CLINICAL ARTICLE

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 superoinferior 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 posteroinferior 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.

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Key words: Anterior shoulder dislocation; Glenoid fracture; Greater tuberosity fracture; Fracture morphology; Injury mechanism

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 shoulder[8–10]. 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 reported[11–14]. 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 fixation[11–14]. 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 clinical 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 morphologies; (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

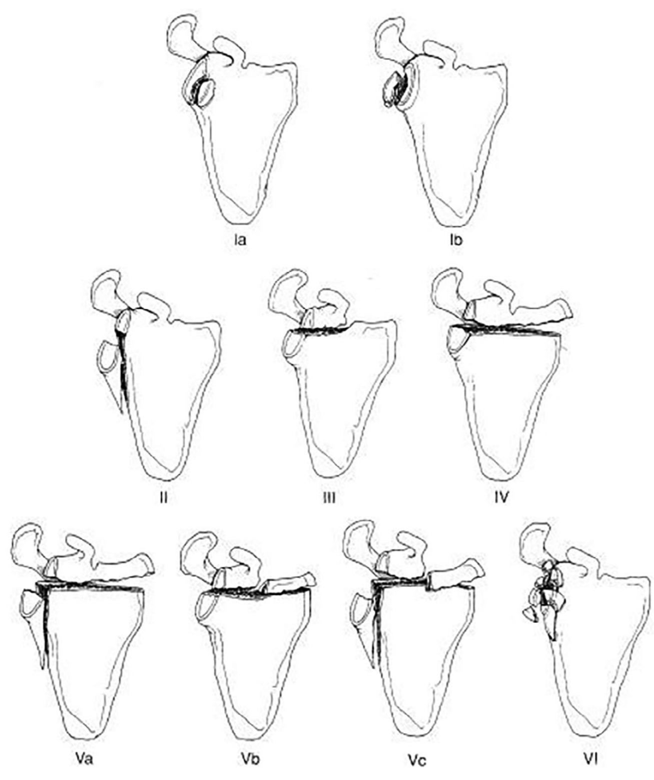

Fig. 1 Ideberg classification, modified by Goss.

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[15], which was modified by Goss[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 *et al.*[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[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.

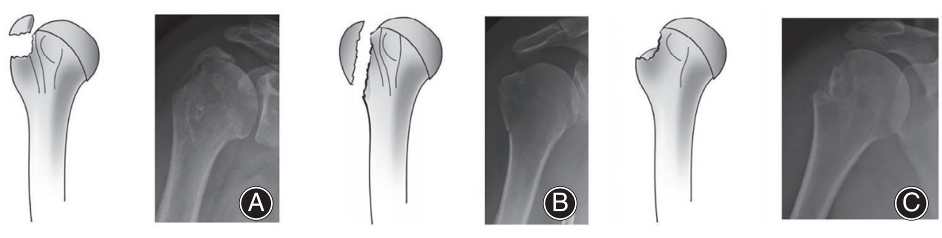

Fig. 2 Greater tuberosity (GT) classification described by Mutch: (A) avulsion, (B) split, and (C) depression.

Fig. 3 Using Sugaya's method, three-dimensional CT was used to reconstruct the glenoid, and the best fit circle was constructed in en-face view. Segment R was the diameter, segment r was the width of the fracture fragment, and the value of r/R was the size of the glenoid fragment (%).

Fig. 4 Three-dimensional CT was used to reconstruct the glenoid, and the displacement of glenoid fractures was measured in en face view. The maximum displacement distance of segment D was taken as the displacement distance (mm).

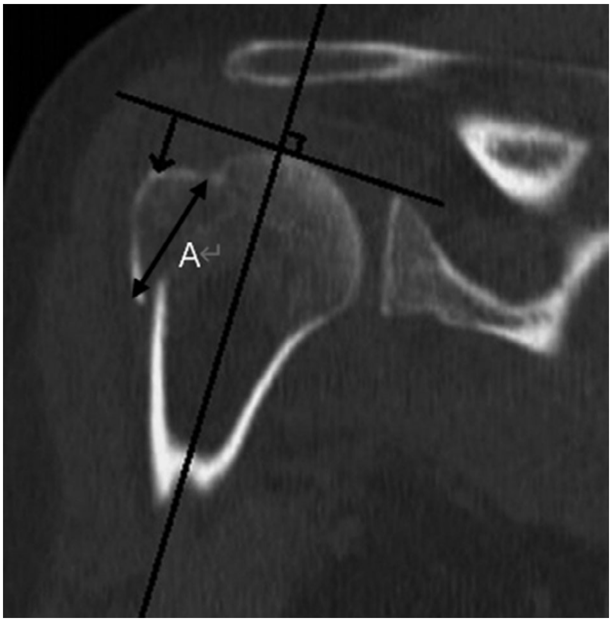

Fig. 5 Superior/inferior displacement is calculated in the coronal plane of CT scans. A line is traced along the center of the humeral shaft and the humeral surgical neck on the slice of the greatest displacement of the greater tuberosity (GT) fragment. The measurement of the displacement is taken parallel to this line. Then along the most superior aspect of the humeral head, a tangent perpendicular line is drawn. The distance between this tangent and the most superior aspect of the GT fragment is calculated as the displacement distance of the GT fragment. The length of segment A is recorded as the size of the GT, as shown.

Size of Greater Tuberosity 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 χ^2 analysis for categorical variables. Analysis of variance was used to compare the three types of GT

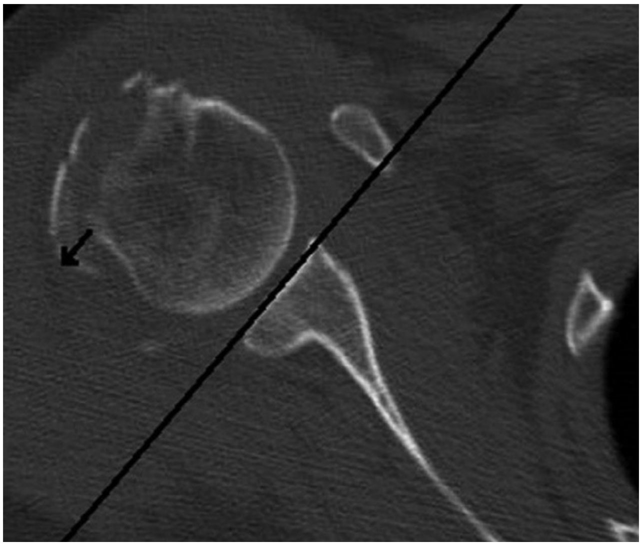

Fig. 6 Anterior/posterior displacement is calculated in the axial plane of CT scans. The plane of displacement was defined parallel to a tangent drawn along the surface of the glenoid. Anterior/posterior displacement of the greater tuberosity (GT) fragment was then directly measured on the slice of the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

fracture. 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

TABLE 1 Univariate analysis of glenoid fracture (mean ± SD or cases [%])

Variables	Ia(*n* = 37)	I 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)		
Female	16 (43.2)	2 (33.3)		
Dominancy				0.547
Dominant	33 (89.2)	5 (83.3)		
Nondominant	4 (10.8)	1 (16.7)		
Comminution of glenoid				0.149
Comminuted	26 (70.3)	6 (100)		
Non comminuted	11 (29.7)	0 (0)		
Comminution of GT				0.319
Comminuted	30 (81.1)	6 (100)		
Non comminuted	7 (18.9)	0 (0)		
Rotator cuff tear				0.182
Yes	27 (73)	6 (100)		
No	10 (27)	0 (0)		
Displacement direction (coronal)				0.373
Superior	11 (29.7)	3 (50)		
Inferior	26 (70.3)	3 (50)		
Displacement direction (axial)				0.038*
nondisplaced	4 (10.8)	3 (50)		
Anterior	7 (18.9)	1 (16.7)		
Posterior	26 (70.3)	2 (33.3)		
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

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					0.216
Dominant	3 (75)	10 (83.3)	25 (92.6)		
Nondominant	1 (25)	2 (16.7)	2 (7.4)		
Comminution of glenoid					0.416
Comminuted	4 (100)	8 (66.7)	21 (77.8)		
Non comminuted	0 (0)	4 (33.3)	6 (22.2)		
Comminution of GT					0.475
Comminuted	4 (100)	9 (75)	24 (88.9)		
Non comminuted	0 (0)	3 (25)	3 (11.1)		
Rotator cuff tear					0.029*
Yes	4 (100)	6 (50)	23 (85.2)		
No	0 (0)	6 (50)	4 (14.8)		
Glenoid fracture classification					0.038*
Ia	3 (75)	8 (66.7)	26 (96.3)		
II	1 (25)	4 (33.3)	1 (3.7)		
Displacement direction (coronal)					0*
Superior	0 (0)	10 (83.3)	4 (14.8)		
Inferior	4 (100)	2 (16.7)	23 (85.2)		
Displacement direction (axial)					0*
nondisplaced	3 (75)	2 (16.7)	2 (7.4)		
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.

TABLE 3 Multivariate analysis of the size of glenoid fragment

Variable	Unstandardized coefficients β	Unstandardized coefficients SE	Standardized coefficients β	*t*-value	*P*-value
Constant	59.126	9.66		6.121	0
GT fracture classification	−9.102	3.006	−0.475	−3.028	0.005
GT fragment size	−0.471	0.17	−0.393	−2.761	0.009

GT, greater tuberosity.

TABLE 4 Multivariate analysis of the size of GT fragment

Variable	Unstandardized coefficients β	Unstandardized coefficients SE	Standardized coefficients β	*t*-value	*P*-value
Constant	25.252	10.382		2.432	0.027
Glenoid fragment size	−0.371	0.134	−0.445	−2.761	0.009

GT, greater tuberosity.

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 $\alpha \leq 0.05$ 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 $Y = 59.126–9.102\ X_1–0.471\ X_2$ (Y represents the size of the glenoid fragment; X_1 represents the GT fracture classification and X_2 represents the size of the GT fragment) ($P < 0.05$, $R^2 = 0.75$) (Table 3); (ii) the size of the GT fragment was affected by the size of the glenoid fragment and the regression equation was $Y = 25.25–0.371\ X_1$ (Y represents the size of the GT fragment and X_1 represents the size of glenoid fragment) ($P < 0.05$, $R^2 = 0.71$) (Table 4).

Discussion

Acute 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 glenoid rim with the humeral head during anterior dislocation, and may also cause labrum or capsule tears, combined with Bankart or Slap lesions.

Greater Tuberosity Fracture

The incidence of shoulder dislocation with GT fracture ranges from 15% to 35%[8–10]. Corresponding to different injury mechanisms and fracture morphologies, Mutch *et al.*[17] proposed a new classification of GT fractures, which was divided into three types: avulsion, split, and depression (among which avulsion and split fractures were the most commo: avulsion 39%, split 41%, depression 20%). Avulsion fractures have small fragments and most fracture lines are horizontal. The injury mechanism is similar to that of rotator cuff tears, which may be caused by powerful contraction of the rotator cuff when anterior shoulder dislocation occurs. The depression fracture mechanism is where the humeral head impacts the inferior of the glenoid when shoulder dislocation occurs or the humeral head impacts beneath the acromion when extreme abduction occurs, which leads to the fracture of the humeral head, the fragments of which are mostly displaced inferiorly. The fracture may be caused by the impingement of the humeral head and the anterior rim of the glenoid when the shoulder is dislocated. The fracture fragments are large and the fracture lines are mostly vertical. Several studies[17, 25–27] have shown that the injury mechanism of the depression fracture of GT is similar to that of Hill–Sachs lesions, which is caused by the impingement between the humeral head and the inferior rim of the glenoid when the shoulder is dislocated, and the injury mechanism of the depression fracture is similar to that of the more lateral Hill-Sachs lesion. However, there is also a clear difference between GT fractures and Hill-Sachs lesions.[28] The GT is the insertion of the rotator cuff in the non-articular area, not involving the articular surface lesion, while the Hill–Sachs lesion is the depression fracture of the posterosuperior humeral head, which is in the articular area involving the articular surface.

The split type is most common (avulsion 27.9%, split 62.8%, depression 9.3%) in this study, and the mean size of split type GT fragments is larger, which is consistent with the conclusion of Mutch *et al.*[17] However, this study found that Ideberg type II glenoid fractures were statistically more likely to be associated with avulsion GT fractures, and Ideberg type Ia glenoid fractures were statistically more likely to be associated with split GT fractures ($P < 0.05$). There is a negative correlation between the size of glenoid and GT fragments ($r = -0.64$, $P = 0.00$). The glenoid fragment in the split GT fracture group is significantly smaller than those of avulsion or depression GT fracture groups ($P < 0.05$).

We speculate that such injury is highly correlated with the degree of external rotation of the humeral head, and also relative spatial location between greater tuberosity and glenoid when the shoulder dislocates. When anterior dislocation occurs, if the humeral head has sufficient external 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)[29] 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[30].

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 facets, 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.

References

1. Liavaag S, Svenningsen S, Reikerås O, *et al*. The epidemiology of shoulder dislocations in Oslo. Scand J Med Sci Sports, 2011, 21: e334–e340.
2. Zacchilli MA, Owens BD. Epidemiology of shoulder dislocations presenting to emergency departments in the United States. J Bone Joint Surg Am, 2010, 92: 542–549.
3. Hayes K, Callanan M, Walton J, Paxinos A, Murrell GA. Shoulder instability: management and rehabilitation. J Orthop Sports Phys Ther, 2002, 32: 497–509.
4. Goebel M, Seebauer L. Open operative treatment of acute glenoid fractures following anterior and posterior shoulder dislocation. Oper Orthop Traumatol, 2008, 20: 228–238.
5. Ideberg R, Grevsten S. Larsson S. epidemiology of scapular fractures incidence and classification of 338 fractures. Acta Orthop Scand, 1995, 66: 395–397.
6. Rowe CR, Patel D, Southmayd WW. The Bankart procedure: a long-term end-result study. J Bone Joint Surg Am, 1978, 60: 1–16.
7. Sugaya H, Kon Y, Tsuchiya A. Arthroscopic repair of glenoid fractures using suture anchors. Art Ther, 2005, 21: 635.
8. Green A, Izzi JJ. Isolated fractures of the greater tuberosity of the proximal humerus. J Shoulder Elbow Surg, 2003, 12: 641–649.
9. Dimakopoulos P, Panagopoulos A, Kasimatis G, Syggelos SA, Lambiris E. Anterior traumatic shoulder dislocation associated with displaced greater tuberosity fracture: the necessity of operative treatment. J Orthop Trauma, 2007, 2: 104–112.
10. Robinson C, Shur N, Sharpe T, Ray A, Murray IR. Injuries associated with traumatic anterior Glenohumeral dislocations. J Bone Joint Surg Am, 2012, 94: 18–26.
11. Pujol N, Fong O, Scharycki S, Remi J, Beaufils P, Boisrenoult P. Simultaneous arthroscopic treatment of displaced greater tuberosity and glenoid fracture using a double-row technique. Knee Surg Sports Traumatol Arthrosc, 2009, 17: 1508–1510.
12. Kim YS, Lee B, Rhee Y, Lee CH. Arthroscopic reduction and internal fixation for displaced anterior glenoid rim and greater tuberosity fractures. J Orthop Sci, 2014, 19: 497–501.
13. Paavo L, Arnoud R, Henk J, Willems WJ. Infraglenoid tubercle avulsion and greater tuberosity fracture resulting from traumatic Glenohumeral anterior dislocation: a case report. J Orthop Trauma, 2012, 26: e1–e3.
14. Shah J, Najeeb M, Jacob D. Treatment of shoulder dislocation with greater tuberosity and Glenoid fractures. J Phys Surg Pak, 2016, 26: 997–999.
15. Ideberg R. Fractures of the scapula involving the glenoid fossa. In: Bateman JE, Welsh R, eds. P Surgery of the Shoulder. Philadelphia, PA: Mosby; 1984; 63–66.
16. Goss TP. Fractures of the glenoid cavity. J Bone Joint Surg Am, 1992, 74: 299–305.
17. Mutch J, Laflamme GY, Hagemeister N, Cikes A, Rouleau DM. A new morphologic classification for greater tuberosity fractures of the proximal humerus: validation and clinical implications. Bone Joint J, 2014, 96: 646–651.
18. Sugaya H, Moriishi J, Dohi M, Kon Y, Tsuchiya A. Glenoid rim morphology in recurrent anterior glenohumeral instability. J Bone Joint Surg Am, 2003, 85: 878–884.
19. Slaa RL, Verburg H, Marti RK. Fracture of the coracoid process, the greater tuberosity,and the glenoid rim after acute first-time anterior shoulder dislocation: a case report. J Shoulder Elbow Surg, 2001, 10: 489–492.
20. Plachel F, Schanda J, Ortmaier R, Auffarth A, Resch H, Bogner R. The “triple dislocation fracture”: anterior shoulder dislocation with concomitant fracture of the glenoid rim, greater tuberosity and coracoid process—a series of six cases. J Shoulder Elbow Surg, 2017, 22: 56–61.
21. Oostveen D, Temmerman O, Burger B, Noort A, Robinson M. Glenoid fractures: a review of pathology, classification, treatment and results. Acta Orthop Belg, 2014, 80: 88–98.
22. Maquieira GJ, espinosa N, Gerber C, Eid K. Non-operative treatment of large anterior glenoid rim fractures after traumatic anterior dislocation of the shoulder. J Bone Joint Surg Br, 2007, 89: 1347–1351.
23. Raiss P, Baumann F, Akbar M, Rickert M, Loew M. Open screw fixation of large anterior glenoid rim fractures: mid- and long-term results in 29 patients. Knee Surg Sports Traumatol Arthrosc, 2009, 17: 195–203.
24. Wiedemann E. Fractures of the scapula. Unfallchirurg, 2004, 107: 1124–1133.
25. Davies MB, Rajasekhar C, Bhamra MS. Irreducible anterior shoulder dislocation: the greater tuberosity Hill-Sachs lesion. Injury, 2000, 31: 470–471.
26. Kaspar S, Mandel S. Acromial impression fracture of the greater tuberosity with rotator cuff avulsion due to hyperabduction injury of the shoulder. J Shoulder Elbow Surg, 2004, 13: 112–114.
27. Bahrs C, Lingenfelter E, Fischer F, Walters EM, Schnabel M. Mechanism of injury and morphology of the greater tuberosity fracture. J Shoulder Elbow Surg, 2006, 15: 140–147.
28. Hill HA, Sachs MD. The grooved defect of the humeral head: a frequently unrecognized complication of dislocations of the shoulder joint. Radiology, 1940, 35: 690–700.
29. Minagawa H, Itoi E, Konno N, *et al*. Humeral attachment of the supraspinatus and infraspinatus tendons: an anatomic study. Art Ther, 1998, 14: 302–306.
30. DeBottis D, Anavian J, Green A. Surgical management of isolated greater tuberosity fractures of the proximal humerus. Orthop Clin N Am, 2014, 45: 207–218.