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ORIGINAL ARTICLE

Conservative treatment of displaced isolated proximal humerus greater tuberosity fractures: preliminary results of a prospective, CT-based registry study

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Abstract

Background Isolated greater tuberosity fractures are uncommon and account for approximately 2-19% [Emerg Radiol. 2018;25(3):235-246] of all proximal humerus fractures. Surgical treatment is the prevailing recommendation in cases of displacement of more than 5 mm for the general healthy population, while conservative treatment is considered to result in inferior outcomes and is not recommended. However, high-grade evidence is lacking for these recommendations.

Methods Twenty patients with conservatively treated isolated greater tuberosity fracture were evaluated prospectively as part of a registry study. Morphological Mutch classification, displacement in millimeters, and direction of displacement were determined by computed tomography (CT). Degree of fragment displacement was classified (nondisplaced to minor: ≤ 5 mm; moderate: 6–10 mm; major: > 10 mm). Constant score (CS), age- and sex-adjusted Constant score (adj. CS), subjective shoulder value (SSV), and radiographic follow-up were compared at a minimum follow-up of 12 months. For statistical analysis, quantitative data were compared using Mann–Whitney *U t*-test. Statistical significance was set at $p \leq 0.05$.

Results Ninteen patients reached the minimum follow-up at an average of 19 months (range, 12–35 months). 13 patients were women. Average age at the time of injury was 51 years (range, 22–75 years). CS and adj. CS averaged 79 ± 17.5 points, and 91 ± 17.7 points, respectively. The SSV averaged $87 \pm 17\%$. No statistically significant difference in clinical outcomes could be observed with respect to the degree of displacement among the three groups.

Conclusion The outcomes of conservatively treated displaced isolated greater tuberosity fractures are underestimated, and current indications for surgical treatment should be questioned. Further studies with larger numbers of patients and longer lengths of follow-up are needed. The protocol of this observational study is registered at ClinicalTrials.gov (NCT03060876). Date of registration: June 8, 2016.

Keywords Proximal humerus fracture · Displaced isolated greater tuberosity fracture · Conservative treatment · Greater tuberosity fracture

Introduction

Isolated greater tuberosity (GT) fractures are uncommon and account for approximately 2-19% [1] of all proximal humerus fractures. In case of greater tuberosity fragment displacement of more than 5 mm, surgical treatment has been the prevailing recommendation for the general healthy population, while 3 mm of displacement is often deemed acceptable in active patients, such as athletes and heavy laborers with frequent overhead activities. Conservative treatment is considered to result in inferior outcomes in such cases and is generally not recommended. The recommendation of Neer to treat proximal humerus fractures with fragment displacements of less than 1 cm non-operatively

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has been revised despite a lack of Level I, Level II, or high-quality Level III studies in the literature comparing specific operative techniques with non-operative management of displaced GT fractures.

The following study presents preliminary results of a prospective, computed tomography (CT)-based registry study, including clinical and radiologic outcomes, of displaced isolated GT fractures treated with an early function conservative treatment regimen.

Materials and methods

This study is authorized by the local ethical committee as part of an observational registry study (Hannover Humerus Registry—HHR) (journalno. 322-2016) and was carried out in accordance with the Ethical standards of the 1964 Declaration of Helsinki as updated in 2004. All patients gave written informed consent. The protocol is registered at ClinicalTrials.gov (NCT03060876).

HHR is a prospective, CT-based single center registry study of a supraregional Level 1 trauma center, aiming to investigate the healing process of proximal humerus and humeral shaft fractures.

A primary early function conservative treatment regimen is provided to all competent patients with proximal humerus fractures after an evidence-based medical briefing, except in cases of locked fracture-dislocations, head split fractures, open fractures, concomitant vascular injury, or patient request for surgery. There are no cut-offs for the conservative treatment regimen, including age, amount of displacement in millimeters or centimeters, and the degree of coronal or sagittal fracture angulation. All patients older than 18 years, except pregnant women, admitted to the emergency department obtained a CT of the proximal humerus in addition to conventional diagnostic radiographs (AP and scapular-Y view).

Thirty patients admitted to our emergency department between January 2016 and December 2017 were identified through the CT-based registry as having an isolated greater tuberosity fracture (Hertel-LEGO type 3). Twenty were available for inclusion and agreed to a primary conservative treatment with a shoulder abduction splint and a progressive, early function four-phase treatment protocol similar to our institutional protocol after rotator cuff repair (Fig. 1).

All glenohumeral dislocations were relocated in closed manner with the Milch technique under control of an image converter (C-arm) prior to the CT scan. Any attempt of closed

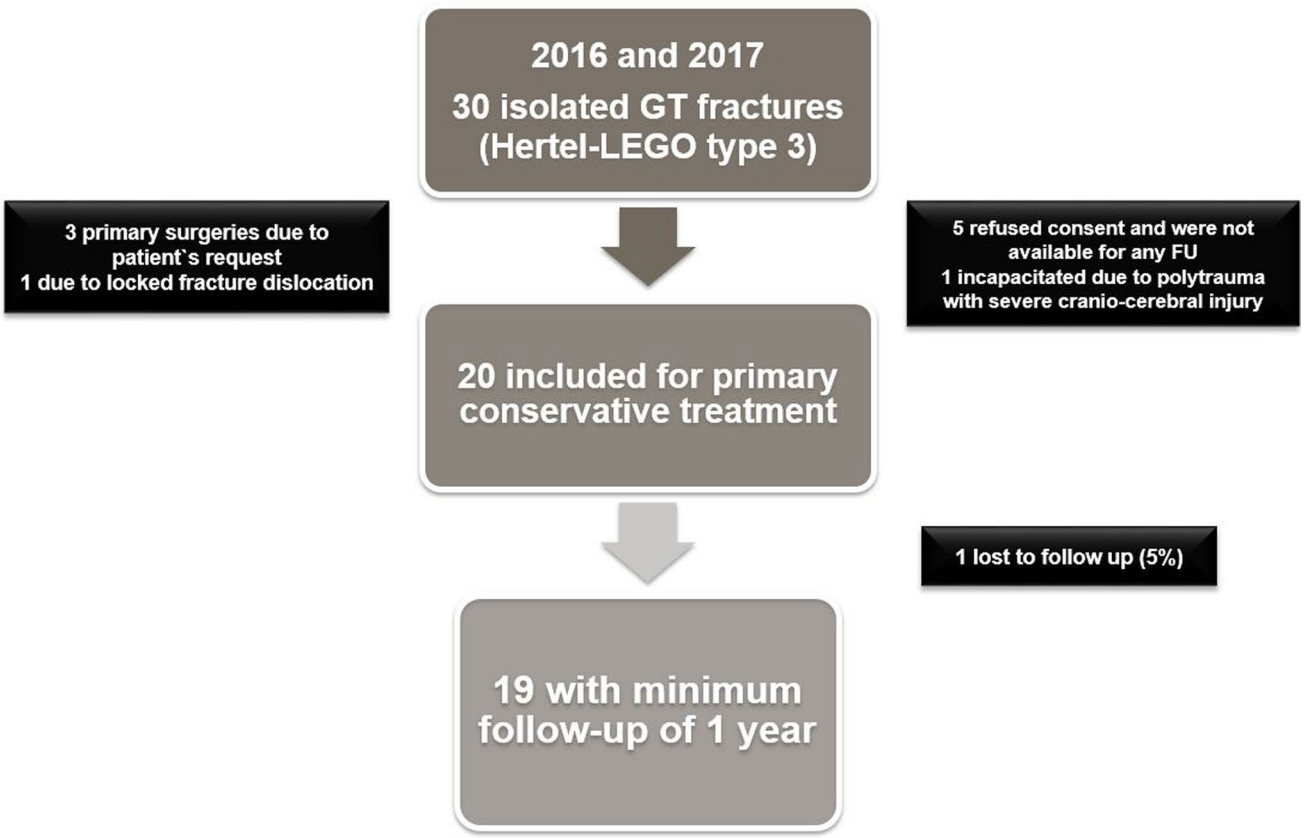

Fig. 1 Flow chart

reduction or fracture manipulation, including the application of the abduction splint as it was executed in all cases with major displacement (> 10 mm) on initial radiographs, was performed with aid of an image converter (C-arm) and also before the CT scan.

Morphological Mutch classification (type 1: avulsion, type 2: split, type 3: depression), displacement in millimeter, and direction of displacement were determined by CT with Visage 7.1 (Visage Imaging Inc.—San Diego, CA, United States). The maximal degree of fragment displacement in any plane was classified (nondisplaced to minor: ≤ 5 mm; moderate: 6–10 mm; major: > 10 mm). Absolute Constant score (CS), age- and sex-adjusted Constant score according to Constant (adj. CS) [2], subjective shoulder value (SSV), and radiographic follow-up of these groups were compared at a minimum follow-up of 12 months in an intention-to-treat analysis. The CS and SSV results were reported in the following categories: excellent (86–100), good (71–85), moderate (56–70), and poor (0–55). Clinical outcome scores were determined by two independent study nurses. The strength component of the Constant Score was measured with an IsoForceControl EVO2 isometric dynamometer (Herkules Kunststoff Oberburg AG, Oberburg, Switzerland) in 90° shoulder abduction at the wrist level. Follow-up radiographs were evaluated by one independent senior physician.

For statistical analysis, quantitative data were compared using Mann–Whitney *U t*-test. Statistical significance was set at $p \leq 0.05$. Data analysis was performed with SPSS 20.0 (IBM, Armonk, New York).

Four-phase conservative treatment protocol

In accordance with our post-operative treatment protocol after rotator cuff repair, the following four-phase conservative treatment protocol was proposed, which puts an emphasis on self-directed exercises:

Phase 1 (week 1)

Therapy goal: reassurance, reduction of swelling, and pain relief

- Abduction splint day and night.
- Unrestricted movement and exercising of elbow, wrist and finger joints.
- Clinical and radiologic follow-up after the first week (AP and scapular-Y views).

Phase 2 (week 2–3)

Therapy goal: passive exercising

- In cases of nondisplaced or minimally displaced fractures without secondary displacement, transition to an arm sling; otherwise, continue the abduction splint.
- Start pendulum exercises and assisted passive movements with the help of contralateral arm up to the tolerable pain threshold.
- Clinical and radiologic follow-up after the third week (AP and scapular-Y views).

Phase 3 (week 4–6)

Therapy goal: active exercising

- Arm sling may be weaned; abduction splint should be worn only at night.
- Continue pendulum exercises, and start active movements up to 90° of flexion and abduction.
- Clinical and radiologic follow-up after the sixth week (AP, scapular Y, and axillary views, if possible).

Phase 4 (week 7–12)

Therapy goal: reintegration into daily activities

- Discontinue all forms of immobilization.
- Start active-assisted and active movements up to full range of motion, and additionally start stretching exercises.
- Clinical and radiologic follow-up after the twelfth week (AP, scapular Y, and axillary views).

Results

Twenty patients were included for primary conservative treatment. Nineteen patients reached the minimum follow-up of 1 year. Length of follow-up was an average of 19 months (range, 12–35 months). Fourteen out of 20 patients were women. Average age at the time of injury was 51 years (range, 22–75 years). Nineteen patients had American Society of Anesthesiologists (ASA) Classification I or II status. Thirteen patients were in full-time employment. Five patients were in the group with none to minor displacement of whom two are overhead workers (patients no. 9 and 12, Table 1), and one does additionally sports with high levels of overhead activity (patient no. 12). Three patients were in the group with moderate displacement of whom only one has to work overhead (patient no. 3). Five patients were in the group with major displacement of whom only one has to

Table 1 Synopsis of clinical and radiological evaluations of 20 study patients

Patient no	Age	Sex	Mutch type	Concomitant dislocation	Direction of displacement in mm				Outcome		Concomitant lesion	Radiographic outcome	Complications
					Cranial	Caudal	Anterior	Posterior	CS	SSV			
No/minor displacement (≤ 5 mm)													
5	55	F	2	–	2	–	–	–	73	70	n.c	Declined	None
8	22	F	3	Anterior	1	–	–	–	78	95	Soft tissue Bankart lesion	Healed	None
9	53	F	1	–	–	–	–	2	18	30	PASTA and pulley lesion	Healed	Secondary adhesive capsulitis
10	69	M	1	Anterior	3	-	-	-	94	95	Transient brachial plexus palsy	Resorption	None
12	33	M	2	–	–	–	–	4	93	90	n.c	Healed	None
17	31	M	1	–	2	–	–	–	95	100	n.c	Healed	None
20	25	F	2	–	1	–	–	5	92	90	n.c	Healed	None
Moderate displacement (6—10 mm)													
2	59	F	2	–	–	–	–	6	89	100	n.c	Healed	None
3	54	M	1	Anterior	–	–	–	6	78	80	n.c	Healed	None
11	57	F	1	Anterior	–	2	–	10	83	99	n.c	Declined	None
14	51	F	2	–	3	–	–	6	–	100	n.c	Declined	None
16	68	F	2	–	1	–	–	6	84	80	n.c	Healed	None
Major displacement (> 10 mm)													
1	37	F	2	–	–	3	–	13	85	90	n.c	Declined	None
4	59	M	2	Anterior	–	–	–	18	Lost to FU		Bony Bankart lesion		
7	38	M	2	Anterior	–	–	–	13	85	95	HAGL lesion	Healed	None
13	74	F	2	Anterior	6	–	–	18	81	98	Bony Bankart lesion	Malunion	None
15	69	F	2	Anterior	7	–	–	14	75	85	n.c	Malunion	None
18	75	F	2	Anterior	–	–	–	11	83	100	n.c	Malunion	None
Converted to operation													
6	54	F	2	–	–	–	–	20	60	75[a]	n.c	Healed	Implant removal after 2 years due to severe implant-associated complaints
19	32	F	2	Anterior	3	–	–	18	80	90	n.c	Declined	None

Constant scores are given as absolute values

n.c. not clear, *malunion* defined as fracture healing in a nonanatomic position evaluated by one independent senior physician

[a]Both scores were measured 1 year after implant removal

work overhead (patient no. 4), and two do sports with high levels of overhead activity (patients no. 7 and 19).

In half of the cases, there was a concomitant glenohumeral dislocation. The degree of displacement averaged 8.9 mm (range, 1–20 mm). A Mutch type 2 fracture could be observed in 14 out of 20 cases.

One patient was only available for patient-reported outcomes, and four others declined radiographic evaluation because of lack of any complaints or pregnancy.

In two cases, treatment was converted to internal plate fixation surgery based on patient request due to secondary fracture displacement after 9 days and 50 days. Both were female, under 55 years of age, and had a split fracture (Mutch type 2) with initial posterior displacement of 18 mm and 20 mm (patients no. 6 and 19, Table 1).

In the conservatively treated patient group, the CS and adj. CS averaged 79 ± 17.5 points, and 91 ± 17.7 points, respectively. The SSV averaged 87 ± 17%. With respect to the degree of fragment displacement, there was no statistically significant difference in clinical outcomes with regards to the mean absolute CS score, adj. CS score and SSV between the three groups as well as concerning a 5 mm cut-off (Tables 2, 3). Only one patient achieved a poor result (CS: 18 points, SSV: 30%) at a follow-up of 20 months despite normal fracture healing, due to the development of adhesive capsulitis, partial articular supraspinatus tendon avulsion, and a concomitant, progressive pulley lesion (Figs. 2, 3, 4).

Figures 5, 6 show illustrative results of another patient from this study with major fragment displacement.

All patients except one (patient no. 9) were able to return to their jobs at least after 8 weeks and practice their prior sports after 12 weeks.

Table 2 Overview of clinical outcomes with respect to degree of fragment displacement

Scores	Degree of fragment displacement		
	None/minor ($n=7$)	Moderate ($n=5$)	Major ($n=7$)
Absolute CS			
86–100 (excellent)	4	1	
71–85 (good)	2	3	6
56–70 (moderate)			1
<55 (poor)	1		
Mean (SD)	78 ± 27.7	84 ± 4.5	78 ± 8.8
p-value			
None/minor vs. moderate	0.65		
Moderate vs. major		0.41	
None/minor vs. major	0.46		
Adj. CS			
86–100 (excellent)	5	4	6
71–85 (good)	1		1
56–70 (moderate)			
<55 (poor)	1		
Mean age (SD)	41 ± 17.8	57 ± 6.5	54 ± 17.4
Mean adj. CS (SD)	84 ± 27	98 ± 5	93 ± 7.7
p-value			
None/minor vs. moderate	0.16		
Moderate vs. major		0.32	
None/minor vs. major	0.81		
SSV			
86–100 (excellent)	5	3	5
71–85 (good)		2	2
56–70 (moderate)	1		
<55 (poor)	1		
Mean (SD)	81 ± 24.6	92 ± 10.8	90 ± 8.5
p-value			
None/minor vs. moderate	0.43		
Moderate vs. major		0.64	
None/minor vs. major	0.71		

Table 3 Clinical outcomes with respect to a 5 mm cut-off

Scores	Degree of fragment displacement	
	≤5 mm ($n=7$)	>5 mm ($n=12$)
Mean age (SD)	41 ± 17.8	56 ± 13.3
Mean displacement in mm (SD)	2.7 ± 1.4	11.8 ± 5.1
Mean FU in months (SD)	19.9 ± 7.8	18.8 ± 7.7
Absolute CS		
86–100 (excellent)	4	1
71–85 (good)	2	9
56–70 (moderate)		1
<55 (poor)	1	
Mean (SD)	78 ± 27.7	80 ± 7.7
p-value		
≤5 mm vs. >5 mm	0.43	
Adj. CS		
86–100 (excellent)	5	10
71–85 (good)	1	1
56–70 (moderate)		
<55 (poor)	1	
Mean adj. CS (SD)	84 ± 27	95 ± 7
p-value		
≤5 mm vs. >5 mm	0.38	
SSV		
86–100 (excellent)	5	8
71–85 (good)		4
56–70 (moderate)	1	
<55 (poor)	1	
Mean (SD)	81 ± 24.6	91 ± 9.1
p-value		
≤5 mm vs. >5 mm	0.48	

Of those three patients who were primarily treated surgically with internal plate fixation based on their request due to major displacement and excluded from this study (Fig. 1), two reached the minimum follow-up. One of them was female, 55-year-old, had a split fracture with initial posterior displacement of 30 mm, and achieved a CS of 82 points and SSV of 90% after 2 years. The other patient was male, 55-year-old, had an avulsion fracture with initial cranial displacement of 28 mm, and achieved a poor outcome with a CS of 41 points and SSV of 50% after 1 year due to greater tuberosity resorption and implant-related complaints. A 59-year-old female with a split fracture and posterior displacement of 6 mm had undergone open reposition and internal plate fixation due to locked fracture-dislocations being exclusion criteria for primary conservative treatment. She achieved a CS of 78 points and SSV of 90% after 2 years.

Discussion

Since a century ago, isolated fractures of the GT have been considered as a particular entity among proximal humerus fractures placing them in a class with scaphoid fractures regarding the great disproportion between size of the fracture and the possible amount of disability it could produce [3]. Nevertheless, there are few studies specifically investigating this type of fracture since the early treatment suggestions.

To date, the choice of operative or conservative treatment is mainly dictated by the amount of osseous fragment displacement [4]. Recommended cut-off values for surgical fixation have been further escalated over the last decades despite a lack of any evidence. Neer`s former recommendation of the 1970s to treat fracture fragment displacements of less than 1 cm non-operatively has been gradually revised and replaced with a 5 mm threshold for the so-called general population and a 3 mm threshold for active patients, including athletes and heavy laborers who are involved in overhead activities, without a clearer definition of these population groups, the direction of displacement, and diagnostic imaging modality [5, 6]. Some authors go even further to considering GT fragment displacement of more than 2 mm as an indication for surgery in general [7, 8].

Proponents of these recommendations suggest that any displacement from the anatomic position can result in malunion, impingement, and significant loss of function of the shoulder due to the negative effects of an altered rotator cuff insertion site on motion of the glenohumeral joint [9, 10].

Thus, conservative treatment is often considered to result in inferior outcome [11] and is not recommended for such displaced, isolated GT fractures, although clinical experiences in the past reported rather inconsistent results (Table 4) [11–16].

While, in the 1960s, McLaughlin reported significant disability in cases of greater than 1 cm of GT displacement and prolonged recovery requiring a reconstructive procedure in 20% of cases with displacement between 0.5 and 1 cm [17], Wallace and Young stated good and acceptable results in seven patients treated non-operatively despite of displacement of even more than 1 cm with satisfactory painless function. Similarly, Kristiansen, in the 1980s, observed excellent and good results in all cases of non-operatively treated GT fractures. Contrary to Santee`s and McLaughlin's findings, patients with displaced GT fractures were not worse than those with displaced surgical neck fractures in the study population of Wallace et al., and radiologic results did not correlate with clinical outcomes [18]. However, despite these aforementioned studies, the exact amount of acceptable displacement remained unclear as well as the effects of the direction of displacement and the rehabilitation protocol.

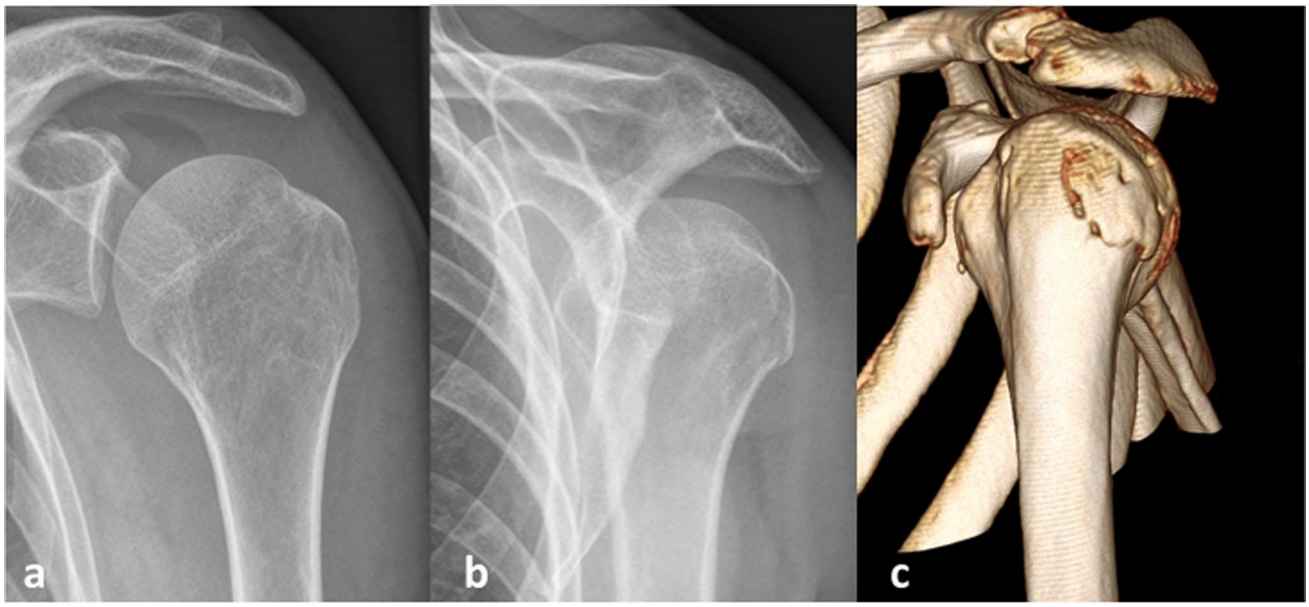

Fig. 2 A 53-year-old teacher sustained an isolated, minimally displaced avulsion fracture (Mutch type 1) of the greater tuberosity after a fall. X-ray of the left shoulder in AP (**a**) and scapular-Y (**b**) views, and CT scan (**c**)

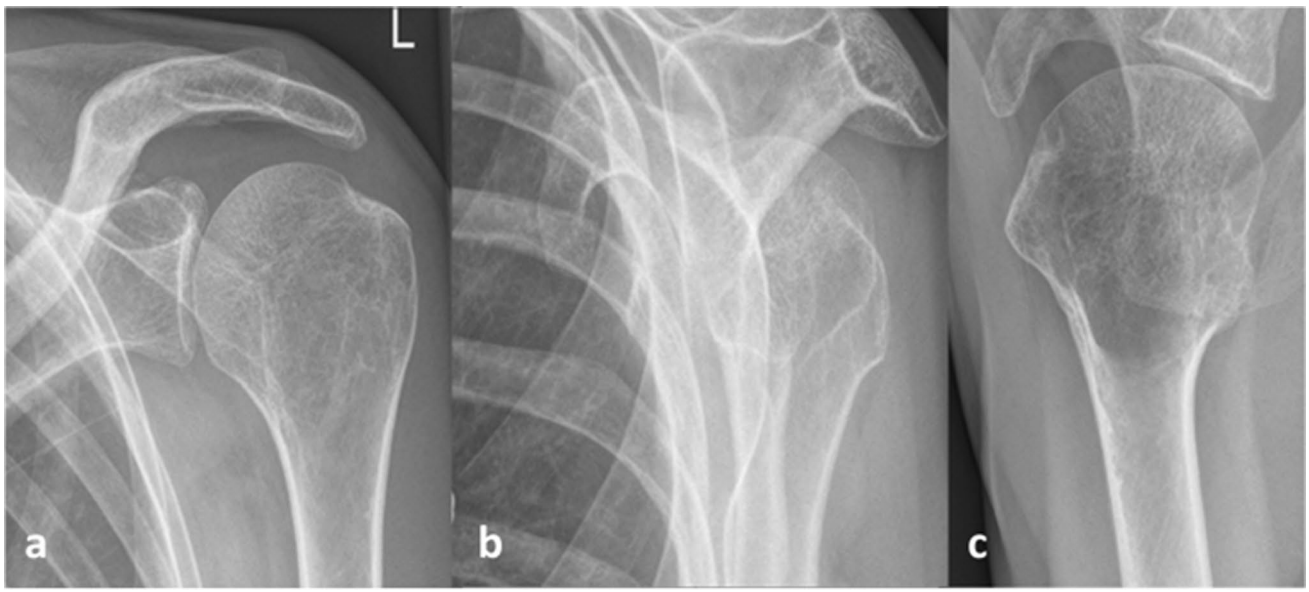

Fig. 3 Radiographic process of fracture healing was without complication. X-ray after 1 year in AP (**a**), scapular-Y (**b**), and axillary (**c**) views. Nevertheless, clinical convalescence remained poor. CS: 18 points, SSV: 30%

At the end of the 1990s, a mainly cadaveric-based preliminary study by Park et al. was performed and continues to serve as the basis for treatment practices of isolated GT fractures today. The authors measured the shortest distance of the transitional area between the uppermost part of the GT footprint and articular cartilage of the humeral head and the width of bicipital groove in 100 Korean adult, uninjured cadaveric humeri. Since their mean values were 3.8 and 8.3 mm, respectively, Park et al. suggested that a displacement of more than 3 mm would result in reduced range of motion, disability, complaints related to the long biceps tendon, and mechanical blockage and impingement. They concluded that GT displacement of more than 5 mm in young patients and more than 3 mm in athletes and heavy laborers with overhead activities should be addressed operatively [5].

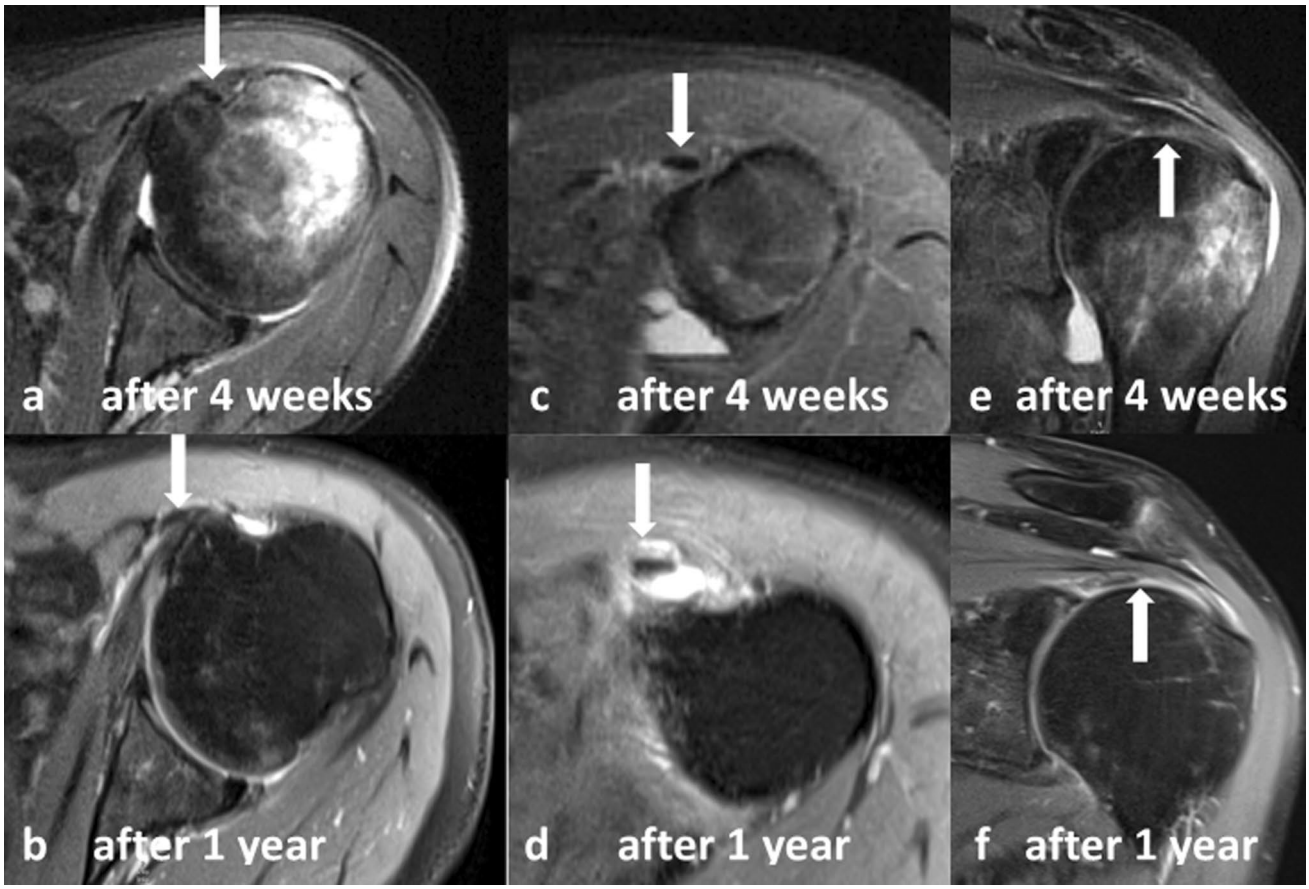

Fig. 4 MRI reveals a progressive pulley and PASTA lesion after 1 year. White arrows shows position of long head of biceps tendon in the transverse plane after 4 weeks (**a** + **c**) and 1 year (**b** + **d**). PASTA lesion is shown after 4 weeks (**e**) and 1 year (**f**)

Platzer et al. gave these suggestions clinical impact at the end of the 2000s. They retrospectively compared functional and radiographic outcome of 52 patients with operatively treated displaced isolated GT fractures at an average follow-up of 5.9 years (range, 2–11 years) with 9 patients who had been treated non-operatively. As surgically treated patients had significantly better results in shoulder function than those treated conservatively, the authors concluded that surgical reduction and fixation of this fracture entity are recommended in the setting of displacement of more than 5 mm in any radiographic plane. However, the control group was biased by selection as these patients were treated conservatively in part due to poor state of health, advanced age, or lack of compliance [19].

For minimally displaced isolated GT fractures, the same colleagues assessed the relationship between degree of displacement ranging from 3 mm inferiorly to 5 mm superiorly and shoulder function in 135 non-operatively treated patients. Statistical analysis showed that the amount of displacement had no significant influence on shoulder function, even though patients with a superior displacement of more than 3 mm had slightly worse results compared to those with less.

Resch and Thoeni also previously suggested that the duration of pain and range of motion may depend on the amount of displacement in the setting of a shoulder dislocation with concomitant isolated GT fracture. Furthermore, they concluded that displacement exceeding 3 mm in one direction should be reduced surgically in active patients [10].

The preliminary results of this observational and CT-based prospective study of conservatively treated displaced, isolated GT fractures are consistent with the findings and assumptions described by Mattyasovszky et al. These colleagues retrospectively assessed 30 patients with isolated GT fractures at an average follow-up of 3 years. No statistically significant difference in clinical outcome could be observed between patients with minor (< 5 mm), moderate (6–10 mm), and major (> 10–20 mm) displacement, although most of the patients with minor and half of the patients with moderate displacement were treated non-operatively. The authors concluded that minor to moderately displacement may be treated successfully without surgery [13]. The assumption that conservatively treated GT

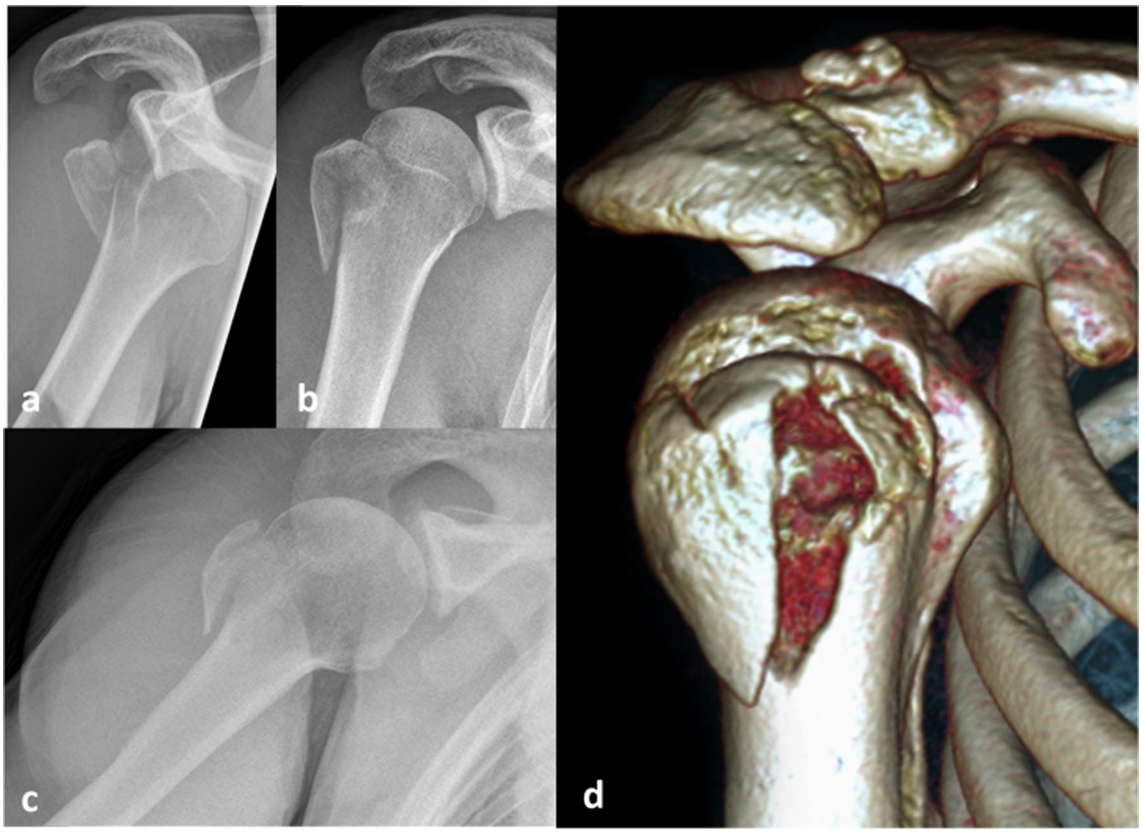

Fig. 5 A 38-year-old highly active anesthetist sustained an isolated, posteriorly displaced split fracture (Mutch type 2) of the greater tuberosity. X-ray of the right shoulder in the AP view before (**a**) and after (**b**) closed reduction, and axillary view (**c**). CT scan after reposition (**d**)

fractures with displacements of 5–8 mm were compatible with good results was documented in a personal communication between Keene and Rockwood, and also stated by Jakob for displacements of 5–10 mm [20, 21]. The authors additionally concluded in retrospect that it was not necessary to treat four of the five patients with major displacement surgically despite their good outcomes.

Nevertheless, this study has limitations to consider. Aside from its preliminary results with a modest number of patients and inadequate power to detect a 10-point difference in the CS (Minimal clinically important difference), the observational design of this registry study limits any recommendation regarding cut-off values of displacement for patients who could benefit of surgical treatment, even though observing nonoperatively treated patients do not crossover to surgery in such a prospective study could be a promising approach to determine a cut-off. The observed CT-based range and mainly posteriorly directed displacement leave us uncertain about the true extent and direction of displacement that can be tolerated. In this regard, previous literature has provided inconsistent suggestions. While according to some authors, superior displacement could cause subacromial impingement and is less well tolerated than posterior displacement [10], others consider also the latter as a more limiting cause of limited external rotation and subacromial joint tracking due to painful longitudinal rotator cuff tearing [10]. Finally, others see in a combination of both posterior and superior displacements as indicative of the worst clinical outcome [22, 23]. Considering the fact that there were only two patients in the group with cranial displacement > 5 mm and the majority had a split fracture (Mutch type 2) limits the representativity of the study participants and the applicability of the study.

Moreover, patients were enrolled in this study at a single institution with a distinct treatment protocol, which limits the external validity of our findings. However, the majority of our study population were ASA I or II in terms of health status, and we feel it reflects the general population.

MRI or ultrasound imaging was not a standardized part of the evaluation in this study, thus the extent and significance of concomitant soft tissue lesions as a confounding variable for the final outcomes remain unclear. From the authors' view, this could be of importance for future studies, in particular where previous reports are inconsistent. Gallo et al. described a relationship between severity of rotator cuff injury and increasing AO and Neer class as well as radiographic GT displacement

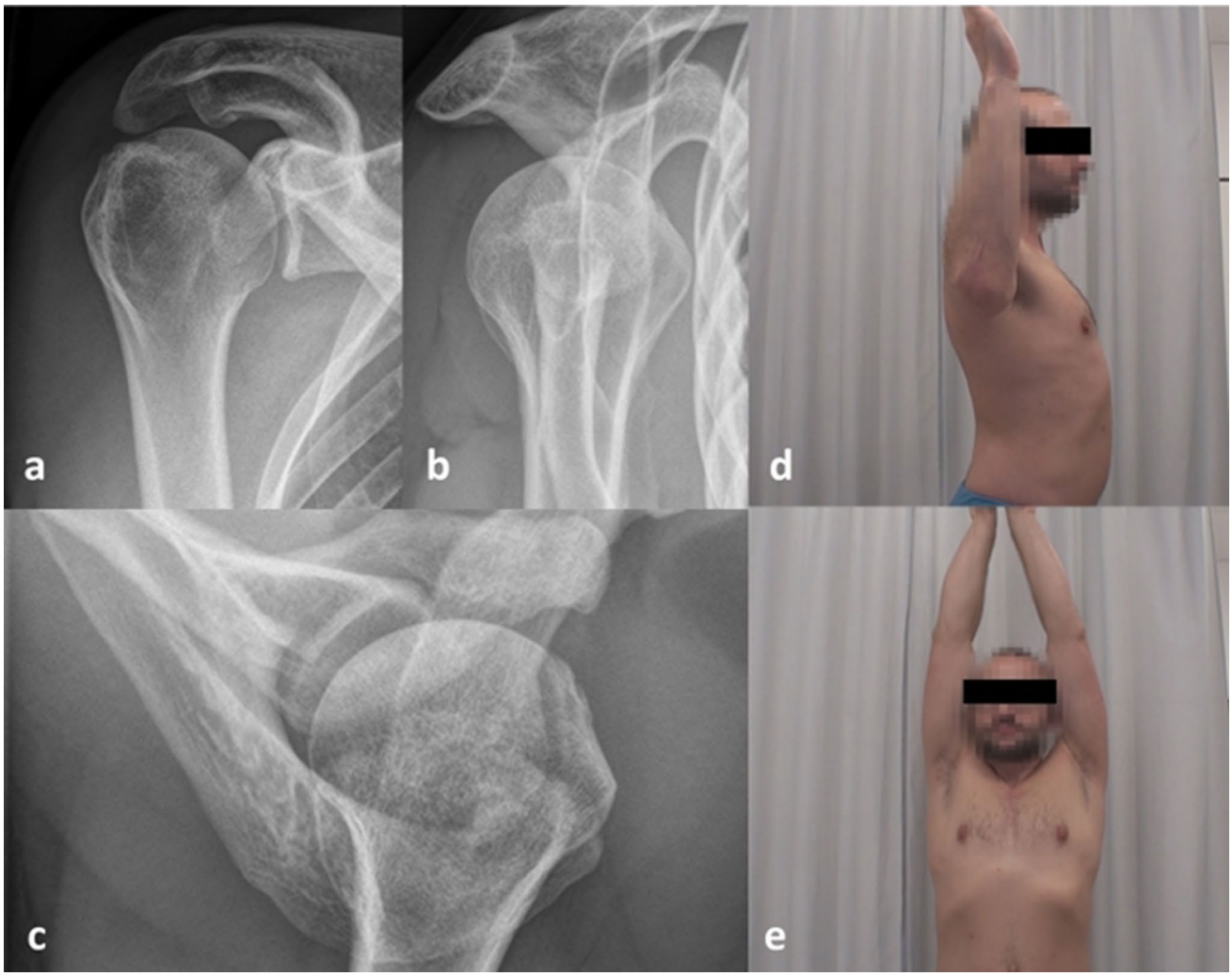

Fig. 6 Clinical and radiographic process of fracture healing was without complication. X-ray after 2 years in the AP (**a**), scapular-Y (**b**), and axillary (**c**) views. CS: 85 points, SSV: 95%. Full active and passive range of motion without any impingement or external rotation blocking phenomenon (**d** + **e**)

of more than 5 mm, and suggested 5 mm as threshold for MRI-apparent rotator cuff injury. However, others did not find correlation between extent of fragment displacement and arthroscopic presence or number of concomitant pathologies, particularly full-thickness tears of the supraspinatus and infraspinatus [24, 25]. On the contrary, Kim et al. found arthroscopically partial-thickness rotator cuff tearing on the articular surface in all twenty-three patients with chronic shoulder pain caused by a minimally displaced GT fracture with an average displacement of only 2.3 mm [26].

Conclusion

The outcomes of conservatively treated displaced, isolated GT fractures are underestimated and current recommendations for surgical treatment should be questioned. Future studies with a larger number of patients, longer lengths of follow-up, and higher levels of evidence in the form of randomized trials are needed.

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Data availability The manuscript has associated data in a data repository.

Code availability Not applicable.

Table 4 Overview of conservative treated displaced isolated GT fractures (Studies published in journals indexed in PubMed—accessed on 01.06.2020)

Study	Year	Level of evidence	Journal	*N*	Diagnostic imaging	Amount of displacement	Direction of displacement	Mean FU[a]	Outcome
McLaughlin HL	1963	V Experience-based	Surg Clin North Am	n.m	n.m	> 5 mm	n.m	n.m	No scores 0.5-1 cm: 20% with sufficient pain and disability needed reconstructive surgery > 1 cm: significant disability
Neer CS	1970	IV-V	JBJS	n.m	x-ray (AP, lateral and axillary)	≤ 1 cm Exact percentage of > 0,5 mm unclear > 1 cm	n.m	n.m	≤ 1 cm: satisfactory[b] > 1 cm: not defined, but difficult to be adequately controlled by closed means
Mills HJ	1985	IV	J Trauma	< 4	x-ray (AP and lateral)	> 1 cm	Cranial and lateral	32.6 m	Excellent and satisfactory for lateral displacement. Satisfactory and poor for cranial displacement[b]
Wallace WA	1985	IV	Bone Joint J	< 7	x-ray	> 1 cm	n.m	6 m	Four good and three acceptable results
Kristiansen B	1987	IV	Acta Orthop. Scand	< 4	x-ray	> 1 cm	n.m	4 y	Excellent or good in all cases. Mean Neer-Score of 82 points
Resch H	1992	IV	Orthopade	10	x-ray (AP and tangential)	> 3 mm	cranial	n.m	No scores. 50% reached full ROM. Mean pain duration 10 m
Chun JM	1994	IV	JSES	< 11	x-ray (true AP, lateral and axillary)	< 1 cm; Exact percentage of > 0,5 mm unclear	n.m	5.1 y	All satisfactory. One excellent, seven good, three fair. No poor case[b]
Park TS	1997	IV	Bull Hosp J Dis	3	x-ray (trauma series) and CT	< 1 cm; Exact percentage of > 0,5 mm unclear	n.m	3.7 y	Mean Neer-Score of 91 points. 81 points for one case with concomitant dislocation
Platzer P	2008	III	J Trauma	9	x-ray (AP and axillary), only one CT[c]	> 5 mm in any plane	n.m	5.9 y	Mean CS: 66.5, VSS: 15.7, UCLA-Score: 23.7 points Six patients (33%) satisfactory with two-thirds points on two of the three shoulder scores. Three patients (67%) had unsatisfactory results

Table 4 (continued)

Study	Year	Level of evidence	Journal	*N*	Diagnostic imaging	Amount of displacement	Direction of displacement	Mean FU[a]	Outcome
Mattyasovszky S	2011	IV	Acta Orthopaedica	4	x-ray (true AP and lateral), one CT	0,6–1 cm	Anteroposterior and craniocaudal	3 y	6 mm cranial + 5 mm anterior = CS: 51, DASH: 23 6 mm cranial + 8 mm anterior = CS: 77, DASH: 5 10 mm posterior = CS: 78, DASH: 7.5 6 mm anterior = CS: 80, DASH: 3.3

N.m. not mentioned

[a]Mean FU of whole study population

[b]According to Neer`s numerical scoring system; [c]in whole study population; *CS* Constant Score, *VSS* Vienna Shoulder Score, *UCLA* University of California, Los Angeles

Compliance with ethical standards

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

Ethical approval This study is authorized by the local ethical committee as part of an observational registry study (Hannover Humerus Registry—HHR) (journalno. 322-2016) and was carried out in accordance with the Ethical standards of the 1964 Declaration of Helsinki as updated in 2004.

Informed consent All patients gave written informed consent.

Consent for publication The manuscript does not include images or information that may identify any person.

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