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ORIGINAL PAPER

Size of greater tuberosity fragment: a risk of iatrogenic injury during shoulder dislocation reduction

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Abstract

Purpose Shoulder dislocation with greater tuberosity fractures (GTF) is becoming increasingly common, as is the number of cases of iatrogenic humeral neck fractures (IHNF) during reduction. This study investigated the relationship between size of greater tuberosity fragment and occurrence of IHNF in patients with shoulder dislocation and GTF.

Methods A retrospective study was made to identify all patients presenting with shoulder dislocation with GTF between September 2014 and July 2016. There were 74 patients with an average age of 52.4 years (range 18–84 years) representing 76 cases of shoulder dislocation associated with GTF. Patient age, injury mechanism and location, treatment waiting time, and reduction method were noted. Using conventional anterior-posterior view radiographs, three points were identified as A, B, and C. Distance ratios between AC and AB were calculated, then the resulting ratio was compared to a critical value of 0.4.

Results More iatrogenic fractures occurred in cases where the AC/AB ratio exceeded 0.4. Most (13) occurred during emergency Hippocratic manual reduction. Only five of 18 iatrogenic fractures (27.78%) occurred during surgery while under traction. Women ran a higher risk of iatrogenic fracture than men (female/male ratio 8:1). On average, women were older than men at the time of fracture (59.75 years for women vs. 42 years for men).

Conclusions A statistically significant relationship exists between size of greater tuberosity fragment and occurrence of iatrogenic humeral neck fractures during the reduction of shoulder dislocation. The larger the greater tuberosity fragment, the higher the incidence of iatrogenic humeral neck fractures. For such fracture dislocations, we recommend open reduction with internal fixation directly and using a Kirschner wire in advance to reinforce the proximal humerus before reduction of the shoulder.

Keywords Shoulder dislocation · Size of greater tuberosity fragment · Reduction · Iatrogenic neck fracture · Retrospective study

Introduction

Shoulder dislocations are commonplace in orthopaedic emergency. It is well known that the shoulder is the most flexible and unstable joint in the human body and that it is the most commonly dislocated joint. Anterior shoulder dislocation is often accompanied by greater tuberosity fractures (GTFs), and posterior dislocation occurs with less tuberosity fracture (LTF) [1, 2]. An estimated 15–30% of shoulder dislocations are complicated by GTF [2, 3].

Treatment options of the shoulder dislocation with greater tuberosity fracture include non-operative management (manual reduction) and open reduction with internal fixation (ORIF). Through a retrospective statistical analysis of 259,506 patients with proximal humeral fractures, Han et al. [4] found that physicians most commonly prefer non-operative treatment of proximal humeral fractures. Green [5] and Platzer [6] reported that, based on their studies, most

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GTFs associated with shoulder dislocation are treated conservatively via clinical manual reduction. In contrast, Kim [7] emphasizes the necessity of ORIF instead of merely initial anatomic reduction for such patients because of the poor results in their studies who were treated by manual reduction. And Matti et al. also found that GTF associated with shoulder dislocation did worse than the isolate GTF [8].

A clear risk of iatrogenic fracture exists regardless of reduction method. Gerber [9] firstly reported the difficulty in treating such fracture-dislocation. He further said that careful closed reduction under general anesthesia with optimal relaxation and fluoroscopic control did not prevent iatrogenic fracture or displacement. And even open reduction and internal fixation were also technically challenging. In his survey, six cases of iatrogenic fracture displacement occurred during attempted closed reduction while one case occurred during attempted open reduction. Atoun [10] and Chu [11] reported five and four cases of iatrogenic humeral neck fracture (IHNF) respectively in their studies that occurred during manual reduction of anterior shoulder dislocation accompanied with GTF.

However, few researchers have sought to understand underlying mechanisms of iatrogenic fracture occurring during reduction of shoulder dislocation complicated by GTF. Also, there have been no methods identified to aid physicians evaluate risk of such fractures. The purpose of this study was to investigate the relationship between size of GTF and occurrence of IHNF. We hypothesized that the fragment size of the GTF might influence occurrence of iatrogenic humeral neck fracture during reduction. To the best of our knowledge, this is the first study to give a quantitative imaging analysis, whose aim was to find the risk factors of such fracture-dislocations.

Methods

A retrospective analysis of orthopaedic fractures was conducted at a single Level I trauma centre to identify all patients presenting with shoulder dislocation with GTF between September 2014 and July 2016.

Patients 18 years or older who were treated with either non-operative manual reduction or surgical open reduction with internal fixation, and who received a minimum of one year of follow-up care, were included. Patients with previous proximal humeral fractures, brain injury, open abdominal injury, multiple fractures, or injuries were excluded. Seventy-four patients (two with bilateral injuries) presenting with shoulder dislocation with GTF met our inclusion and exclusion criteria. Patients were retrospectively assigned to two study groups: those in which IHNF occurred were placed in group A; those in which no IHNF occurred were placed in group B.

Electronic inpatient and outpatient medical records, and all radiographs of each case in the two groups, were reviewed by two orthopaedic surgeons not involved in patients' care. The radiographs of each patient were measured for two times by two surgeons separately and if the consequences differed greatly, a third time is needed. Use the average value of the measurements as the final. In 76 cases presenting with shoulder dislocation and GTF, 18 cases of IHNF were identified. Of those 18 cases, 13 (72.22%) occurred during emergency Hippocratic manual reduction while five (27.78%) occurred during open reduction with internal fixation procedures. Patient demographics, comorbidities, injury mechanisms, treatment waiting times, and other variables were recorded and calculated for each case. This study was approved by the institutional internal review board of the participating institution.

All surgeons and orthopaedic trainees attempting reduction were experienced in treating shoulder injuries.

Measurement

Complete data were obtained for 76 cases (74 patients) of shoulder dislocation with greater tuberosity fractures. Radiographs of all fractures were classified Type 11-A1 according to the Orthopaedic Trauma Association (OTA) classification, and as one-part or two-part fracture with shoulder dislocation according to the Neer classification.

Fujifilm Synapse 3.2.1 Workstation Software was used to examine the anterior-posterior radiographs of all fractures. Point "A" was placed at the vertex of the humeral greater tuberosity, point "B" was placed at the maximum curvature of the medial cortex between humeral surgical neck and anatomic neck, and point "C" was placed at the fracture line crossing the line segment AB (Figs. 1 and 2). The lengths of line segments AB and AC were measured separately, and then the ratio of AC/AB was determined. MedCalc v11.4 for Windows was used to calculate critical value via a ROC (receiver operating characteristic) curve. SPSS v.24.0 for Windows was used to perform statistical analysis. Count data was expressed in percentage (%); measurement data was represented by use of mean ± standard deviation ($\bar{X}\pm$ S). Chi-square or Fisher's exact tests and likelihood-ratio test were applied to all outcome analyses where appropriate. For all tests, P values < 0.05 were considered to be significant. We compared AC/AB ratios to the critical value to learn if a relationship might exist between size of greater tuberosity fragment and iatrogenic injury.

Results

All (100%) dislocations were anterior. None were chronic dislocations. All greater tuberosity fractures were acute. All

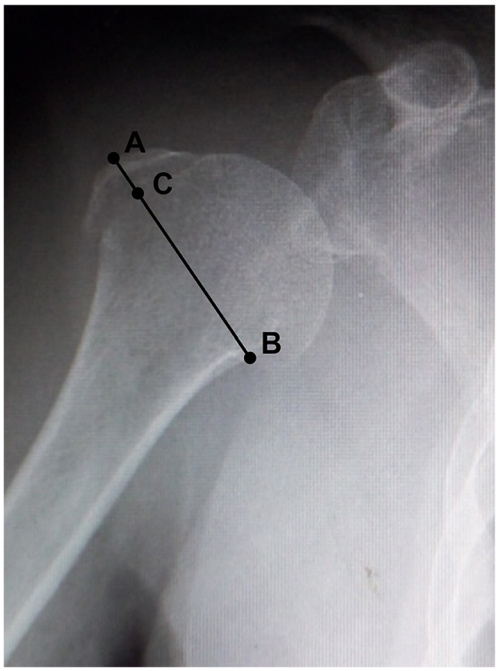

Fig. 1 In an AP view X-ray of the shoulder, define three points. Place Point A at the vertex of humeral greater tuberosity, point B at the maximum curvature of the medial cortex between the humeral surgical neck and anatomic neck, and point C at the fracture line where it crosses the line segment AB

iatrogenic humeral surgical neck fractures were closed. Of 76 cases involving greater tuberosity fractures associated with shoulder dislocations, 40 (52.6%) were in men and 36 (47.4%) were in women. Average age was 52.4 years (range, 18–84 years). Forty (52.63%) were on the left side and 36 (47.37%) were right-side dislocations. In 76 cases, six (7.9%) included nerve injury and all were contusions. Four cases (5.3%) had accompanying glenoid injury, one case (1.3%) included a rupture of the supraspinatus, four cases (5.3%) had scapula fracture, and 14 cases (18.4%) were accompanied by other fractures.

Low-energy falls (from a standing position) caused 32 (42.11%) fractures; falls from a considerable height or downstairs caused 21 (27.63%) fractures; motor vehicle accidents caused 18 (23.7%) fractures; other events caused fractures in five cases (6.6%). Average time from injury to treatment (emergency manual reduction or ORIF) was 34.3 ± 53.6 h (range, 1–216 h).

Incidence rate was significantly influenced by gender and age. In group A (shoulder dislocation with GTF in which IHNF occurred), 18 iatrogenic fractures occurred. More women had iatrogenic fractures than men. Of 18 secondary fracture cases, 16 (88.9%) were female with average of 59.8 years while only two (11.1%) were male with an average of 42 years. In group B (shoulder dislocation with GTF but having no iatrogenic fracture), there were more men than women: 38 men (76.0%) vs. 20 women (24.0%). More people in group B were younger than 50 (34, or 58.6%) than were 50 or older (24, or 41.4%).

Women aged 50 years or older experienced more secondary fractures. Secondary fractures occurred in 13 (46.4%) of 28 women ≥ 50 years old who presented with GTF associated with shoulder dislocations. More men under 50 years had GTF fractures compared to women. No significant differences ($P > 0.05$) were observed in injury mechanism, treatment waiting time, or dislocation side (Table 1).

Significant differences were found in the numbers of cases displayed by distribution of the AC/AB ratios in two groups. With the numbers of cases displayed by distribution of the AC/AB ratios in two groups as in Table 2, we found the proportion of cases with the ratios > 0.4 was significantly higher in group A vs. those in group B (94.4 vs. 8.6%). In addition, in cases with the ratios of AC/AB ≤ 0.4, only one of 54 cases (1.9%) took place iatrogenic fracture ($P = 0.000$, Table 2).

Of 76 total cases, 33 (43.4%) received manual reduction while 43 (56.6%) received ORIF. Among the 18 iatrogenic fracture cases, 13 (72.2%) occurred during manual reduction while only five (27.8%) occurred during ORIF. This was a statistically significant difference ($P = 0.005$, Table 3).

The ROC curve reflects the relationship between the true positive rate (sensitivity) and false positive rate (1-specificity). The area beneath the ROC curve reflects the likelihood of causing IHNF. According to the ROC curve in our study, the area under the ROC curve was 0.951 (95% confidence interval 0.876–0.987). After comprehensive consideration of sensitivity and specificity, we defined 0.4 (0.3982 in accurate) as the critical value (Fig. 3). By comparing AC/AB ratios in all 76 cases to the critical value of 0.4, we learned that a statistically very significant number of iatrogenic fractures had occurred in cases where the size of the fragment had an AC/AB ratio greater than 0.4. IHNF was significantly higher in group A (17 of 18, or 94.4%) than in group B (5 of 58 cases, 8.6%). In 22 GTF cases with an AC/AB ratio greater than 0.4, 17 (77.3%) were iatrogenic. In 54 GTF cases with an AC/AB ratio ≤ 0.4, only one was an iatrogenic fracture (Table 2).

Discussion

Fractures of the greater tuberosity may frequently occur at the same time as a shoulder dislocation [12]. Attempting shoulder reduction usually may be the primary treatment for such fracture-dislocation patients. However, there have been a number of cases described in recent literature that a clear risk of iatrogenic humeral fracture exists during reduction of shoulder dislocations regardless of method, drawing this practice into debate [9–11]. Atoun et al. [10] investigated 92 patients older than 40 years with anterior dislocation of the shoulder; 19 patients were diagnosed with concomitant GTF.

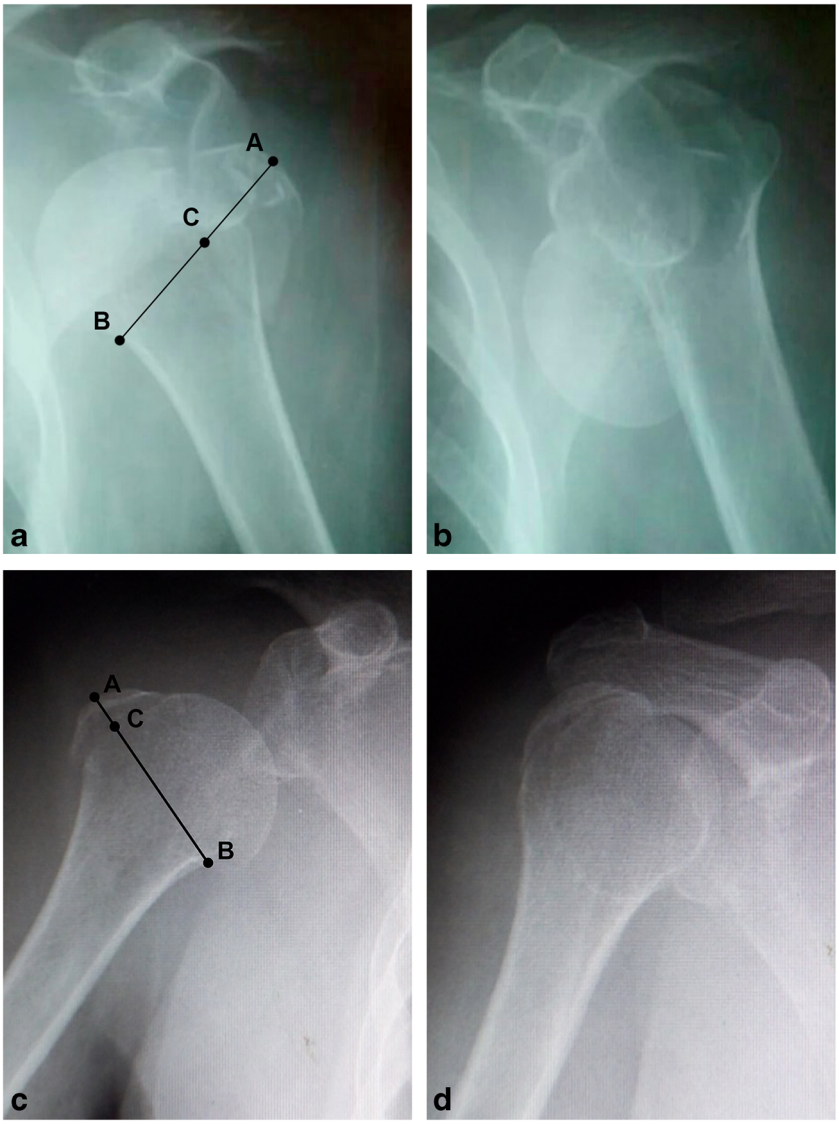

Fig. 2 **a** A 72-year-old female patient with shoulder dislocation associated with GTF and the ratio of AC/AB is 0.45. **b** IHSNF(IHNF) occurred during manual reduction. **c** A 60-year-old female patient with shoulder dislocation associated with GTF and the ratio of AC/AB is 0.18. **d** IHSNF(IHNF) did not occur during emergency Hippocratic manual reduction

Reduction attempts under sedation in the emergency room resulted in iatrogenic humeral fractures in five cases for those patients. Chu et al. [11] reported four cases of iatrogenic humeral neck fractures (IHNF) that occurred during manual reduction of anterior shoulder dislocation and GTF. And also, Gerber [9] reported seven cases, five of which belonged to anterior dislocation with GTF, and two patients belonged to posterior dislocation with LTF. After accepted primary treatment, six cases of iatrogenic fracture displacement occurred during attempted closed reduction while one case occurred during attempted open reduction.

A number of researchers [2, 12–16] previously found and explained in their surveys that the results which were associated with an undisplaced fracture of the humeral neck finally led to displacement, which were unrecognized in radiographs before reduction. Ferkel et al. [2] described two cases of anterior dislocation of the shoulder with a greater tuberosity fracture and missed undisplaced humeral neck fractures on initial radiographs, after attempted reduction by emergency room physicians; subsequent X-rays showed a complete separation of the humeral head from the neck. Ranawat et al. [13] reported five cases of iatrogenic humeral neck fracture or displacement after closed reduction attempt, in which four patients were attempted reduction under intra-articular anesthesia or conscious sedation except for one case unspecified. Demirhan et al. [14] reported six cases of primary replacement of the humeral head where closed reduction of a shoulder dislocation associated with an undisplaced fracture of the humeral neck led to displacement of the neck fracture. And all dislocations examined were anterior with a displaced greater (tuberosity) fracture.

In seven cases reported by Gerber [9], five patients got complete displacement of the head segment. The neck fracture had not initially been recognized in three of them. Then he said humeral neck fractures must always be ruled out by performing adequate radiological investigations that could

Table 1 Demographics and variables

Variables	Secondary fractures group (group A) ($n = 18$)	Normal group (group B) ($n = 58$)	P value
Gender, n (%)			0.000*
Male	2 (11.1%)	38 (76.0%)	
Female	16 (88.9%)	20 (24.0%)	
Age, n (%)			0.022*
< 50 years	5 (27.8%)	34 (58.6%)	
≥ 50 years	13 (72.2%)	24 (41.4%)	
Dislocation side, n (%)			0.798
Left	9 (50.0%)	31 (53.4%)	
Right	9 (50.0%)	27 (46.6%)	
Comorbidities, n (%)			
Nerve injury	1 (5.6%)	5 (8.6%)	0.562
Glenoid injury	0	4 (6.9%)	0.331
Rupture of supraspinatus	0	1 (1.7%)	0.763
Scapula fracture	2 (11.1%)	2 (3.4%)	0.236
Other fracture	2 (11.1%)	12 (20.7%)	0.296
None	13 (72.2%)	37 (63.8%)	0.510
Injury mechanisms, n (%)			0.234
Low-energy falls	8 (44.4%)	24 (41.4%)	
High falling injury	7 (38.9%)	14 (24.1%)	
Motor vehicle accidents	3 (16.7%)	15 (25.9%)	
Others	0	5 (8.6%)	
Treatment waiting time, n (%)			0.141
< 6 h	4 (22.2%)	24 (41.4%)	
≥ 6 h	14 (77.8%)	34 (58.6%)	

*Statistically significant difference ($P < 0.05$)

be in the form of axillary lateral film or CT scans, which is advocated in other literatures [2, 9, 16–18]. And he also emphasized this should be added if there is any suspicion of a neck fracture in patients with dislocated shoulder, especially in subglenoid dislocations associated with GTF [12].

However, Ahmad [18] concluded that despite advances in imaging, the neck fractures are frequently missed and diagnosed later, which is a similar result with Joseph that although the majority of fractures associated with shoulder dislocations are seen on pre-reduction radiographs, more than one third of fractures may be visible only on post-reduction X-rays [19]. In our opinion, an occasional proximal humeral fracture may not be detected easily because of the difficulty to position the painful patient or superimposition of fracture fragments.

According to our data, there were 18 iatrogenic fractures that occurred in 76 patients; the ratio was kind of high. All 18 cases maybe were taken as iatrogenic fracture instead of

Table 2 Group A and Group B cases by distribution of AC/AB ratios

Group	Group A ($n = 18$)	Group B ($n = 58$)	Total ($n = 76$)
Ratio of AC/AB ≤ 0.2	0 (0.0%)	8 (13.8%)	8
0.2 < ratio of AC/AB ≤ 0.3	0 (0.0%)	18 (31.0%)	18
0.3 < ratio of AC/AB ≤ 0.4	1 (5.6%)	27 (46.6%)	28
0.4 < ratio of AC/AB ≤ 0.5	7 (38.9%)	4 (6.9%)	11
0.5 < ratio of AC/AB ≤ 0.6	8 (44.4%)	1 (1.7%)	9
Ratio of AC/AB > 0.6	2 (11.1%)	0 (0.0%)	2

$P = 0.000$*

*Statistically significant difference ($P < 0.05$)

Table 3 Differences in manual vs. ORIF reduction

Group	Group A ($n = 18$)	Group B ($n = 58$)	Total ($n = 76$)
Manual reduction	13 (72.2%)	20 (34.5%)	33
ORIF	5 (27.8%)	38 (65.5%)	43

$P = 0.005$*

*Statistically significant difference ($P < 0.05$)

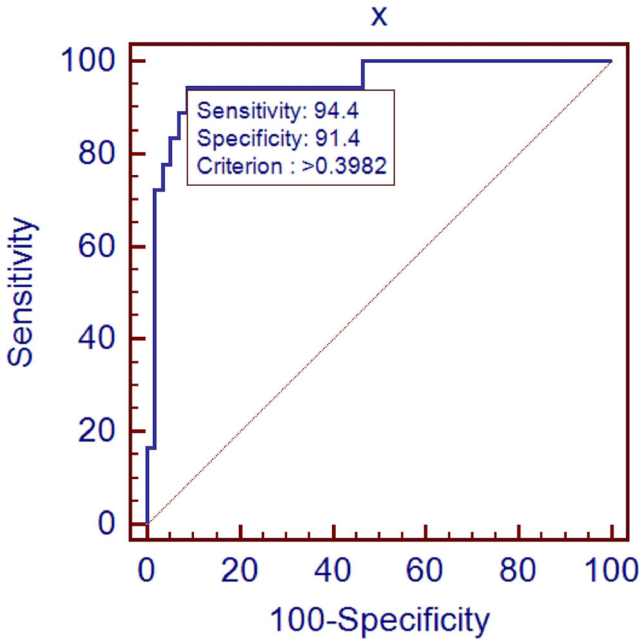

Fig. 3 The ROC curve reflects the relationship between the true positive rate (sensitivity) and false positive rate (1-specificity). The area beneath the ROC curve reflects the likelihood of causing IHSNF(IHNF). According to the ROC curve in our study, the area under the ROC curve was 0.951 (95% confidence interval 0.876–0.987). After comprehensive consideration of sensitivity and specificity, we defined 0.4 (0.3982 in accurate) as the critical value

iatrogenic displacement of humeral neck fracture which probably previously existed before attempting reduction. This is owing to our insufficient radiology applying. However, Razemon et al. [20] reviewed 1415 fractures and fracture-dislocations of the proximal humerus and concluded that iatrogenic displacement of a neck fracture occurs only very rarely in association with fracture-dislocations of the greater tuberosity. And all of our closed reduction attempts were made only under pain medication instead of under conscious sedation or with a local anaesthetic intra-articular injection, which is recommended by previous studies [2, 15, 16]. All these researches conclude that iatrogenic injuries can occur by insufficient muscle relaxant and rough manoeuvre without general anesthesia. Additionally, there was no established treatment protocol for such fracture-dislocations, and reduction methods were mostly dependent on orthopaedic surgeons' preferences with various levels of experience and training. Though there were multiple techniques of reduction that exist, Hippocratic manual reduction is still the most popular method in the emergency department in our country when treating shoulder dislocation. After conducting this study, the practice in our hospital had changed.

Based on our observations, we also found that closed reduction caused more iatrogenic fractures than open reduction and women aged 50 years or older are more prone to iatrogenic fractures.

Incidence of proximal humeral fracture in people over 50 years old has increased greatly. Some sources estimate that 80% of them occur in females [21]. According to our consequence, a high rate of iatrogenic humeral neck fractures occurs among women older than 50 years. This finding supports researches already published: female patients, especially those aged more than 50 years old, are more prone to suffer iatrogenic proximal humeral fracture during reduction. This is attributable to age-related factors such as osteoporosis [15]. Lee [22] pointed out in their respective study that elderly women should receive the highest priority for prevention because of their bone fragility.

To the best of our knowledge, this is the first quantitative imaging analysis of manual reduction risk for shoulder dislocation with GTF. In this study, our findings clearly suggest that size of the greater tuberosity fragment can influence occurrence of such complicated fractures. This supports the conclusions of Mutch et al. who reported that fragment size, shape, and orientation of GTF may reflect different mechanisms and velocity of injury [23]. Then Mutch gave a morphological classification of GTF based on fragment morphology and its possible mechanism of injury (avulsion fracture, split fracture, and depressed fracture); their new classification contributes neither to determine stability of the proximal humerus after fracture nor to anticipate likelihood that a secondary fracture will occur during reduction. However, based on our data, physicians can better avoid IHSNF(IHNF) by including a ratio-based measurement of the GTF before deciding on a reduction method. We propose that physicians evaluate risk of IHNF by using conventional clinical AP view radiographs, measuring the ratios of AC/AB, then comparing them to the critical value of 0.4. Shoulder dislocation presenting with greater tuberosity fractures can then be classified as either "Type I Stable" or "Type II Unstable" cases. A Type I Stable fracture has an AC/AB ratio ≤ 0.4. Risk of iatrogenic fracture of the humeral neck is low during reduction in such cases. A Type II Unstable fracture has an AC/AB ratio > 0.4. Risk of iatrogenic fracture is high.

Our observations found that more iatrogenic fractures occur during closed reduction, which has been demonstrated in researches that the tendon of the long head of the biceps interposed between the head of the humerus and the greater tuberosity fragment [24] or between the displaced humeral head and the humeral neck [25], and causing the difficulty of reduction. IHSNF(IHNF) from two-part fractures (Neer classification) to complex three-part fractures can easily interfere with branches of anterior humeral circumflex artery and axillary nerves, which increases surgical complications and worsens prognosis. So we recommend that ORIF be preferred for the reduction of Type II Unstable fractures, which is similar with other researches [2, 3, 7]. Our opinion is the same with Gerber [9] and Ranawat [13] that the best treatment may be prophylactic surgical stabilization of the neck fracture in situ by using a Kirschner wire in advance to reinforce the proximal humerus before gentle reduction of the shoulder.

In this study, the X-ray may not show the real anterior-posterior view, which may result in the inaccurate measurement. At least, it draws an attention to that the larger the greater tuberosity fragment, the higher the incidence of iatrogenic humeral neck fracture. The relative strength of this study is the use of highly accurate electronic medical record system and this is the first study to give a quantitative imaging analysis, whose significance may be highly useful for evaluation of the iatrogenic fracture risk in shoulder dislocation accompanied by greater tuberosity fracture. Limitations to this study include the small sample size, its retrospective design, and need for subsequent large prospective studies to be conducted that confirm these conclusions. Moreover, a lack of long-term (e.g., > 3 year) follow-up could have also influenced the results.

Conclusion

A statistically significant relationship exists between size of greater tuberosity fragment and occurrence of iatrogenic humeral neck fractures during reduction. For such fracture dislocations, we recommend open reduction with internal fixation directly and using a Kirschner wire in advance to reinforce the proximal humerus before reduction of the shoulder.

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Author contributions statement Junfei Guo and Zhiyong Hou designed the study. Junfei Guo and Lin Jin collected the data of the study. Junfei Guo drafted the manuscript. Yingchao Yin, Yueju Liu, Zhiyong Hou, and Yingze Zhang revised the manuscript before submission. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was approved by the institutional internal review board of the participating institution.

Informed consent For this type of study, formal consent is not required.

Abbreviations GTF, greater tuberosity fractures; LTF, less tuberosity fracture; IHNF, iatrogenic humeral neck fractures; ORIF, open reduction with internal fixation; OTA, Orthopaedic Trauma Association; ROC curve, receiver operating characteristic curve

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