RESEARCH ARTICLE

Quantitative 3-dimensional Computerized Tomography Modeling of Isolated Greater Tuberosity Fractures with and without Shoulder Dislocation

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Abstract

Background: The aim of this study was to assess differences in fracture morphology and displacement between isolated greater tuberosity (GT) fractures (i.e. fractures of the greater tuberosity without other fractures of the proximal humerus) with and without shoulder dislocation utilizing quantitative 3-dimensional CT imaging.

Methods: Thirty-four CT-scans of isolated greater tuberosity fractures were measured with 3-dimensional modeling. Twenty patients (59%) had concomitant dislocation of the shoulder that was reduced prior to CT-scanning. We measured: degree and direction of GT displacement, size of the main fracture fragment, the number of fracture fragments, and overlap of the GT fracture fragment over the intact proximal humerus.

Results: We found: (1) more overlap –over the intact humerus– in patients without concomitant shoulder dislocation as compared to those with shoulder dislocation (*P=0.03*), (2) there was a trend towards greater magnitude of displacement between those without (mean 19mm) and those with (mean 11mm) a concomitant shoulder dislocation (*P=0.07*), and (3) fractures were comparable in direction of displacement (*P=0.50*) and size of the fracture fragment (*P=0.53*).

Conclusion: We found substantial variation in degree and direction of displacement of GT fracture fragments. Variation in degree of overlap and displacement is partially explained by concomitant shoulder dislocation.

Level of evidence: IV

Keywords: Humerus, Fracture, Greater tuberosity, Q3DCT, Shoulder

Introduction

Fractures of the greater tuberosity (GT) without other fractures of the proximal humerus (herein referred to as an "isolated" fracture of the GT) occur in patients with and without concomitant shoulder dislocation and are relatively uncommon (1-3). Neer recommended operative treatment for fractures displaced more than a centimeter (4). Some surgeons feel that as little as 3 to 5mm of displacement might impair abduction and forward flexion, which might be important to active patients involved in frequent overhead activities (1, 5-11). Some authors emphasize superior displacement, which may impinge on the acromion creating a mechanical block and rotator cuff dysfunction (3, 6, 7, 11, 12). Others suggest that

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posterior displacement can cause impairment related to the degree of overlap of the GT fragment over the posterior articular surface (13).

It is not clear that GT fracture displacement can be accurately or reliably assessed on radiographs (14). CT –3-dimensional reconstructions in particular—may provide more detail, and merits additional study (15, 16). Quantitative 3-dimensional analysis of CT scans can provide us with information about fracture morphology: direction and degree of displacement of fracture fragments, degree of comminution, size of fracture fragments, and articular surface involvement (15, 16). GT fractures occur after a fall on outstretched hand or direct impact to the shoulder, either isolated or in combination with a glenohumeral (i.e. shoulder) dislocation (2, 17, 18). Several fracture mechanisms are described in literature: forceful pull by the rotator cuff avulsing the greater tuberosity, shearing of the greater tuberosity against the glenoid rim, or impaction of the greater tuberosity against the acromion (1-3, 18-20). Glenohumeral dislocations are thought to cause avulsion injuries, while hyperabduction and extreme rotation might cause impaction and comminution of the greater tuberosity (3, 18). These theories suggest there might be an association of fracture mechanism with fracture morphology.

Understanding the association of GT fracture morphology with glenohumeral dislocation might improve our understanding of fracture mechanisms and could eventually aid in surgical decision-making. This study aims to describe fracture characteristics of isolated GT fractures using quantitative 3-dimensional analysis of CT-scans and compare GT fractures with and without a shoulder dislocation (21, 22).

We tested the null hypotheses that there is no difference in: (1) the amount of displacement, (2) direction of displacement, (3) size of the main GT fracture fragment, (4) overlap of the main GT fracture fragment over the proximal humerus, and (5) number of fracture fragments between isolated GT fractures with and without shoulder dislocation after reduction of the dislocation.

Materials and Methods

Study design

This retrospective study was approved by our institutional review board. A search of billing and diagnostic records identified 86 patients with an isolated fracture of the greater tuberosity of the humerus who were evaluated with a computed tomography (CT) scan between 2003 and 2013 in 4 trauma hospitals (Massachusetts General Hospital in Boston, Brigham and Women's Hospital in Boston, Onze Lieve Vrouwe Gasthuis Hospital in Amsterdam, Sint Lucas Andreas Hospital in Amsterdam). Exclusion criteria were: (1) age ≤ 16 years of age, (2) CT-scan slice thickness above 2.5mm, (3) GT fractures occurring in conjunction with other fractures of the proximal humerus (e.g. surgical neck fracture, lesser tuberosity fracture), and (4) CT-scan obtained with the shoulder still dislocated. Thirty-four CT scans were

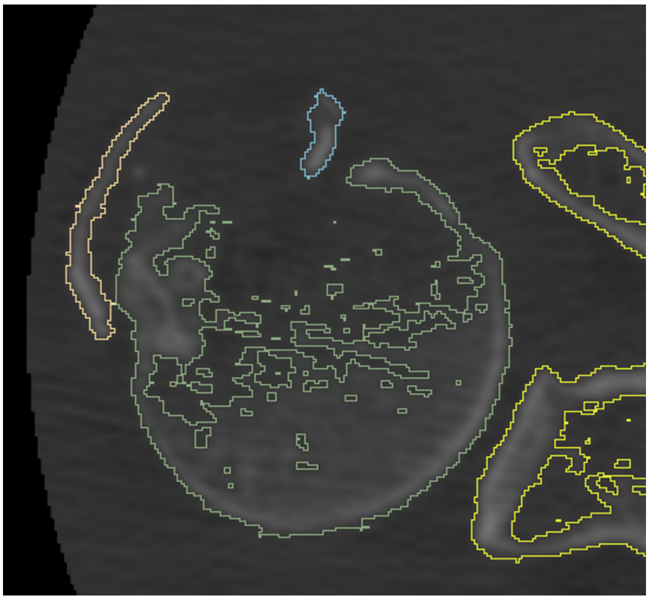

Figure 1. Transverse Computed Tomography image of proximal humerus with greater tuberosity fracture in 3D Slicer. (Scapula colored yellow is not used for calculations).

included in this study for 3D modeling. There were no concomitant glenoid rim fractures that interfered with 3D modeling.

Creating the three-dimensional models

Several different CT scanners were used up to 120 - 140Kv and 500 to 700 mA. CT scan DICOM (Digital Imaging and Communications in Medicine) files were obtained through the radiology archiving system of the 4 hospitals. The persons (SJJ, DPM, BL) creating the 3-dimensional models was blinded for the presence of shoulder dislocation prior to the CT-scan to avoid information bias.

Three-dimensional models were rendered using 3D Slicer (3D Slicer, version 4.2, Boston, USA), which is able to identify high-density structures (e.g. cortical bone) based on the Hounsfield units (>250 Hounsfield units) [Figure 1]. This creates a hollow 3-dimensional mesh model of cortical bone [Figure 2]. The fracture fragments and proximal humerus were identified and isolated for analyses [Figure 1 and 2]. Only the mesh model of the main GT fracture fragment and proximal humerus were imported into Rhinoceros (Version 5, Wenatchee, USA) for displacement, direction, size, and overlap analysis of the main GT fracture fragment [Figure 3A].

The position of the 3-dimensional model was standardized using the x, y and z axis in Rhinoceros to allow for measurement of degree and direction of displacement. The medullary canal of the humeral diaphysis was used to define superior and inferior direction (y-axis), the lesser tuberosity was used to define anterior – posterior direction (z-axis), and

Figure 2. 3-dimensional model of proximal humerus in 3D slicer. (Scapula colored yellow and clavicle colored brown are not used for calculations).

medial – lateral direction (x-axis).

Evaluation of the 3-dimensional models

Following the rendering of the 3-dimensional model and anchoring it in the standardized position; the main GT fracture fragment was reduced digitally to the proximal humerus using the borders of the main fracture fragment and the borders of the defect in the proximal humerus as a reference [Figure 3A and 3B]. The center-point coordinates of the non-reduced and reduced main GT fracture fragment was determined using Rhinoceros. The displacement and direction of displacement was calculated based on the center-point coordinates of the non-reduced and reduced main fracture fragment.

The percentage of overlap was calculated by dividing the area of the main GT fracture fragment part overlapping the proximal humerus by the total area size (total area size = overlapping part + non-overlapping part) of this fragment. The overlapping and non-overlapping parts are discerned by a line which follows the outline of the bony defect in the proximal humerus.

Statistical analysis

Variables were presented with frequencies and percentages for categorical variables and as median with interquartile range for continuous distributed variables.

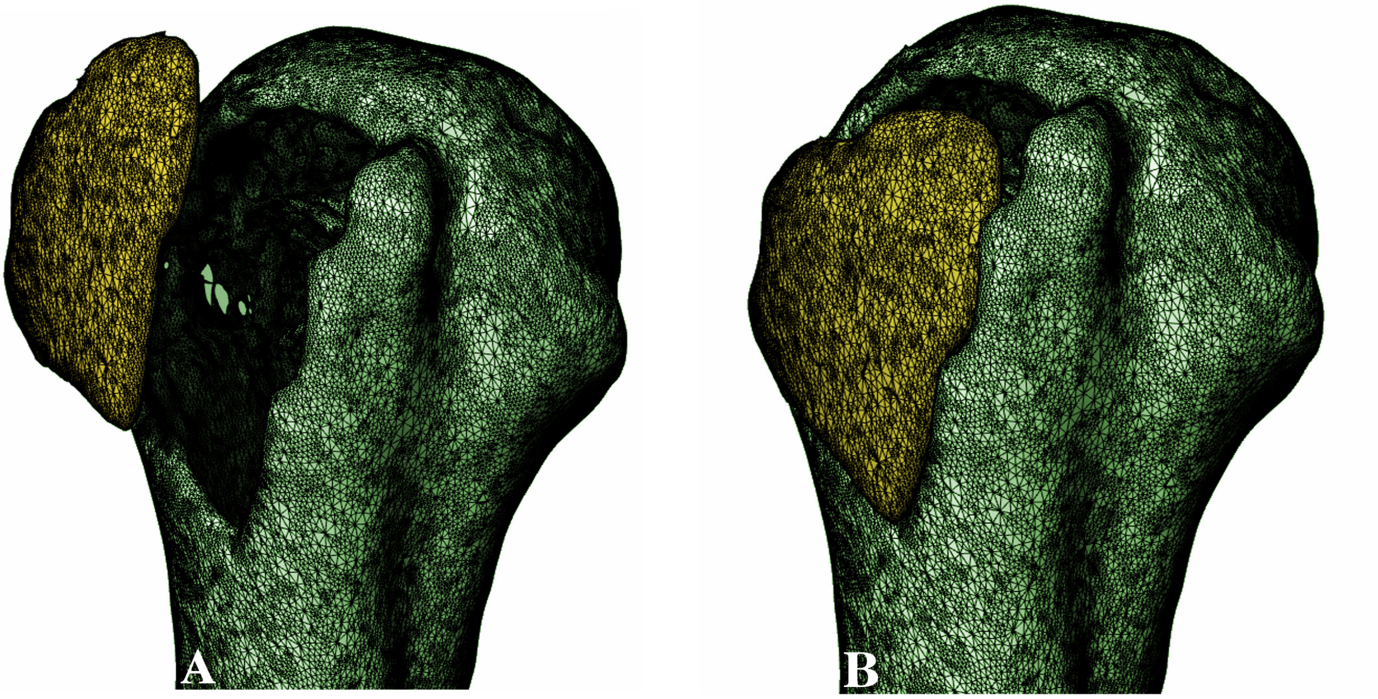

Figure 3. Anterolateral view of 3-dimensional polygon mesh models of high density cortical bone of the right proximal humerus (Green) and the main greater tuberosity fracture fragment (Yellow) in Rhinoceros. (A) Prior to digital reduction. (B) After digital reduction.

A graph was drawn to demonstrate the direction of displacement of the main GT fracture fragment.

In bivariate analysis, the association between the response variable (shoulder dislocation) and dichotomous explanatory variables was examined using the Fisher exact test. Relation between response variable (shoulder dislocation) and continuous distributed explanatory variables were examined using the Mann-Whitney-U test.

A Spearman rank correlation was used to assess the relationship between displacement and overlap of the main GT fracture fragment over the proximal humerus. Statistical analysis was performed using Stata 13 (StataCorp, USA).

Results

There were 13 (38%) men and 21 (62%) women with a median age of 49 (interquartile range of 38 to 63; range 17 to 91 years) [Table 1]. The median time between injury and CT-scan was 3 days (interquartile range of 0 to 10, range 0 to 50 days). Twenty (59%) patients had a dislocated shoulder that was relocated prior to undergoing a CT-scan.

There was a difference in overlap of the main GT fracture fragment over the proximal humerus between patients with concomitant shoulder dislocation (35%) and patients without shoulder dislocation (61%) (*P=0.03*) [Figure 4]. The displacement of the main fragment seemed to be trending towards greater magnitude of displacement between those without (mean 19 mm), and those with (mean 11 mm) a concomitant dislocation, but did not reach significance (*P=0.07*) [Figure 5]. There was no difference in direction of displacement (*P=0.50*); the size of the main GT fracture fragment (*P=0.53*) and number of fragments (*P=0.97*) [Tables 2 and 3; Figure 6].

Table 1. Patients Demographics

	Median (interquartile range)
Age in years	49 (38 - 63)
	n (%)
Women	21 (62%)
Left-side	19 (56%)
Mechanism of injury	
Fall	19 (56%)
Sports	7 (21%)
Road traffic accident	3 (9%)
Seizure	2 (6%)
Other/Unknown	3 (9%)
Shoulder dislocation	20 (59%)

n=34

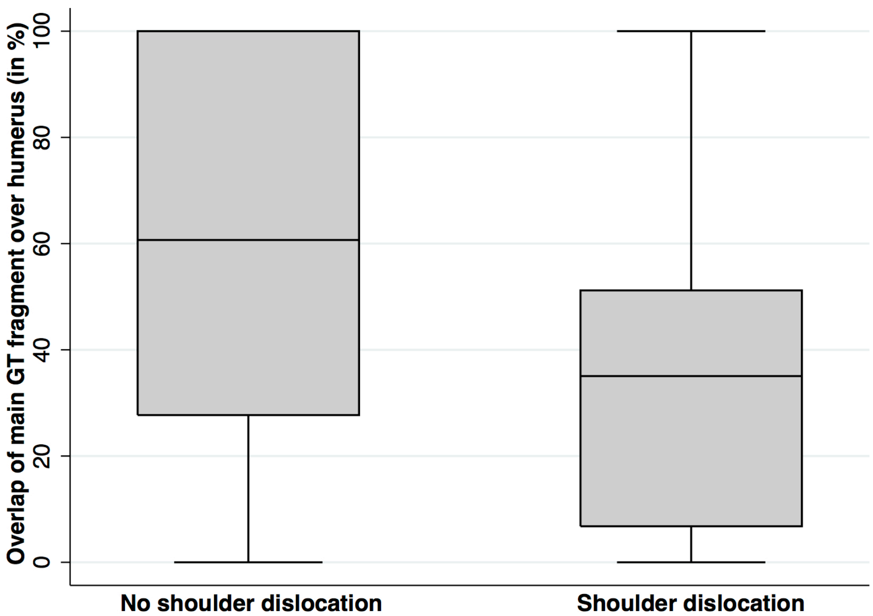

Figure 4. Box and Whisker plot demonstrating the difference in main fracture fragment overlap (in %) between Greater Tuberosity (GT) fractures with and without concomitant shoulder dislocation) (*P=0.03*).

There was a strong correlation between displacement of the main GT fracture fragment and overlap of the fragment over the proximal humerus (r=0.90, $P<0.001$) [Figure 7]. Overall, median displacement of the main GT fracture fragment was 13mm; however, displacement varied from 0 to 40mm [Table 3]. Nineteen (56%) GT fractures were displaced posterosuperior, 15 (44%) posteroinferior [Figure 6].

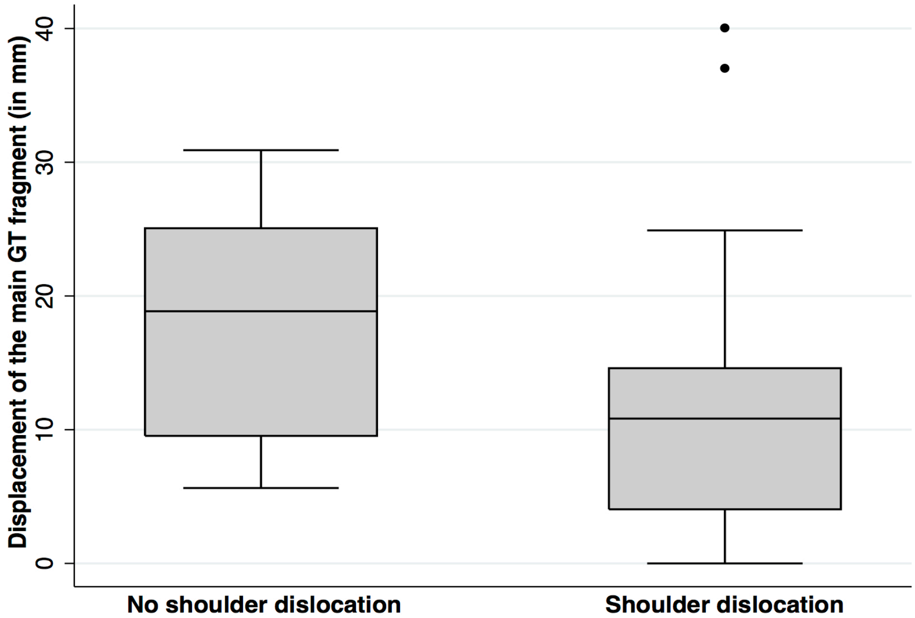

Figure 5. Box and Whisker plot demonstrating the displacement (in mm) of the main fracture fragment of Greater Tuberosity (GT) fractures with and without concomitant shoulder dislocation) (*P=0.07*).

Table 2. Bivariate analysis

	Patients without shoulder dislocation (n = 14)	Patients with shoulder dislocation (n = 20)	*P value*
Sex	n (%)	n (%)	
Women	9 (64%)	12 (60%)	*0.99*
Men	5 (36%)	8 (40%)	
Direction of displacement	n (%)	n (%)	
Posterosuperior	9 (64%)	10 (50%)	*0.50*
Posteroinferior	5 (36%)	10 (50%)	
	Median (Interquartile range)	**Median (Interquartile range)**	
Number of fracture fragments	3 (2 - 4)	3 (2 - 4)	*0.97*
Age (in years)	50 (33 - 65)	47.5 (38 - 62)	*0.83*
Displacement of main fragment (in mm)	19 (10 - 25)	11 (4 - 15)	*0.07*
Overlap of main GT fragment over humerus (in %)	61 (28 - 100)	35 (7 - 51)	***0.03***
Size of the main GT fragment (in mm2)	477 (225 - 776)	574 (408 - 663)	*0.53*

n = 34, GT = greater tuberosity, mm = millimeter

Table 3. Fracture Characteristics

Direction of displacement	n (%)	
Posterosuperior displacement	19 (56%)	
Posteroinferior displacement	15 (44%)	
Number of fracture fragments	n (%)	
1	3 (9%)	
2	9 (26%)	
3	10 (29%)	
≥4	12 (35%)	
	Median (interquartile range)	**Range**
Displacement of main fragment (in mm)	13 (7 - 20)	0 - 40
Overlap of main GT fragment over humerus (in %)	43 (18 - 66)	0 - 100
Size of the main GT fragment (in mm2)	560 (328 - 761)	141 - 975

n = 34, GT = greater tuberosity, mm = millimeter

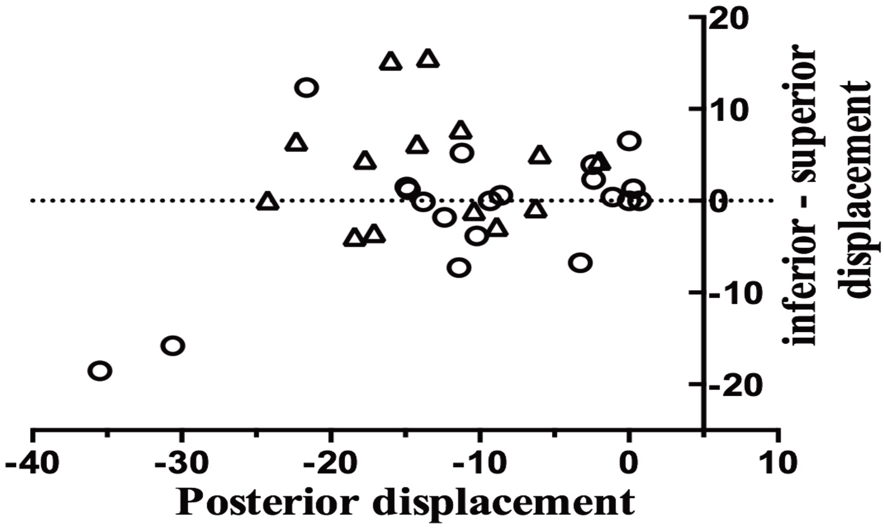

Figure 6. Graph demonstrating the magnitude and direction of displacement of the main greater tuberosity fracture fragment of the cases with (O) and without (Δ) shoulder dislocation.

Discussion

Isolated GT fractures are uncommon and the indication for operative treatment of displaced fractures is debated (3, 10, 11, 17). Various mechanisms of injury have been proposed and several studies describe the size, shape, and displacement of greater tuberosity fractures (1-3, 18-20). Computed Tomography imaging and quantitative 3-dimensional modeling may allow more detailed measurement of fracture morphology and displacement, and might affect decision-making (13, 16, 18). We measured substantial variation in size, shape, fragmentation, and displacement among GT fractures.

The limitations of this study are the following: first, our patient cohort is unlikely to be representative of the overall patient population sustaining isolated GT fractures given CT scanning of these injuries is not conducted routinely in these cases. The patients in this study group were likely selected for CT scanning due

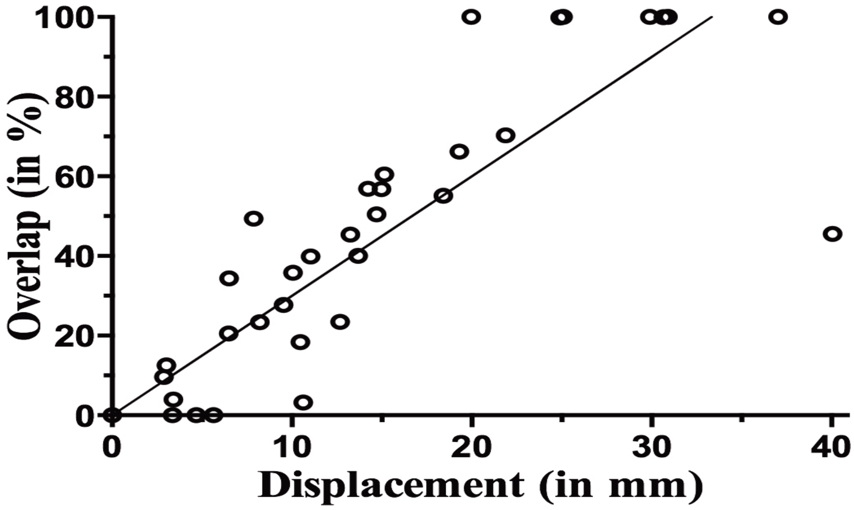

Figure 7. Graph demonstrating the relationship between magnitude of displacement and overlap of the main greater tuberosity fracture fragment over the proximal humerus.

to patient and injury factors, such as more displaced, complex fracture configurations or 'borderline' cases, where further diagnostic information was deemed necessary by the treating physician. This may explain the relatively high average displacement (13 mm) in this study as compared to the displacement reported in other studies (1, 19). Second, a spontaneous relocation of the shoulder joint might have occurred prior to clinical assessment. Cases might have been falsely assigned to the group of patients without shoulder dislocation. Third, the number of patients is relatively small and therefore the statistical power is limited; a larger sample size might have identified a significant difference in degree of displacement.

The proportion of patients with concomitant glenohumeral dislocation in our cohort (59%), is consistent with prior studies (30 to 57%) (1, 18). Our finding that there is substantial variation in fracture morphology is consistent with a prior study by Bahrs et al. of radiographs of 103 GT fractures with and without anterior shoulder dislocation (18). This study demonstrated that of the 103 fractures, 20 (19%) were more than 1 centimeter displaced, 29 (28%) less than 1 centimeter, and 54 (53%) were nondisplaced in the anteroposterior view (18).

Direction of displacement was more or less equally distributed in their study: 47% (23 of 49 cases) were posterosuperiorly displaced, and 53% (26 of 49 cases) were posteroinferiorly displaced (18). This is in line with our results: 56% (19 of 34 cases) were posterosuperiorly, and 44% (15 of 34 cases) were posteroinferiorly displaced. The direction of displacement might be dictated by the force vectors of the rotator cuff attachments; the supraspinatus might pull the GT fracture fragment superiorly, while the infraspinatus and teres minor might cause the GT fracture fragment to displace inferiorly (2, 17). However, the posteroinferior displacement of GT fractures occurring in combination with glenohumeral dislocation is inconsistent with the theory that shoulder dislocations cause a simple avulsion fracture of the GT by the rotator cuff. Depending on the magnitude of forces during dislocation of the shoulder, different patterns of bony lesions of the proximal humerus may occur. A Hill Sachs lesion may occur with variable size or even a GT fracture may be present. Variation of the fracture morphology in case of shoulder dislocations might also be associated with the position of the arm when dislocation occurs and with the mechanical properties of the rotator cuff. Understanding the direction and degree of displacement and its consequences might help in the decision to operate and surgical strategy. Posterior displacement can block external rotation, while superior displacement can impinge the subacromial space impairing abduction (3, 17). Additional study is needed to identify factors associated with substantial variation in number of fracture fragments, direction of displacement, degree of displacement and overlap, and size of the main GT fracture fragment. The variation in fracture morphology should be kept in mind when planning internal fixation of a GT fracture.

Foruria et al. studied 93 fractures of the proximal humerus of which 15 (16%) were GT fractures (13). In the 93 fractures of the proximal humerus, they found 20% overlap of the GT fracture fragment over the articular surface of the proximal humerus (measured in 2-dimensional CT-images), this was correlated with a worse functional outcome after 12 months (13). Three-dimensional modeling may allow for more accurate estimation of overlap of the main GT fracture fragment over the proximal humerus and articular surface.

The overlap measured by quantitative 3-dimensional analysis is strongly correlated with displacement as demonstrated in our study (r=0.90, *P<0.001*). Our technique might improve quantification of overlap and thereby displacement and could be used in the decision for operative treatment as overlap is correlated with functional outcome.

In conclusion, the only difference between fractures with and without concomitant shoulder dislocation was more overlap and a trend towards greater displacement in patients without dislocation as compared to those with dislocation. Additional study is need to determine the factors associate with variation in size, displacement, and fragmentation of GT fractures.

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References

1. Mattyasovszky SG, Burkhart KJ, Ahlers C, Proschek D, Dietz SO, Becker I, et al. Isolated fractures of the greater tuberosity of the proximal humerus: a long-term retrospective study of 30 patients. Acta Orthop. 2011; 82(6):714-20.
2. Gruson KI, Ruchelsman DE, Tejwani NC. Isolated tuberosity fractures of the proximal humeral: current concepts. Injury. 2008; 39(3):284-98.
3. Green A, Izzi J Jr. Isolated fractures of the greater tuberosity of the proximal humerus. J Shoulder Elbow Surg. 2003; 12(6):641-9.
4. Neer CS 2nd. Displaced proximal humeral fractures. I. Classification and evaluation. J Bone Joint Surg Am. 1970; 52(6):1077-89.
5. Bigliani LU, Pollock RG. Fractures of the proximal humerus. Philadelphia: WB Saunders; 1998.
6. Bono CM, Renard R, Levine RG, Levy AS. Effect of displacement of fractures of the greater tuberosity on the mechanics of the shoulder. J Bone Joint Surg Br. 2001; 83(7):1056-62.
7. Gerber C, Warner JJ. Alternatives to hemiarthroplasty for complex proximal-humeral fractures. Philadelphia: Lippincott-Raven; 1997. P. 215-43.
8. McLaughlin HL. Dislocation of the shoulder with tuberosity fracture. Surg Clin North Am. 1963; 43(6):1615-20.
9. Paavolainen P, Bjorkenheim JM, Slatis P, Paukku P. Operative treatment of severe proximal humeral fractures. Acta Orthop Scand. 1983; 54(3):374-9.
10. Park TS, Choi IY, Kim YH, Park MR, Shon JH, Kim SI. A new suggestion for the treatment of minimally displaced fractures of the greater tuberosity of the proximal humerus. Bull Hosp Jt Dis. 1997; 56(3):171-6.
11. Platzer P, Kutscha-Lissberg F, Lehr S, Vecsei V, Gaebler C. The influence of displacement on shoulder function in patients with minimally displaced fractures of the greater tuberosity. Injury. 2005; 36(10):1185-9.
12. Depalma AF, Cautilli RA. Fractures of the upper end of the humerus. Clin Orthop. 1961; 20(1):73-93.
13. Foruria AM, de Gracia MM, Larson DR, Munuera L, Sanchez-Sotelo J. The pattern of the fracture and displacement of the fragments predict the outcome in proximal humeral fractures. J Bone Joint Surg Br. 2011; 93(3):378-86.
14. Ogawa K, Yoshida A, Ikegami H. Isolated fractures of the greater tuberosity of the humerus: solutions to recognizing a frequently overlooked fracture. J Trauma. 2003; 54(4):713-7.
15. Braunstein V, Wiedemann E, Plitz W, Muensterer OJ, Mutschler W, Hinterwimmer S. Operative treatment of greater tuberosity fractures of the humerus--a biomechanical analysis. Clin Biomech (Bristol, Avon). 2007; 22(6):652-7.
16. Castagno AA, Shuman WP, Kilcoyne RF, Haynor DR, Morris ME, Matsen FA. Complex fractures of the proximal humerus: role of CT in treatment. Radiology. 1987; 165(3):759-62.
17. Yin B, Moen TC, Thompson SA, Bigliani LU, Ahmad CS, Levine WN. Operative treatment of isolated greater tuberosity fractures: retrospective review of clinical and functional outcomes. Orthopedics. 2012; 35(6):e807-14.
18. 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(2):140-7.

19. 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; 21(2):104-12.
20. Kim E, Shin HK, Kim CH. Characteristics of an isolated greater tuberosity fracture of the humerus. J Orthop Sci. 2005; 10(5):441-4.
21. Brouwer KM, Bolmers A, Ring D. Quantitative 3-dimensional computed tomography measurement of distal humerus fractures. J Shoulder Elbow Surg. 2012; 21(7):977-82.
22. Guitton TG, van der Werf HJ, Ring D. Quantitative three-dimensional computed tomography measurement of radial head fractures. J Shoulder Elbow Surg. 2010; 19(7):973-7.