Injury Mechanism of Acute Anterior Shoulder Dislocation Associated with Glenoid and Greater Tuberosity Fractures: A Study Based on Fracture Morphology

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Objective: Based on the morphological characteristics of glenoid and greater tuberosity (GT) fractures and the relationship between them, we explored the injury mechanism of acute anterior shoulder dislocation associated with glenoid and GT fractures.

Methods: From December 2013 to December 2019, we retrospectively reviewed the clinical data of patients who were diagnosed with acute anterior shoulder dislocation associated with glenoid and GT fractures in our hospital. According to the fracture site, a glenoid fracture group and a greater tuberosity fracture (GT) group were established, and the morphological characteristics of both glenoid and GT fractures were measured and statistically analyzed.

Results: A total of 41 patients (43 shoulders) met the inclusion criteria (39 unilateral shoulders and 2 bilateral shoulders). The mean age was 50.21 years (range, 22–71 years). A total of 27 shoulder injuries (62.8%) were split GT fractures and 33 shoulder injuries (76.7%) were combined with rotator cuff tears. The mean size of glenoid fragments was 30.16% and the mean displacement was 8.85 mm. The mean size of GT fragments was 28.43 mm. The mean superior-inferior and anteroposterior displacements of the GT fragment were 6.77 mm and 4.96 mm, respectively. There was a negative correlation between the size of glenoid and GT fracture fragments ($r = -0.64$, $P < 0.05$). The glenoid fragments in the Ideberg type Ia glenoid fracture group were smaller than those in the Ideberg type II glenoid fracture group (28.41% and 40.95%, respectively), while the size of GT fragments in the type Ia group were larger than those in the type II group (29.77 mm and 20.21 mm, respectively) ($P < 0.05$). The GT fragments in the split GT fracture group were larger than those in the avulsion or depression GT fracture group (33.69 mm, 19.07 mm and 21.12 mm, respectively), while the size of glenoid fragments in the split GT fracture group were smaller than those in the avulsion or depression GT fracture group (23.57%, 41.37%, and 43.42%, respectively) ($P < 0.05$). As for the displacement direction of GT fragments, depression fractures were mainly inferior displacements, avulsion fractures were mainly anterosuperior displacements, while split fractures were mainly posterior-inferior displacements ($P < 0.05$). Multiple regression analysis suggested that the type and the fragment size of GT fractures have a significant influence on the size of glenoid fragments.

Conclusion: Acute anterior shoulder dislocations associated with glenoid and GT fractures are often combined with rotator cuff tears. There is a negative correlation between the size of glenoid and GT fragments, and split GT fractures are most common. Such injuries are highly correlated to the relative spatial location between the GT and the glenoid when the shoulder dislocates.
Introduction

The glenohumeral joint is the joint most susceptible to dislocation due to its instability caused by extensive range of motion. The dislocation rate is between 24 and 56 per 100,000 person-years, and anterior dislocation accounts for 96%-98%1-3. Corresponding to different injury mechanisms, after the primary shoulder dislocation, shoulder fractures often occur, such as proximal humeral fractures, greater tuberosity (GT) fractures, coracoid fractures, and glenoid fractures.

Glenoid fractures are the most common complication in anterior dislocations of the shoulder, with the incidence of glenoid bony lesions ranging from 5% to 75%4-7. Isolated greater tuberosity (GT) fractures are reported in approximately 15%-35% of anterior dislocations of the shoulder8,9. In addition to fractures, soft tissue injuries are also not negligible. The GT is the insertion of the rotator cuff tendon (supraspinatus, infraspinatus, teres minor), which is attached to three facets of the superior margin of the GT. Therefore, rotator cuff tears are very common in dislocations and fractures of the shoulder. Owing to the rotator cuff retraction, the GT fragment will be displaced, which will make the treatment more complicated. If the assessment and repair of rotator cuff tears are neglected, good shoulder function cannot be obtained, even if the fracture is fixed.

Acute anterior shoulder dislocations associated with glenoid and GT fractures are rare, and only a few cases of this kind of injury have been reported10-14. Anterior shoulder dislocation associated with glenoid and GT fractures can cause shoulder pain and dysfunction. If not treated properly, it will cause malunion, instability, and secondary arthritis, and have other catastrophic consequences.

There are reports on the various treatments for acute anterior shoulder dislocation associated with glenoid and GT fractures, including conservative treatment, open reduction and internal fixation, and arthroscopic fixation. The fixation methods include plate fixation, screw fixation, anchor fixation, and suture fixation11-14. In 2001, Ron et al. reported a 73-year-old woman with concomitant fractures of the GT, glenoid, and coracoid who underwent nonoperative treatment and was followed up for 6 months, with a VAS score of 2 and a constant score of 89. In 2009, Pujol et al. first used arthroscopy to treat such injuries with the double-row technique. In 2012, Kim et al. first used arthroscopic techniques and hollow screws to treat such injuries. In 2016, a case of open reduction and internal fixation using two surgical approaches was reported. In summary, not only treatment management but also surgical follow-up results vary.

When formulating a treatment plan, we have to consider the fracture morphology of both fracture localizations at the GT, on the one hand, and at the glenoid, on the other hand. In terms of fracture morphology and localization, GT fractures can be divided into three categories: avulsion, split, and depression, all of which may occur with glenoid fractures. On the glenoid side, the more frequent glenoid rim fractures and the rarer glenoid fossa fractures can be found together with GT fractures. Therefore, this kind of injury is more complex, and its treatment should refer to its specific injury mechanism and fracture morphology.

However, due to the rarity of such injuries, until now, the injury mechanism and fracture morphology have remained unclear. We believe that through the analysis of fracture morphology and the exploration of injury mechanism, it is beneficial for our orthopaedic surgeons to further understand this rare injury to formulate more rational and personalized treatment plans.

In our clinical practice, we noticed that when GT and glenoid fractures occur simultaneously, the morphology of GT and glenoid fractures has certain regularity, which may be related to the injury mechanism of this kind of injury. We hypothesized that there is a positive correlation between the size of glenoid and GT fracture fragments, and such injuries are mainly caused by the anterior dislocation of the glenohumeral joint and the impact mechanism between the humeral head and the glenoid.

Therefore, we retrospectively reviewed the clinical data of patients who were diagnosed with acute anterior shoulder dislocation associated with glenoid and GT fractures in our hospital. We measured and analyzed the fracture morphology of glenoid and GT.

The purpose of this study was to: (i) improve the understanding of the fracture morphology of this kind of injury; (ii) provide references for surgeons in the diagnosis and treatment of different fracture mechanisms; (iii) analyze the morphological characteristics of both glenoid and GT fractures and the possible injury mechanisms.

Materials and Methods

Subjects
From December 2013 to December 2019, patients who were diagnosed with acute anterior shoulder dislocation associated with glenoid and GT fracture were retrospectively reviewed. Patients who were diagnosed with acute anterior shoulder dislocation associated with glenoid and GT fractures were included in this study.

The inclusion criteria were as follows: (i) patients with initial anterior shoulder dislocation due to trauma; (ii) clinical signs and imaging confirmed acute anterior shoulder dislocation associated with glenoid and GT fracture; (iii) general information and initial X-ray, CT, and MRI imaging data were complete; (iv) the imaging data were clear.
and of high quality; and (v) informed consent had been provided by the patients.

The exclusion criteria were as follows: (i) pathological fractures; (ii) fractures combined with proximal humeral fractures in part 3 and 4; and (iii) previous shoulder fracture.

Basic demographic data including age and gender, the side of the injury, and the cause of injury were recorded. The classification of glenoid and GT fractures was determined by X-ray and CT. The sizes and displacements of glenoid and GT fragments, and the superoinferior and anteroposterior displacements of the GT fragments were calculated using CT scans as described below.

Indexes

**Classification of Glenoid and Greater Tuberosity Fractures**
The classification of glenoid fractures was described by Ideberg\textsuperscript{15}, which was modified by Goss\textsuperscript{16} (Fig. 1). Type I was divided into avulsion fractures of the anterior (Type Ia) and the posterior rim (Type Ib). Type II were described as horizontal fractures through the glenoid fossa with displacement of inferior fragments, and type III were oblique fractures running through the glenoid and onto the superior scapular border (seen with acromioclavicular and coracoids process fractures). Type IV were transverse fractures running through the medial border of the blade, and type V fractures were described as type IV fractures with added separation of inferior glenoid fragments. Type VI were comminuted fractures of the glenoid.

**Classification of Greater Tuberosity Fractures**
Depending on the fracture morphology, we divided GT fractures into three categories: avulsion, split, and depression, which are described by Mutch \textit{et al.}\textsuperscript{17} Avulsion fractures involve a small fracture fragment, with horizontal fracture line and similar injury mechanism to rotator cuff tear. Split fractures are caused by the impact of the GT and the anterior rim of the glenoid during dislocation or subluxation of the shoulder and the fracture fragment is large; the fracture line is vertical. Depression fractures are caused by the impact beneath the inferior surface of the glenoid during shoulder dislocation, and also by the impact beneath the inferior surface of the acromion during extreme abduction, which the GT fragment is inferiorly displaced (Fig. 2).

**Size of Glenoid Fragments**
The size of glenoid fragments was defined as the ratio of the width of the fracture fragment to the diameter of the circle. Sugaya’s method\textsuperscript{18} was used to measure the fracture size of the glenoid according to the best fit circle. Three dimensional CT was used to reconstruct the glenoid, and the best fit circle was constructed in en-face view (Fig. 3). The glenoid fragment size was measured to evaluate the extent and classification of the glenoid fracture.

**Displacement of Glenoid Fragments**
The displacement of glenoid fragments was defined as the maximum displacement distance of the glenoid fracture fragment. Displacement of the glenoid fragment was also measured on the en-face view of the glenoid (Fig. 4). The displacement of the glenoid fragment was measured to evaluate the degree of displacement of the glenoid fragment.
The size of the GT fragment was defined as the maximum length of the fragment of the GT fracture fragment in the coronal plane of CT scans (Fig. 5). The size of the GT fragment was measured to evaluate the extent and classification of the GT fracture.

Displacement of Greater Tuberosity Fragments
The displacement of the GT fragment was defined as the maximum displacement distance of the GT fracture fragment. The distance of the GT fragment was calculated in the coronal and axial plane of the CT scans (Fig. 5 and Fig. 6). The displacement of the glenoid fragment was measured to evaluate the degree of displacement of the GT fragment and the direction of the displaced GT fragment.

Statistical Analyses
In the statistical analysis, patients were divided into glenoid and GT fractures. In the univariate analysis, statistical significance was assessed with a Student t-test for continuous variables, and with $\chi^2$ analysis for categorical variables. Analysis of variance was used to compare the three types of GT fragments.
Fisher exact testing was used if the number of samples was <5 for any comparison. After performing the correlation analysis and the correlation was confirmed, multivariate regression analysis was undertaken to evaluate the relationship between glenoid and GT fractures. The significance level was set at 0.05 for all tests.

**Results**

**General Results**

There were 41 patients (39 unilateral shoulders and 2 bilateral shoulders), including 23 men and 18 women. The mean age was 50.21 years (range, 22–71 years); 27 shoulder injuries (62.8%) were split GT fractures and 33 shoulder injuries (76.7%) were combined with rotator cuff tears. There were 18 left sides and 25 right sides, involving 19 dominant sides. Causes of injury: fall from standing (22 patients), fall from higher than standing height (10 patients), vehicular trauma (6 patients), electric injury (2 patients), and epilepsy (1 patient). There were 3 shoulders with ipsilateral coracoid fractures, 2 shoulders with ipsilateral olecranon fractures, 1 shoulder with rib fracture, 1 case with brachial plexus injury, and 33 cases with rotator cuff tears. The mean size of glenoid fragments was 30.16% and the mean displacement was

![Fig. 6](image.png)

Fig. 6 Anterior/posterior displacement is calculated in the axial plane of CT scans. The plane of displacement was defined parallel to a tangent drawn along the surface of the glenoid. Anterior/posterior displacement of the greater tuberosity (GT) fragment was then directly measured on the slice of the greatest fragment displacement, as shown.

| TABLE 1 Univariate analysis of glenoid fracture (mean ± SD or cases [%]) |
|-----------------------------|-----------------|-----------------|-------------|-----------|
| Variables                   | Ia (n = 37)     | I (n = 6)       | t-value     | P-value   |
| Age (years)                 | 51.24 ± 13.05   | 43.83 ± 12.20   | 1.3         | 0.201     |
| Gender                      |                 |                 |             | 0.503     |
| Male                        | 21 (56.8)       | 4 (66.7)        |             | 0.547     |
| Female                      | 16 (43.2)       | 2 (33.3)        |             | 0.149     |
| Dominant                    | 33 (89.2)       | 5 (83.3)        |             | 0.319     |
| Nondominant                 | 4 (10.8)        | 1 (16.7)        |             | 0.432     |
| Comminution of glenoid      |                 |                 |             | 0.182     |
| Comminuted                  | 26 (70.3)       | 6 (100)         |             | 0.373     |
| Non comminuted              | 11 (29.7)       | 0 (0)           |             | 0.038*    |
| Comminution of GT           |                 |                 |             | 0.149     |
| Comminuted                  | 30 (81.1)       | 6 (100)         |             | 0.319     |
| Non comminuted              | 7 (18.9)        | 0 (0)           |             | 0.182     |
| Rotator cuff tear           |                 |                 |             | 0.373     |
| Yes                         | 27 (73)         | 6 (100)         |             | 0.373     |
| No                          | 10 (27)         | 0 (0)           |             | 0.373     |
| Displacement direction (coronal) |             |                 |             | 0.373     |
| Superior                    | 11 (29.7)       | 3 (50)          |             | 0.373     |
| Inferior                    | 26 (70.3)       | 3 (50)          |             | 0.373     |
| Displacement direction (axial) |             |                 |             | 0.373     |
| nondisplaced                | 4 (10.8)        | 3 (50)          |             | 0.373     |
| Anterior                    | 7 (18.9)        | 1 (16.7)        |             | 0.373     |
| Posterior                   | 26 (70.3)       | 2 (33.3)        |             | 0.373     |
| Displacement of glenoid (mm)| 8.18 ± 5.38     | 12.99 ± 11.77   | −0.98       | 0.367     |
| Glenoid fragment size (%)   | 28.41 ± 12.64   | 40.95 ± 7.51    | −2.35       | 0.024*    |
| Displacement (coronal, mm)  | 7.04 ± 6.34     | 5.06 ± 4.32     | 0.74        | 0.466     |
| Displacement (axial, mm)    | 5.43 ± 4.66     | 2.05 ± 2.61     | 1.72        | 0.093     |
| GT fragment size (mm)       | 29.77 ± 10.81   | 20.21 ± 4.29    | 3.83        | 0.001*    |

* Indicates that there is a significant difference between glenoid type Ia and type II fractures.; GT, greater tuberosity.
8.85 mm, with 37 cases of Ideberg type Ia glenoid fractures and 6 cases of type II. The avulsion, split, and depression GT fractures were identified in 12, 27, and 4 shoulders, respectively. The mean size of GT fragments was 28.43 mm. In the coronal plane of CT scans, the GT fragment was displaced superiorly in 14 shoulders and inferiorly in 29 shoulders, with mean displacement of 6.77 mm. In the axial plane, the GT fragment was displaced posteriorly in 28 shoulders and anteriorly in 8 shoulders, while not displaced in 7, with a mean displacement of 4.96 mm.

Univariate Analysis of Glenoid and Greater Tuberosity Fractures

The mean size of glenoid fragments in the type Ia glenoid fracture group was 28.41%, which was significantly smaller than that in the type II glenoid fracture group (40.95%) \( t = -2.35, P < 0.05 \). The mean size of GT fragments in the type Ia group was significantly larger than that in the type II group (29.77 mm and 20.21 mm, respectively) \( t = 3.83, P < 0.05 \). The GT fragment in the type Ia glenoid fracture group was mainly displaced posteriorly \( P < 0.05 \) (Table 1).

Compared with avulsion fractures, the superoinferior displacement of depression fractures was significantly different \( (P < 0.05) \), but there was no significant difference in other factors \( (P > 0.05) \).

The GT fragments in the split GT fracture group are larger than those in the avulsion or depression GT fracture groups, while superoinferior and anteroposterior displacements in the split GT fracture group are smaller than those in avulsion or depression GT fracture groups \( (P < 0.05) \). As for the displacement direction of GT fragments, depression fractures were mainly inferior displacements, avulsion fractures were mainly anterosuperior displacements, while split fractures were mainly posteroinferior displacements \( (P < 0.05) \) (Table 2).

Correlation and Multivariate Analysis

In the correlation analysis, there were correlations between the size of the glenoid fragment and the size of the GT fragment \( (r = -0.64, P = 0.00) \), GT displacement \( (r = -0.35, P = 0.02) \), glenoid and GT fracture classification, and the displacement direction of the GT fragment (superoinferior and anteroposterior). The size of the GT fragment was significantly

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**TABLE 2 Univariate analysis of GT fracture (mean ± SD or cases [%])***

| Variables                      | Depression \( n = 4 \) | Avulsion \( n = 12 \) | Split \( n = 27 \) | F-value | P-value |
|--------------------------------|------------------------|-----------------------|-------------------|---------|---------|
| Age (years)                    | 59.5 ± 16.52           | 46.75 ± 14.83         | 50.85 ± 11.91     | 1.469   | 0.242   |
| Gender                         |                        |                       |                   |         |         |
| Male                           | 3 (75)                 | 7 (58.3)              | 15 (55.6)         | 0.763   |         |
| Female                         | 1 (25)                 | 5 (41.7)              | 12 (44.4)         |         |         |
| Dominancy                      |                        |                       |                   |         |         |
| Dominant                       | 3 (75)                 | 10 (83.3)             | 25 (92.6)         | 0.216   |         |
| Nondominant                    | 1 (25)                 | 2 (16.7)              | 2 (7.4)           |         |         |
| Communion of glenoid           |                        |                       |                   |         |         |
| Comminuted                     | 4 (100)                | 8 (66.7)              | 21 (77.8)         | 0.416   |         |
| Non comminuted                 | 0 (0)                  | 4 (33.3)              | 6 (22.2)          |         |         |
| Communion of GT                |                        |                       |                   |         |         |
| Comminuted                     | 4 (100)                | 9 (75)                | 24 (88.9)         | 0.475   |         |
| Non comminuted                 | 0 (0)                  | 3 (25)                | 3 (11.1)          | 0.029*  |         |
| Rotator cuff tear              |                        |                       |                   |         |         |
| Yes                            | 4 (100)                | 6 (50)                | 23 (85.2)         | 0.038*  |         |
| No                             | 0 (0)                  | 6 (50)                | 4 (14.8)          |         |         |
| Glenoid fracture classification|                        |                       |                   |         |         |
| Ia                             | 3 (75)                 | 8 (66.7)              | 26 (96.3)         | 0*      |         |
| II                             | 1 (25)                 | 4 (33.3)              | 1 (3.7)           | 0*      |         |
| Displacement direction (coronal)|                        |                       |                   |         |         |
| Superior                       | 0 (0)                  | 10 (83.3)             | 4 (14.8)          | 0*      |         |
| Inferior                       | 4 (100)                | 2 (16.7)              | 23 (85.2)         | 0*      |         |
| Displacement direction (axial) |                        |                       |                   |         |         |
| nondisplaced                   | 3 (75)                 | 2 (16.7)              | 2 (7.4)           | 0*      |         |
| Anterior                       | 1 (25)                 | 6 (50)                | 1 (3.7)           |         |         |
| Posterior                      | 0 (0)                  | 4 (33.3)              | 24 (88.9)         |         |         |
| Displacement of glenoid (mm)   | 7.1 ± 3.35             | 8.41 ± 4.34           | 9.52 ± 7.79       | 0.223   | 0.801   |
| Glenoid fragment size (%)      | 43.42 ± 10.77          | 41.37 ± 5.34          | 23.57 ± 10.35     | 21.081  | 0*      |
| Displacement (coronal, mm)     | 3.55 ± 1.17            | 3.22 ± 2.13           | 8.82 ± 6.79       | 4.881   | 0.013*  |
| Displacement (axial, mm)       | 0.78 ± 1.56            | 2.68 ± 2.02           | 6.59 ± 4.88       | 6.06    | 0.005*  |
| GT fragment size (mm)          | 21.12 ± 6.9            | 19.07 ± 4.02          | 33.69 ± 9.69      | 14.563  | 0*      |

* Indicates that there is a significant difference between Depression, avulsion and split greater tuberosity (GT) fractures.
correlated with the size of the glenoid fragment \( (r = -0.64, \ P = 0.000) \), the anteroposterior displacement of the GT fragment \( (r = 0.32, \ P = 0.038) \), the glenoid and GT fracture classification, and the displacement direction of GT fragments (superoinferior and anteroposterior).

A multivariate regression model was established according to the above correlation, and the multivariate linear regression analysis was carried out with the entry probability of \( \alpha < 0.05 \) and the removal probability of \( \alpha \geq 0.1 \). The results showed that: (i) there was a linear regression relationship between the size of the glenoid fragment and the size of the GT fragment, and GT fracture classification. The regression equation was 

\[
Y = 59.126 - 9.102X_1 - 0.471X_2 \quad (Y \text{ represents the size of the glenoid fragment; } \ X_1 \text{ represents the GT fracture classification and } \ X_2 \text{ represents the size of the GT fragment}) \quad (P < 0.05, \ R^2 = 0.75) \quad (\text{Table 3})
\]

(ii) the size of the GT fragment was affected by the size of the glenoid fragment and the regression equation was 

\[
Y = 25.25 - 0.371X_1 \quad (Y \text{ represents the size of the GT fragment and } \ X_1 \text{ represents the size of glenoid fragment}) \quad (P < 0.05, \ R^2 = 0.71) \quad (\text{Table 4})
\]

**Discussion**

A cute shoulder dislocation is often caused by trauma. Anterior shoulder dislocation is the most common type of shoulder dislocation. Due to different combined forces and dislocation directions of the glenohumeral joint, shoulder dislocation is often combined with different injuries, such as GT fractures, glenoid fractures, coracoid process fractures, and rotator cuff tears\(^{19, 20}\); however, anterior shoulder dislocations associated with glenoid and GT fractures are rare. To our knowledge, this is the first study to explore the injury mechanism and influencing factors of such injuries based on fracture morphology.

**Glenoid Fractures**

Anterior glenoid rim fractures are the most common glenoid fractures, accounting for 75%–85%\(^{15, 21}\). The mean age of patients with glenoid rim fractures is 40–50 years, while glenoid fossa fractures mainly occur in young male patients\(^ {5, 21}\). The occurrence of glenoid rim fractures is mainly associated with anterior dislocation of the shoulder, which is caused by excessive traction of the capsule-labral-ligament complex or direct impingement of the glenoid rim against the humeral head during shoulder dislocation. The latter has a larger fragment and typically occurs in patients who have sustained higher energy injuries. Glenoid fossa fractures are more common in high energy injuries and when the humeral head directly impacts the glenoid fossa, and common in young people with sports injuries or elderly people with vehicular trauma\(^ {4, 16, 22–24}\).

The mean age of patients in this study was 50.21 years (range, 22–71 years); 79% were over 40 years old. A total of 36 cases were Ideberg type Ia (mean age 51.24 years), accounting for 86%, 6 cases were type II (mean age 43.83 years), and 10 cases were combined with capsule-labral injury (Bankart lesion), which was not significantly different from the reported epidemiology of glenoid fractures. Statistical analysis in this study showed that patients with Ideberg type Ia glenoid fractures had smaller glenoid fragments than those with type II, which was similar to the findings of Ideberg et al.\(^ {5}\). This indicates that glenoid side fractures of this kind of injury are still dominated by glenoid rim fractures, which are mainly caused by the impingement of the

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**TABLE 3 Multivariate analysis of the size of glenoid fragment**

| Variable                    | Unstandardized coefficients | Standardized coefficients | t-value | P-value |
|-----------------------------|-----------------------------|----------------------------|---------|---------|
| Constant                    | 59.126                      | 9.66                       | 6.121   | 0       |
| GT fracture classification   | -9.102                      | 3.006                      | -3.028  | 0.005   |
| GT fragment size            | -0.471                      | 0.17                       | -2.761  | 0.009   |

GT, greater tuberosity.

**TABLE 4 Multivariate analysis of the size of GT fragment**

| Variable                    | Unstandardized coefficients | Standardized coefficients | t-value | P-value |
|-----------------------------|-----------------------------|----------------------------|---------|---------|
| Constant                    | 25.252                      | 10.382                     | 2.432   | 0.027   |
| Glenoid fragment size       | -0.371                      | 0.134                      | -2.761  | 0.009   |

GT, greater tuberosity.
rotation, the GT will impact with the anterior or inferior rim of the glenoid, so the fracture fragments on the GT side are larger; the fracture lines are mostly vertical, while the fragments on the glenoid side are small. If the external rotation is insufficient, due to the strong contraction of the rotator cuff or the impact of the humeral head on the inferior rim of the glenoid, the GT fracture is avulsion or depression type, and the fragment is small. However, under such conditions, the contact area between the humeral head and the glenoid is larger, and high-energy injuries lead to glenoid fractures with larger fragments.

**Displacement of Greater Tuberosity Fragment**

The GT is the insertion of the rotator cuff tendon (supraspinatus, infraspinatus, teres minor), which is attached to three facets of the superior margin of the GT: the superior, middle, and inferior facets. Minagawa et al. (1998) found that the supraspinatus inserted on the superior facet and the superior half of the middle facet, while the infraspinatus inserted on the whole middle facet covering part of the supraspinatus. The displacement directions of the GT fragments are dependent on the directions of the force vector of the three rotator cuff tendons. The force of the supraspinatus tendon displaces the fragment anterosuperiorly, while the force of the infraspinatus tendon causes the fragment to displace posteroinferiorly.

In our study, the depression GT fractures mainly displaced inferiorly, the avulsion fractures mainly displaced anterosuperiorly, while the split fractures mainly displaced posteroinferiorly ($P < 0.05$). According to the characteristics of the fragment size of the three types, avulsion fractures have a smaller fragment, and the fracture line is mostly in the anterior part of the superior section; the fragment displaces inferiorly due to the retraction of the supraspinatus tendon. However, the fragment of split fractures is larger, and the fracture line is located in the middle and inferior sections, which is affected by the traction of the infraspinatus tendon; therefore, the fragment displaces posteroinferiorly.

**Limitations**

There are also several limitations in this study. First, such injuries are rare; therefore, the sample size included in this study is limited. Second, the fracture fragment size and the displacement distance of the glenoid and the GT are impacted by the projection position and the measurement, and there is no unified measurement method. Especially for the measurement of GT fragment displacement, there is no simple and reproducible measurement method at present.

**Conclusion**

Acute anterior shoulder dislocation associated with glenoid and greater tuberosity fractures is a relatively rare injury, often occurring in middle-aged or elder people and combined with rotator cuff tears. There is a negative correlation...
between the size of glenoid and GT fragments, and split GT fractures are most common. The displacement direction of fracture fragments is affected by the force vector of the rotator cuff tendon. Such injuries are highly correlated with relative spatial location between the greater tuberosity and the glenoid when the shoulder dislocates.

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