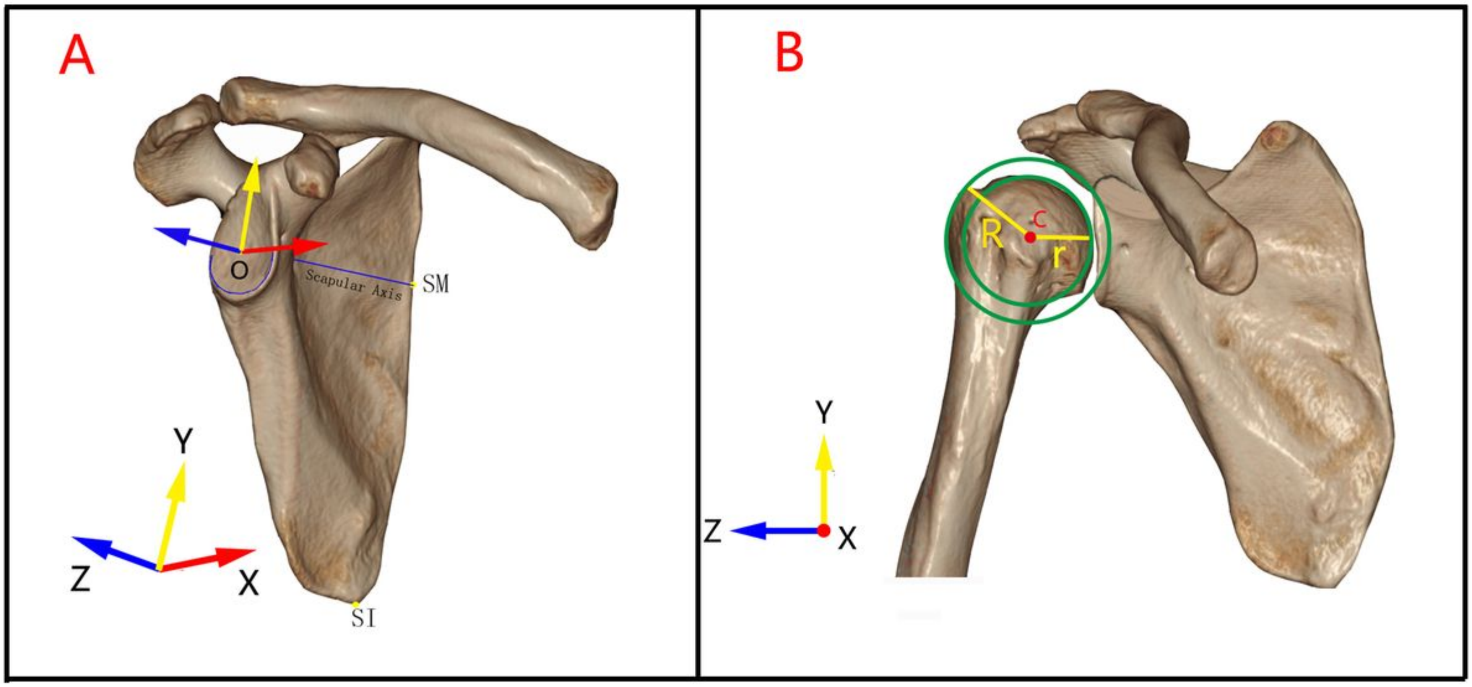

Figure 1

(A) The coordinate system based on scapula. (B) A true anteroposterior view of scapula. The point C is the center of the best-fit circle of the humeral head. The r is the radius of the best-fit circle of the humeral head. The R is the radius of the concentric circle with the point C as the center and passing through the most superolateral edge of the greater tuberosity.

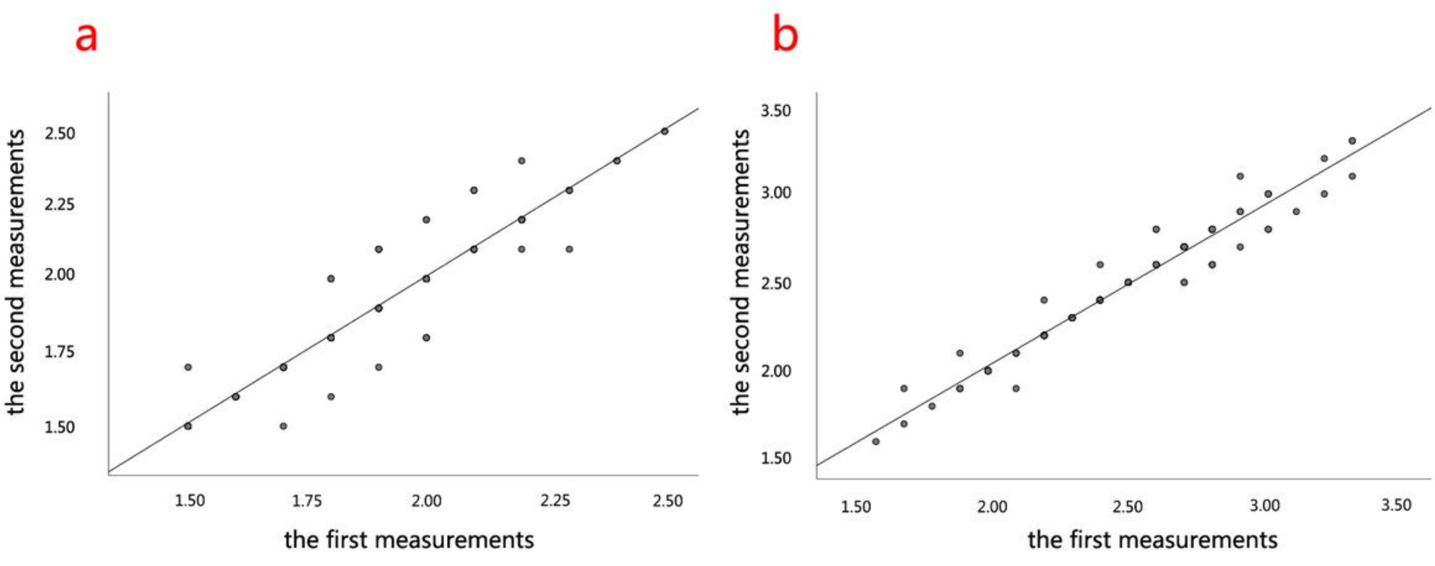

Figure 2

The scatter diagrams show high reliability and reproducibility of the measurements. (a) The measurements of the values of the r. (b) The measurements of the values of the R. Horizontal axis, the measurements at the first time point. Vertical axis, the measurements at the second time points.

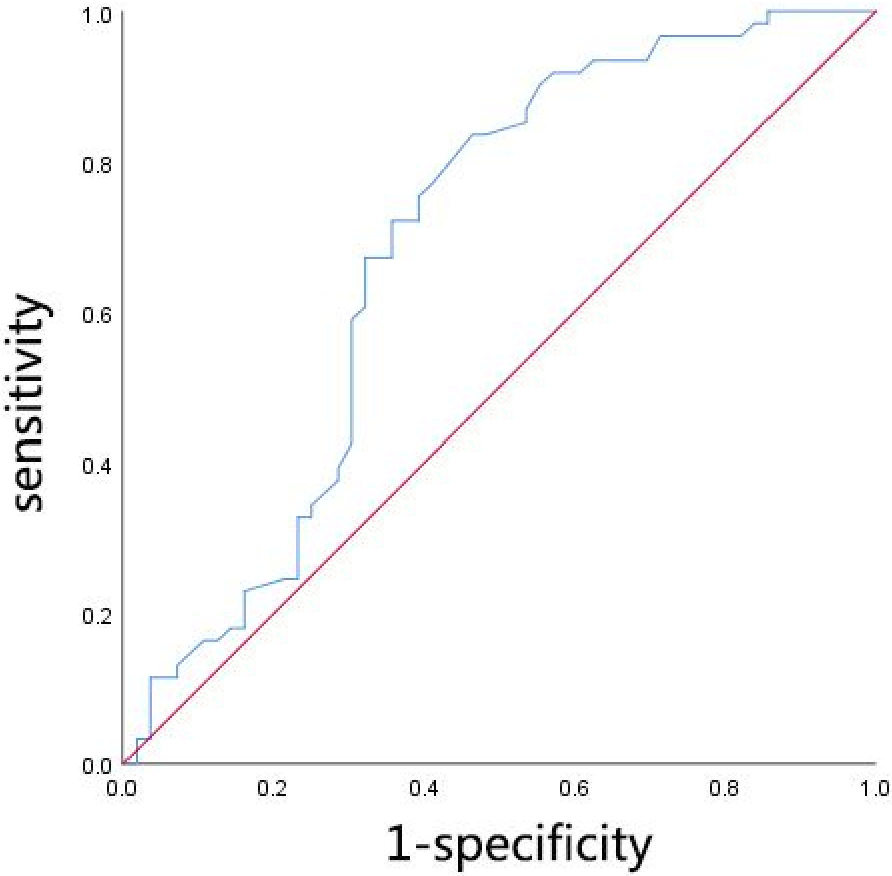

Figure 3

The receiver operating characteristic (ROC) curve based on the values of the greater tuberosity radius ratio (GTRR).