

## RESEARCH ARTICLE

# Long-term Results, Functional Outcomes and Complications after Open Reduction and Internal Fixation of Neglected and Displaced Greater Tuberosity of Humerus Fractures

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Received: 30 July 2016

Accepted: 29 August 2016

## Abstract

**Background:** Humerus fractures include 5% to 8% of total fractures. Non-union and delayed union of GT (GT) fractures is uncommon; however they present a challenge to the orthopedic surgeons. Significant controversy surrounds optimal treatment of neglected fractures. The purpose of this article was to perform a comparative study to evaluate the outcomes of open reduction and internal fixation (ORIF) of neglected GT fractures.

**Methods:** We retrospectively evaluated the results of surgical intervention in 12 patients with displaced nonunion of GT fractures who were referred to our center. Before and minimally 25 months after surgery ROM, muscle forces, Constant Shoulder Score (Constant-Murley score) (CSS), Visual Analogue Scale (VAS), Activities of Daily Living (ADL) Score and American Shoulder and Elbow Surgeons (ASES) Score were all recorded. Additionally, the results were compared with undamaged shoulder.

**Results:** Between March 2006 and January 2013, 12 patients underwent surgical intervention and followed for 36.2 months in average. All fractures healed. Anatomic reduction achieved only in 6 cases with no report of avascular necrosis or infection. All ROMs and muscle forces increased significantly (Mean Forward Flexion: 49.16 to 153.3, Mean Internal Rotation: 3 to 9, Mean External Rotation: -5 to 27.5) ( $P$  value<0.0001). All functional scores including CSS, VAS, ADL and ASES score improved significantly (Mean VAS: 6.5 to 1.3, Mean CSS: 29.83 to 86, Mean ADL: 6.6 to 27.1, Mean ASES: 28.6 to 88.9) ( $P$  value<0.0001).

**Conclusion:** ORIF for neglected and displaced GT fractures has satisfactory functional outcomes, despite of non-anatomical reduction of the fracture.

**Keywords:** Nonunion, Greater tuberosity, Reduction, Shoulder fractures

## Introduction

Proximal Humerus fractures remain one of the most common orthopedic injuries, particularly in the elderly. Humerus fractures include 5% to 8% of all fractures. Recent reports showed that over 70% of all proximal humeral fractures occur in patients over 60 years of age. Non-unions are uncommon, but when they occur, they present a challenge to the orthopedic surgeons (1, 2). Indications for surgical reconstruction of acute GT fractures include fracture displacement more than 5 mm in general population or 3 mm of displacement in athletes or in patients performing frequent occupational or recreational

overhead activities (3). Nonunion and malunion are of the most frequently reported complications after proximal humerus fractures and pain is a key component of patient satisfaction (4-6). Although non-union and delayed union of GT fractures is uncommon, the incidence is increasing due to growth in rate of sports and road accidents and prevalence of osteoporosis (7). Nonunion or Malunion of GT fractures occurs when non-surgical treatment fails, diagnosis is missed, medical status is poor, especially in developing countries that medical care services is not accessible (8). Isolated malunions and nonunions of the GT are relatively common, however, are usually debilitating only

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in younger, and physically active patients. The deforming forces of the attached cuff muscles cause the tuberosity to retract posterosuperomedially but the articular surface is unaffected. The posterior displacement may produce a bony block to external rotation, while superior displacement may block abduction and lead to subacromial impingement. Tuberosity malposition can also produce cuff dysfunction, attrition, and tears (9). Suggested patient-related risk factors for nonunion of the proximal humerus fracture are osteoporosis, poor physiologic state, medical comorbidities and drug treatment, heavy smoking, and alcohol abuse (10, 11). The complete disruption of the periosteal sleeve leads to mechanical instability, and soft tissue interposition of periosteum, muscle, and the tendinous portion of the long head of biceps and may inhibit callus formation (12). Pain, stiffness, and loss of shoulder function are the most common complaints. The pain is usually severe, debilitating, and aggravated through shoulder motions. In addition to radiography, CT scan is indicated to confirm the nonunion, the degree of separation and the feasibility of reduction and fixation of the fracture (13). In some cases of severe tuberosity mal-union or displaced nonunion humeral head arthroplasty or reverse shoulder arthroplasty may be indicated but there is a high rate of complications (14-16). Treatment of neglected fractures of proximal humerus is controversial. Displaced fractures often require surgery, and management can be challenging because of poor bone quality (17). Significant disagreement surrounds optimal treatment of mal-union of GT fractures, including reverse total shoulder arthroplasty (RTSA), hemiarthroplasty (HA) and open reduction internal fixation (ORIF) (3).

On the other hand, there is still a challenge relevant to the outcomes of delayed surgical treatment due to poor proximal humerus bone repair and absent of appropriate evaluation of neglected fractures fixation (18). There exists limited evidence in articles to guide surgeons in the management of these complications. Cost and benefits of surgical repair is still a controversy. The purpose of this retrospective comparative study was to evaluate the results of delayed ORIF of neglected and displaced GT fractures.

### Materials and Methods

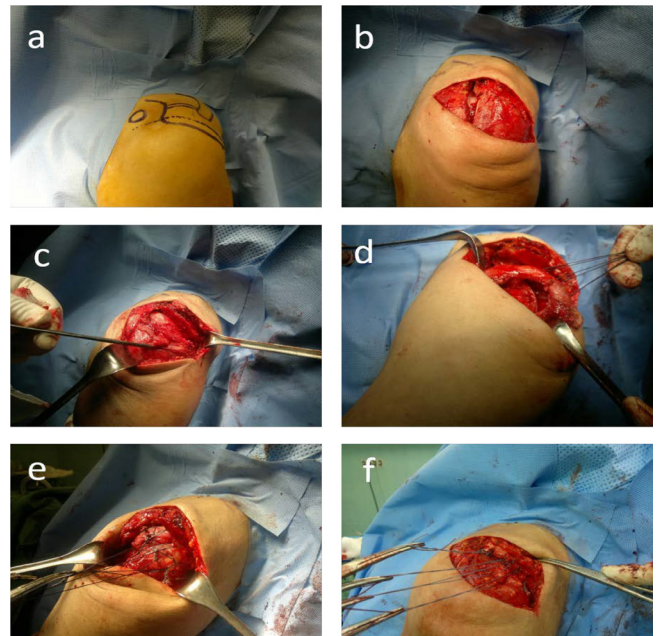
All patients with nonunion GT fractures referred to Shafa Orthopedic Hospital during 2006 to 2013 were included in this study. In total, 12 patients with neglected GT fractures and more than 1 centimeter displacement, approved by X-Rays and Computed tomography scans, were included. The referral time of the patients was at least 10 months after injury. Exclusion criteria included those with associated fractures or concomitant injuries in each of shoulders like fracture – dislocation, bilateral humeral fractures, and those with previous full thickness rotator cuff tears (that were revealed during surgery) and patients who did not accept to receive surgical treatment or were lost to follow up for at least 10 months. Nine patients had received physiotherapy before referral to our center. Our institutional review board of medical ethics committee has approved the method and setting of this study.

### Preoperative evaluation

All patients were examined vigilantly, with special attention to the injured shoulder and its neuromuscular status. Other data including age, sex, side of involved shoulder, intervals between trauma to surgery and physiotherapy sessions before surgery were recorded. Preoperative ROM of both shoulders in forward flexion, external rotation with arm at side and internal rotation, and muscle forces in abduction, external and internal rotations were determined clinically and recorded. For preoperative planning, an anteroposterior, true lateral scapular view and lateral axillary view X-rays and a three-dimensional CT scan of the affected shoulder were obtained to determine the location of the fractured tuberosity, its anatomical bed and also to detect any other fractures if present. Ethical committee of our hospital approved this study and written consent was obtained from the patients in order to publish their data.

### Operative Technique

With semi-setting position and anteroposterior incision on superior shoulder (saber cut), deltoid muscle was split between its anterior and the middle third for about 4 cm and a stay-suture was inserted at the end of the split to prevent propagation of the split and damage to axillary nerve branches [Figure 1a]. Coracoacromial ligament was released from the acromion by electrocautery [Figure 1b]. The middle third of deltoid was detached



**Figure 1.** A 27-year-old man with received surgical treatment for his left shoulder 5 months after trauma; a) skin incision; b) deltoid was split and coracoacromial ligament was released; c) middle third of deltoid was detached of the acromion with a shell of bone; d) GT was released and retracted anteriorly; e) GT was fixed with transosseous sutures, and f) Transosseous fixation of the middle third of the deltoid.

from the lateral acromion with a small shell of bone using 1 cm straight osteotome [Figure 1c]. The fractured fragment of the GT was released and retracted anteriorly with multiple heavy nonabsorbable sutures passed through the posterior and superior cuff [Figure 1d]. The debridement of fracture bed on head of the humerus and internal surface of the fractured fragment was performed by a surgical curette. One end of each heavy sutures which was on the internal surface of the fractured fragment was passed from the bed of the fracture into intact surrounding cortices on the proximal humerus, but did not tied at this stage. By holding the arm in 40 to 60 degrees of abduction and 20 to 30 degrees of external rotation, the GT was reduced and fixed transosseously with mentioned heavy non-absorbable sutures [Figure 1e]. The middle third of deltoid with its attached fragment of lateral acromion was fixed to its anatomical bed of lateral acromion with 5-6 transosseous heavy non-absorbable sutures [Figure 1f]. Anteroposterior X-ray was obtained intraoperatively to determine the quality of reduction and presence of any missed unreduced fragment. The coracoacromial ligament sutured firmly to the anterior of acromion transosseously with the same non-absorbable sutures. The deltoid split was sutured on a hemovacuum drain and the wound was closed and dressed. Shoulder abduction brace with 40-60 degrees of abduction and 20-30 degrees of external rotation was prescribed for 6 weeks. Pendulum and passive ROM was started after 6 weeks. Active ROM after 8 weeks and strengthening exercise after 12 weeks were started, respectively. The patients were educated to perform these exercises at home for at least 4 hours in a day, whereas physiotherapy was prescribed at physiotherapy center two sessions weekly until the progression of ROMs and forces reached to a plateau.

### Post-operative Assessments

All patients were visited at weeks 2, 6 and 12 of the first 3 months. Subsequently, patients were visited every 3 months for the first year; every 6 months for the second year, and annually then. Two views including anteroposterior and true lateral scapular view X-rays of the affected shoulder were obtained immediately after surgery, and 2 and 6 weeks postoperatively to determine any displacement of the fractured fragment. Thereafter, three views including anteroposterior, true lateral scapular and lateral axillary view X-rays were taken to determine any sign of nonunion. After 3 month postoperatively, the patients were examined to assess and record shoulder ROM in forward flexion, external rotation with arm at side, and internal rotation were assessed and recorded. At the 6th month visit and also for the next follow up visits, muscle forces in abduction, external and internal rotations were added to any

examination.

### Statistical Analysis

We gathered all the preoperative and postoperative findings regarding the cause of neglecting, size of fragment and its displacement and so on. To summarize the studies, we only performed statistical analysis in terms of demographic data and functional results. Data including age, gender, side of injury, interval between injuries to surgery, sessions of pre and postoperative physiotherapy and functional results were recorded. Before and after operative treatment, researchers evaluated function of both damaged and undamaged shoulders by physical examination, reviewing medical records and filling prepared 4 questionnaires included Constant Shoulder Score (Constant-Murley score) (CSS), Visual Analogue Scale (VAS), Activities of Daily Living (ADL) Score and American Shoulder and Elbow Surgeons (ASES) Score. ASES score was assessed using the following equation below:  $[(10 - \text{visual analog scale pain score}) \times 5] + [(5/3) \times \text{Cumulative ADL score}]$  (19,20). ROMs in internal rotations were assessed as the highest spinus process that the thumb reached. If the thumb could not reach to the spine, four anatomical locations including thigh, greater trochanter, buttock and superior gluteal fold were considered as references. To making a numerical mode for analysis, the mentioned anatomical locations were concerned as consecutive numbers that showed in [Table 1]. For the statistical analysis, the statistical software SPSS version 20.0 (SPSS Inc., Chicago, IL) was used.  $P < 0.05$  was considered as statistically significant.

### Results

Between March 2006 and January 2013, 12 patients, (11 men and 1 woman) with mean age of 41.08 years (24 - 56 years old) were included in this study. All patients were right dominant hand and the fracture was occurred in right shoulder for 11 patients and 1 case in left side. Interval between trauma to surgery time ranged from 2.5 to 10 months (mean of 5.3 months). The cause of fracture was trauma in 10 patients, and convulsion due to tramadol abuse in 2 another patients. 9 patients received physiotherapy before surgery for 10 to 60 sessions (mean 19). Patients were followed up clinically for at least 25 months after surgery (ranged from 25 to 51 months, with mean of 36.2 months). All patients received 25 to 50 sessions of physiotherapy after surgery (mean of 30.41 months). The mean ROM in forward flexion of the involved shoulders was 153.3° [Table 2]. As it is shown, all ROMs of the involved shoulders increased significantly ( $P$  value < 0.0001), but they were less than other normal side. The mean muscle forces of the involved shoulders in abduction and external rotation were 4.50 and 4.62 (out of 5), respectively [Table 3] ( $P$  value < 0.0001).

Table 1. Range of motion in internal rotation and their corresponded numbers

Thigh	GT <sup>1</sup>	Buttock	SGF <sup>2</sup>	S <sub>1</sub>	L <sub>5</sub>	L <sub>4</sub>	L <sub>3</sub>	L <sub>2</sub>	L <sub>1</sub>	T <sub>12</sub>	T <sub>11</sub>	T <sub>10</sub>	T <sub>9</sub>	T <sub>8</sub>	T <sub>7</sub>	T <sub>6</sub>	T <sub>5</sub>	T <sub>4</sub>	T <sub>3</sub>
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20

1: Greater Trochanter; 2: Superior Gluteal Fold

**Table 2. ROMs of the involved and uninvolved shoulders and their differences**

ROMs	Affected side - pre operative Mean and (Range)	Affected side - last follow up Mean and (Range)	Unaffected side - last follow up Mean and (Range)	Difference between pre-operative and last follow up - affected side (P-Value)	Difference between affected and unaffected sides at last follow up (P-Value)
FF <sup>1</sup>	49.16° (20°-80°)	153.3° (140°-160°)	170° (160°-180°)	0.000	0.000
E.R <sup>2</sup>	-5° (-20°-10°)	27.5° (20°-40°)	42.5° (30°-60°)	0.000	0.000
I.R <sup>3</sup>	3 (1-5)	9 (8-11)	14.5 (3-18)	0.000	0.000

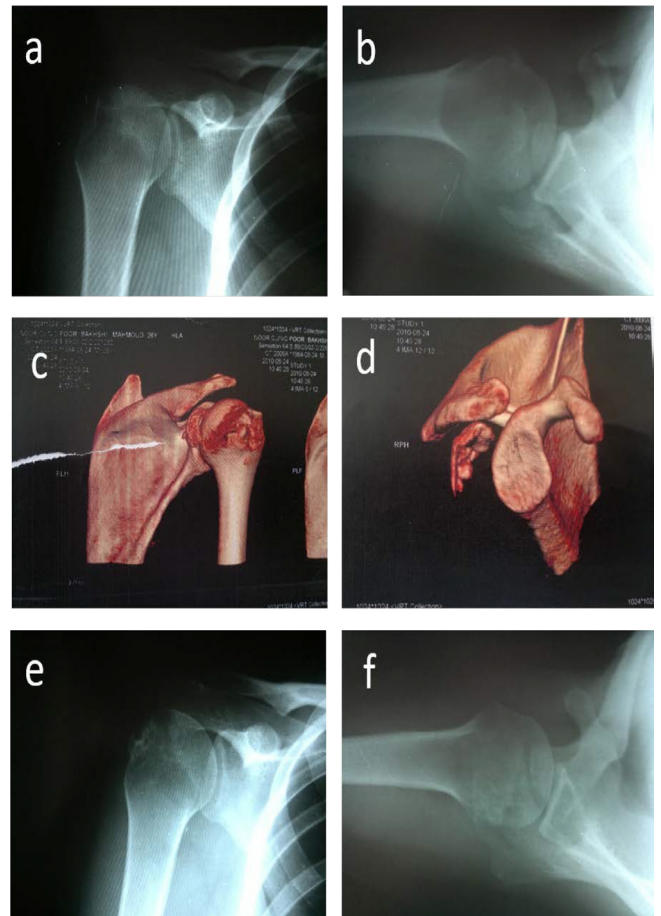
1: Forward Flexion; 2: External Rotation with arm at side; 3: Internal Rotation, thumb to opposite spinus process of vertebrae; anatomical locations were concerned as corresponded numbers as shown in Table 1

Surprisingly, this increase was observed in internal rotation forces, too [Figure 2]. All four scores of the involved shoulders were improved significantly and were not as good as other normal sides ( $P < 0.05$ ). Immediate post-operative radiographic studies revealed that anatomical reduction achieved only in 6 cases during

surgery, and missed in 2 of them afterwards [Figure 3]. No intra-operative complications were recorded. There was no any neurovascular injuries, infection, heterotopic calcification, avascular necrosis of the head, or skin problems. Radiographic studies revealed complete union in 7 fractures at 3 months and in all fractures at 6 months



**Figure 2.** Near full ROM of the shoulder, 2 years postoperatively in the same case that was presented in Figure 1 and 2; a) scar of surgical incision, b) forward flexion, c) internal rotation and, d) external rotation.



**Figure 3.** Radiography and CT scans of the same case that was presented in Figure 1. a) to d) pre-operative X-rays and CT scans and e) to f) 2 years post-operative X-rays.

**Table 3. Muscle forces of the involved and uninvolved shoulders and their differences**

Muscle forces	Affected side – pre operative Mean and (Range)	Affected side – last follow up Mean and (Range)	Unaffected side – last follow up Mean and (Range)	Difference between pre-operative and last follow up – affected side (P-Value)	Difference between affected and unaffected sides at last follow up (P-Value)
ABD <sup>1</sup>	3.58 (2.5 - 4)	4.50 (3.5 - 4.5)	4.91 (4.5 - 5)	P value is 0.000	P value is 0.026
E.R <sup>2</sup>	3.41 (2.5 - 4)	4.62 (3.5 - 4.5)	4.79 (4.5 - 5)	P value is 0.000	P value is 0.000
I.R <sup>3</sup>	4.41 (4 - 5)	4.70 (4 - 5)	4.87 (4.5 - 5)	P value is 0.000	P value is 0.000

1: Abduction; 2: external rotation with arm at side; 3: internal rotation

**Table 4. Functional scores of involved and uninvolved shoulders and their differences**

Functional scores Or scales (Range)	Affected side – pre op. Mean (Range)	Affected side – last follow up Mean (Range)	Unaffected side – last follow up Mean (Range)	Difference between pre-operative and last follow up – affected side (P-Value)	Difference between affected and unaffected sides at last follow up (P-Value)
VAS <sup>1</sup> (0-10)	6.50 (5-9)	1.30 (0-3)	0.08 (0-1)	0.000	0.001
CSS <sup>2</sup> (10-94)	29.83 (29-42)	86.25 (77-94)	96.83 (89-100)	0.000	0.001
ADL <sup>3</sup> (0-30)	6.60 (3-11)	27.16 (21-30)	29.58 (27-30)	0.000	0.001
ASES <sup>4</sup>	28.60 (10-44)	88.90 (79-100)	98.50 (95-100)	0.000	0.000

1: Visual Analogue Scale for pain; 2: Constant Shoulder Score; 3: Activity Daily Living scale 4: American Shoulder and Elbow Surgeons score

postoperatively.

## Discussion

The result of ORIF in early-presented proximal humerus fractures is favorable. Paavolainen reported satisfactory results when they surgically fixed 6 displaced fractures of the GT (21). Flatow et al. also reported excellent and good results for 16 displaced GT fractures following the surgical fixation (22).

However, regarding to recent studies, controversy surrounds the benefits of delayed treatment of nonunion of GT fractures by reverse total shoulder arthroplasty (RTSA), hemiarthroplasty (HA) or open reduction internal fixation (ORIF). These operative treatments are technically demanding and frequently with a relatively high rate of complications (3, 9). Martin TG and Iannotti JP showed that reverse shoulder arthroplasty (RSA) has successful clinical outcomes for the treatment of complex fracture sequelae in proximal humerus (23). To the best of our knowledge, there are few studies discussing delayed treatments of GT fractures and we did not find enough evidence to help surgeons to decide whether late surgery can achieve satisfactory outcomes or not. Lu et al. treated 39 proximal humerus fractures including isolated 2-part GT fractures with ORIF after a delay of 21-120 days from the initial injury. ROM were improved except for internal rotation and all of the evaluated scores including visual

analogue scale (VAS), Constant-Murley score, University of California Los Angeles (UCLA) scoring system score and Simple Shoulder Test (SST) score demonstrated great reconstruction. The results of delayed ORIF in patients with complications were not efficient as in patients who had no complications before (8). All our cases had isolated nonunion of GT fracture and treated much later than that study. Despite this latency, our result looks satisfactory. It may be due to enough exposure and release of the fractured fragment, stable fixation and effective post-operative rehabilitation with mean 30 sessions in addition to educated daily home exercises. 9 of 12 patients received physiotherapy before surgery with mean of 19 sessions that revealed continued intend to avoid any surgery.

There are a few reports of the results of treatment of GT malunion or nonunions, which report substantial pain relief and functional improvement but with prolonged recovery times. Beredjikian et al. treated 39 patients operatively for malunion of a fracture of the proximal humerus. Results were satisfactory for 27 patients (69%) and unsatisfactory for the remaining 12 (31%). 11 patients had malposition of the greater or lesser tuberosity preoperatively and 10 of them were treated with either osteotomy of the tuberosity or acromioplasty, and 9 of them had a satisfactory result. They suggested that in cases of malunion of the fracture of the proximal humerus, both osseous and soft-tissue abnormalities are the cause of pain and stiffness. Therefore,

they stated that surgical treatment of these patients is successful only if all osseous and soft-tissue abnormalities are corrected during surgery (24).

Both pain and impingement of displaced GT fracture to acromion can restrict ROM and some degrees of stiffness will be occurred. These causes can be resolved by an effective surgery. Three out of four rotator cuff tendons attached to GT, therefore rotator cuff forces decreased in cases of displaced GT fractures and can be increased by fixation of the fracture fragment anatomically as much as possible (9). Our postoperative rehabilitation regime and daily home exercises might play some role in these results. The patients were educated precisely, asked to exercise at home for at least 4 hours in a day, and prescribed physiotherapy two sessions weekly until the progression of ROMs and forces reached to a plateau. Mean Visual Analogue Scale for pain (VAS) decreased significantly from 6.5 (out of 10) preoperatively to 1.3 postoperatively. This decrease reveals that pain, which is a major complaint in shoulder disease, had been improved (20). Pain may be due to several causes like impingement and muscle weakness that mainly resolved with this surgery. Pain, decreased ROM and muscle forces can affect Activity Daily Living (ADL) score, whereas pain and ADL together are main parts of American Shoulder and Elbow Surgeons (ASES) Score (20). ADL score of the involved shoulder increases from 6.60 preoperatively to 27.16 post-operatively, and ASES score from 28.60 to 88.90, respectively. Both such increases were significant and mean improvement of the function of the operated shoulders. Constant Shoulder Score (CSS) consists of 8 components including pain, activity level, ROM and strength of the shoulder and ranged from the worst score of 10 to the best of 94. The scoring was as follows: difference with the normal side > 30 means Poor, between 21 to 30 is Fair, between 11 to 20 is Good and < 11 is an Excellent result (19). In our patient, the mean CSS of the involved shoulder increased significantly from 29.83 preoperatively to 86.25 postoperatively. CSS of the uninvolved shoulder was 96.83. The difference between final CSS of two sides was 10.58 that is less than 11 which means excellent results. Data revealed that anatomical reduction achieved only in 4 cases during surgery, and missed in 2 of them afterwards. It may be due to poor bone quality and/or retraction by shortened cuff muscles. Despite of this occurrence, all these shoulders improved significantly in all calculated. It indicated that final results may not be influenced significantly by some

degrees of displacement. We did not obtain postoperative CT scan to determine the amount of displacements, which did not decrease our results significantly. Complete union was occurred in 7 patients at 3 months and in all patients at 6 months post-operatively. We did not have any intra-operative or post-operative complications except achieving non-anatomical reduction or loss of anatomical reduction that explained in the above paragraph. No any hardware was used for these fractures and this maybe a psychological factor for more satisfaction and may influence the results. All patients have been operated by the same surgeon and the same surgical approach and post-operative care was applied for all patients. To the best of our knowledge no previous similar study has been published.

Our article also contains some weak points, which should be pointed out. The inability to compare the outcome of nonunion GT fracture surgery with ORIF acute GT could be considered as the biggest limitation of our study. Since ORIF acute GT fractures have been performed by different surgeons and post-operation care of these cases was not comparable, such comparison was not possible in our study.

In conclusion, regarding to appropriate outcomes and significant results of our data analysis, we can suggest that ORIF of neglected and displaced GT fractures associated with a post-operative management in our manner, can result in satisfactory functional outcomes without noticeable complications. Probable non-anatomical reduction cannot influence the results significantly. Based on the result of this study, surgical intervention of the displaced GT fracture is positively correlated with satisfactory clinical and functional outcomes without any major complication.

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## References

1. Baron JA, Barrett JA, Karagas MR. The epidemiology of peripheral fractures. *Bone*. 1996; 18(3 Suppl):209S-13.
2. Baron JA, Karagas M, Barrett J, Kniffin W, Malenka D, Mayor M, et al. Basic epidemiology of fractures of the upper and lower limb among Americans over 65 years of age. *Epidemiology*. 1996; 7(6):612-8.
3. Gerber C. Reconstructive surgery following malunion of fractures of the proximal humerus in adults. *Orthopade*. 1990; 19(6):316-23.
4. Boyle MJ, Youn SM, Frampton CM, Ball CM. Functional outcomes of reverse shoulder arthroplasty compared with hemiarthroplasty for acute proximal humeral fractures. *J Shoulder Elbow Surg*. 2013; 22(1):32-7.
5. Carbone S, Tangari M, Gumina S, Postacchini R, Campi A, Postacchini F. Percutaneous pinning of three- or

- four-part fractures of the proximal humerus in elderly patients in poor general condition: MIROS® versus traditional pinning. *Int Orthop*. 2012; 36(6):1267-73.
6. Hardeman F, Bollars P, Donnelly M, Bellemans J, Nijs S. Predictive factors for functional outcome and failure in angular stable osteosynthesis of the proximal humerus. *Injury*. 2012; 43(2):153-8.
  7. Muncibì F, Paez DC, Matassi F, Carulli C, Nistri L, Innocenti M. Long term results of percutaneous fixation of proximal humerus fractures. *Indian J Orthop*. 2012; 46(6):664-7.
  8. Lu Y, Jiang C, Zhu Y, Wang M, Bowles RJ, Mauffrey C. Delayed ORIF of proximal humerus fractures at a minimum of 3 weeks from injury: a functional outcome study. *Eur J Orthop Surg Traumatol*. 2014; 24(5):715-21.
  9. Siegel JA, Dines DM. Proximal humerus malunions. *Orthop Clin North Am*. 2000; 31(1):35-50.
  10. Healy WL, Jupiter JB, Kristiansen TK, White RR. Nonunion of the proximal humerus. A review of 25 cases. *J Orthop Trauma*. 1990; 4(4):424-31.
  11. Scheck M. Surgical treatment of nonunions of the surgical neck of the humerus. *Clin Orthop Relat Res*. 1982; 167(1):255-9.
  12. Court-Brown CM, McQueen MM. Nonunions of the proximal humerus: their prevalence and functional outcome. *J Trauma*. 2008; 64(6):1517-21.
  13. Dines DM, Warren RF, Altchek DW, Moeckel B. Posttraumatic changes of the proximal humerus: Malunion, nonunion, and osteonecrosis. Treatment with modular hemiarthroplasty or total shoulder arthroplasty. *J Shoulder Elbow Surg*. 1993; 2(1):11-21.
  14. Boileau P, Chuinard C, Le Huec JC, Walch G, Trojani C. Proximal humerus fracture sequelae: impact of a new radiographic classification on arthroplasty. *Clin Orthop Relat Res*. 2006; 442(2):121-30.
  15. Boileau P, Krishnan SG, Tinsi L, Walch G, Coste JS, Mole D. Tuberosity malposition and migration: reasons for poor outcomes after hemiarthroplasty for displaced fractures of the proximal humerus. *J Shoulder Elbow Surg*. 2002; 11(5):401-12.
  16. Antuña SA, Sperling JW, Sánchez-Sotelo J, Cofield RH. Shoulder arthroplasty for proximal humeral nonunions. *J Shoulder Elbow Surg*. 2002; 11(2):114-21.
  17. Pinkas D, Wanich TS, DePalma AA, Gruson KI. Management of mal-union of the proximal humerus: current concepts. *J Am Acad Orthop Surg*. 2014; 22(8):491-502.
  18. Duralde XA, Leddy LR. The results of ORIF of displaced unstable proximal humeral fractures using a locking plate. *J Shoulder Elbow Surg*. 2010; 19(4):480-8.
  19. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. *Clin Orthop Relat Res*. 1987; 214(4):160-4.
  20. Richards RR, An KN, Bigliani LU, Friedman RJ, Gartsman GM, Gristina AG, et al. A standardized method for the assessment of shoulder function. *J Shoulder Elbow Surg*. 1994; 3(6):347-52.
  21. Paavolainen P, Bjorkenheim JM, Slati P, Paukku P. Operative treatment of severe proximal humeral fracture. *Acta Orthop Scand*. 1983; 54(3):374-9.
  22. Garg A, McQueen MM. Nerve injury after greater tuberosity fracture dislocation. *J Orthopaed Trauma*. 2000; 14(2):117-8.
  23. Martin TG, Iannotti JP. Reverse total shoulder arthroplasty for acute fractures and failed management after proximal humeral fractures. *Orthop Clin North Am*. 2008; 39(4):451-7.
  24. Beredjikian PK, Iannotti JP, Norris TR, Williams GR. Operative treatment of malunion of a fracture of the proximal aspect of the humerus. *J Bone Joint Surg Am*. 1998; 80(10):1484-97.