Clinical and Radiographic Outcomes After Surgical Treatment of Proximal Humeral Fractures with Head-Split Component

Paulina-Maria Peters, Fabian Plachel, MD, Victor Danzinger, Michele Novi, Sven Märdian, MD, Markus Scheibel, MD, and Philipp Moroder, MD

Investigation performed at the Center for Musculoskeletal Surgery, Campus Virchow, Charité-Universitaetsmedizin Berlin, Berlin, Germany

Background: Head-split fractures are a subgroup of proximal humeral fractures in which the fracture line affects the articular surface. Limited data are available regarding outcomes and risk factors for failure following surgical treatment of this rare fracture type.

Methods: Of 45 patients with head-split fractures identified, a total of 30 (67%) were included in this retrospective study, with a mean follow-up of 49 ± 18 months (range, 12 to 83 months). Of those 30, 24 were treated with open reduction and internal fixation (ORIF), 4 with reverse total shoulder arthroplasty (RTSA), and 2 with hemiarthroplasty. Subjective Shoulder Value, Simple Shoulder Test, Constant score, and biplanar radiographs were assessed. Fracture pattern, quality of reduction, eventual complications, revision procedures, and clinical failure (adjusted Constant score < 40) were analyzed, and risk factors for failure were calculated.

Results: The overall complication rate was 83% (ORIF: 21 of 24 [88%]; RTSA: 3 of 4 [75%]; and hemiarthroplasty: 1 of 2 [50%]). The most common complications following ORIF were humeral head osteonecrosis (42%), malunion of the lesser tuberosity (33%), and screw protrusion (29%), whereas all complications following RTSA were related to tuberosity problems. Revision was performed in 7 of 24 (29%) of initial ORIF patients, and no revisions were performed in RTSA or hemiarthroplasty patients. Four patients (17%) who underwent primary ORIF underwent conversion to RTSA, and 3 patients (12.5%) had screw removal due to penetration. The overall clinical failure rate was 50% (ORIF: 12 of 24 [50%]; RTSA: 1 of 4 [25%]; and hemiarthroplasty: 2 of 2 [100%]). No significant association was found between preoperative factors and clinical failure. ORIF and primary RTSA showed higher average clinical outcome scores than primary hemiarthroplasty and secondary RTSA. In general, patients who required revision had worse Subjective Shoulder Value (p = 0.014), Simple Shoulder Test (p = 0.028), and adjusted Constant scores (p = 0.069).

Conclusions: Head-split fractures of the humerus treated with ORIF showed high complication and revision rates. RTSA resulted in comparable clinical outcomes and complication rates; however, the complications associated with RTSA were mostly related to tuberosity problems, which in this small series did not require revision. Therefore, RTSA may be the most predictable treatment option for head-split fractures in elderly patients.

Level of Evidence: Therapeutic Level IV. See Instructions for Authors for a complete list of levels of evidence.

Proximal humeral fractures are common and account for 5.7% of all fractures[1]. The present study focused on head-split fractures, a rare subgroup in which the fracture line involves the articular surface of the humeral head[2]. The usual pathomechanism is a direct impact on the shoulder with the head impacting against the glenoid, sometimes in combination with a dislocation of the glenohumeral joint[3]. Whereas treatment options for proximal humeral fractures range from nonoperative treatment to various surgical options, head-split fractures often represent an indication for surgical intervention[2]. However, as this type of fracture is relatively rare, no clear algorithm for treatment has been established.

Disclosure: The authors indicated that no external funding was received for any aspect of this work. On the **Disclosure of Potential Conflicts of Interest** forms, *which are provided with the online version of the article*, one or more of the authors checked "yes" to indicate that the author had a relevant financial relationship in the biomedical arena outside the submitted work (http://links.lww.com/XXXXXXX).

TABLE I Patient Characteristics*

	ORIF (N = 24)	Primary RTSA (N = 4)	Hemiarthroplasty (N = 2)	P Value
Age *(yr)*	60 ± 13 (30-82)	76 ± 10 (64-87)	74 ± 0	0.042
Time from injury to operation *(days)*	4.2 ± 11	2.2 ± 1.2	1.1 ± 0.7	0.089
Dominant side†	15	3	1	0.981
BMI *(kg/m²)*	30 ± 7	31 ± 10	30 ± 10	0.862
ASA score	1.7 ± 0.7	1.9 ± 0.7	2 ± 1.4	0.784
Duration of physiotherapy *(wk)*	80 ± 91 (0-312)	38 ± 14 (20-52)	208 ± 220 (52-364)	0.653

*The values are given as the mean and standard deviation, with or without the range in parentheses, unless otherwise noted. †Values are given as the number of patients.

Most fractures of the humeral head are treated with open reduction and internal fixation (ORIF)[4]. According to Nowak et al., ORIF is also a suitable treatment for fractures with a head-split component[5], especially in young and active patients, whereas arthroplasty can be considered in older patients[6]. A notable downside of ORIF is the complication rate, which ranges from 20% to 60%, with complications including malunion, nonunion, osteonecrosis of the humeral head, screw protrusion, and glenoidal erosion. These complications often lead to dissatisfying clinical and radiographic outcomes and make a revision procedure for implant removal or secondary shoulder replacement necessary[7].

Khmelnitskaya et al. suggested that shoulder arthroplasty is the most suitable option for most patients with head-split fractures, and that surgical reconstruction should be attempted in patients <50 years old[6]. For older patients whose quality of life would not be compromised by the limited functional outcomes associated with hemiarthroplasty, the procedure is an adequate choice because it has a relatively low rate of revision and, thus, a lower risk of the complications associated therewith[7]. Greiwe et al. showed that patients with head-split fractures in particular benefit from hemiarthroplasty because it results in better forward elevation compared with other types of proximal humeral fractures[8]. However, the integrity of the rotator cuff and whether there is foreseeable tuberosity malunion or nonunion determine which type of arthroplasty should be used. Although anatomical hemiarthroplasty is becoming less popular because the success of the procedure relies heavily on the healing of the tuberosities, reverse total shoulder arthroplasty (RTSA) has gained popularity because it offers a higher degree of constraint and therefore can be used even in the presence of an irreparable rotator cuff, comminuted tuberosities, and comorbidities predisposing to malunion of the tuberosities[9,10]. According to Boyle et al., RTSA for proximal humeral fracture leads to better 5-year functional outcomes compared with hemiarthroplasty[10]. The most common complications of RTSA are instability, infection, screw loosening, fracture, and bone defects, as well as glenoid complications and glenoid component loosening. With a reoperation rate ranging from 10% to 50%, a revision procedure may be required following RTSA, making this option less preferable for younger patients[11].

To our knowledge, this retrospective study is the first clinical and radiographic evaluation of a large number of head-split fractures, with the additional aim of identifying risk factors related to an unsatisfactory functional outcomes and failure of treatment.

Materials and Methods

Approval was obtained from the local ethical committee prior to the inclusion of patients. All patients with a surgical neck fracture of the humerus with a head-split component treated surgically at our department between 2011 and 2016 were included in this retrospective study, regardless of treatment type or concomitant injuries. Generally, at our department, the pathomorphological surgical indication criteria for these types of fractures include displacement of fragments by >5 mm and/or angulation of >20°. Forty-five patients were invited for a follow-up examination. Of those 45, 3 had died of a cause not related to the operative shoulder, 4 could not be contacted because of missing contact information, and 8 declined an examination for reasons not related to the operative shoulder. Thus, the final follow-up rate was 67%.

The remaining 30 patients had an average age (and standard deviation) at the time of the surgical procedure of 63 ± 14 years (range, 30 to 87 years) and a mean body mass index (BMI) of 30 ± 7 kg/m² (range, 19 to 46 kg/m²) (Table I). Sixteen patients (53%) were female, and the dominant side was affected in 19 patients (63%). The mean preoperative interval, defined as the time between injury and initial surgical treatment, was 4 ± 9 days (range, 0 to 48 days). The mean follow-up was 49 ± 18 months (range, 12 to 83 months). The American Society of Anesthesiologists (ASA) score was 1 in 15 patients (50%), 2 in 9 patients (30%), and 3 in 6 patients (20%).

In order to determine risk factors for clinical failure, the subjective and objective clinical outcomes, as well as radiographically detected complications at the time of the follow-up examination, were correlated with general patient-specific factors and with fracture characteristics, including surgical reduction results.

Clinical Follow-up

The clinical follow-up examination included a standardized questionnaire that assessed the satisfaction of the patient with

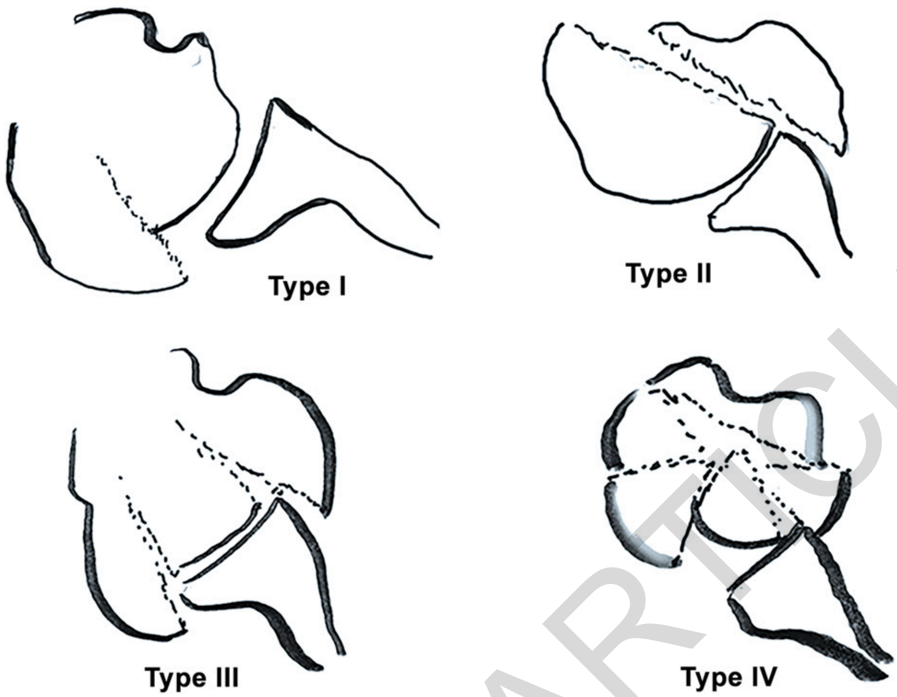

Fig. 1
Illustration showing 4 different head-split fracture patterns[19]. (Reproduced, with modification, under Creative Commons Attribution 4.0 International License [https://creativecommons.org/licenses/by/4.0/], from: Scheibel M, Peters P, Moro F, Moroder P. Head-split fractures of the proximal humerus. Obere Extremität. 2019:14[2]:93-102.)

the procedure (1 = very satisfied, 2 = satisfied, 3 = rather satisfied, 4 = sufficiently satisfied, and 5 = unsatisfied), identified possible complications, and determined whether the patient underwent revision following the index procedure, as well as the Subjective Shoulder Value[12], Simple Shoulder Test[13,14], and Constant score[15]. The Constant score was adjusted for age and sex according to Tavakkolizadeh et al.[16]. Clinical failure was defined by an adjusted Constant score <40[17].

Radiographic Follow-up

All preoperative and postoperative imaging was gathered from the institutional database. All 30 patients had preoperative radiographs, and 16 patients (53%) had additional computed tomography (CT) scans. Preoperative images were retrospectively analyzed to determine the fracture pattern according to Resch et al.[18]; the head-split pattern according to Scheibel et al.[19] (Fig. 1); and the presence of glenohumeral dislocation, sagittal and coronal angulation of >20°, fracture and displacement of the tuberosities (<5 or ≥5 mm), impaction and/or avulsion, shaft displacement of >50% of the diameter of the shaft, metaphyseal extension (<8 or ≥8 mm), and medial hinge displacement (<2 or ≥2 mm) (Table II). All patients had biplanar immediate postoperative radiographs (true and scapular Y-view) available for evaluation. Postoperative quality of reduction was determined to be either anatomical, minor malreduction, or major malreduction. Radiographic analysis was independently performed by 2 specialized shoulder surgeons not involved in the surgical treatment of the study patients. As it was an anonymous evaluation, patient data and outcome were blinded at the time of analysis. In the case of disagreement, consensus was found after re-analysis was performed jointly. Minor malreduction was defined as non-anatomical reduction but with an acceptable result, no implant conflict, and presumably sufficient primary stability. Major malreduction was defined as very poor reduction, implant conflict, and/or presumed lack of sufficient primary stability.

As part of the follow-up protocol, true anteroposterior, axillary, and scapular Y-view radiographs were made for all patients. For patients who underwent ORIF, these radiographs were analyzed for malunion (displacement of ≥5 mm), nonunion, partial or complete head necrosis, screw protrusion, and glenoidal erosion, as well as for full or partial implant removal. For patients who underwent arthroplasty, these radiographs were analyzed for malunion and nonunion of the tuberosities and for decentering and misplacement of the prosthetic components.

Radiographic analysis was independently performed by 2 specialized shoulder surgeons not involved in the surgical treatment of the study patients. In the case of disagreement, consensus was found after re-analysis was performed jointly.

Statistical Analysis

Statistical analysis was performed with use of SPSS Software (version 21; IBM). All values were assessed for a normal distribution with use of the Kolmogorov-Smirnov test. Frequency tables and descriptive statistics were used to assess patient-related factors as well as pathomorphological characteristics

TABLE II Preoperative and Immediate-Postoperative Pathomorphological Factors

	No. of Patients (%) (N = 30)
Classification according to Resch et al.[18]	
2G	2 (7%)
2L	3 (10%)
3G	5 (17%)
3GL	6 (20%)
4G	4 (13%)
4GL	3 (10%)
5G	3 (10%)
5GL	4 (13%)
Classification according to Scheibel et al.[19]	
I	10 (33%)
II	13 (43%)
III	7 (23%)
IV	0
Glenohumeral dislocation	6 (20%)
Anterior	4 (13%)
Posterior	2 (7%)
Sagittal angulation	13 (43%)
>20° anterior	3 (10%)
>20° posterior	10 (33%)
Coronal angulation	22 (73%)
>20° varus	8 (27%)
>20° valgus	14 (47%)
Impaction	15 (50%)
Avulsion	14 (47%)
Neutral	1 (3%)
Fractured greater tuberosity	27 (90%)
<5 mm	8 (27%)
≥5 mm	19 (63%)
Fractured lesser tuberosity	17 (57%)
<5 mm	5 (17%)
≥5 mm	12 (40%)
Shaft displacement	25 (83%)
<5 mm	6 (20%)
≥5 mm	19 (63%)
Metaphyseal extension <8 mm	15 (50%)
Medial hinge displacement ≥2 mm	18 (80%)
Anatomical reduction	16 (53%)
Minor malreduction	11 (37%)
Major malreduction	3 (10%)

regarding treatment, revision, and clinical and overall failure. The Kruskal-Wallis test was used to compare clinical results between patients who underwent ORIF, primary RTSA, primary hemiarthroplasty, and secondary RTSA. Characteristics of patients who experienced failure were analyzed with use of frequency tables and the chi-square test. The chi-square test and the Fisher exact test were used to find associations of the ASA score and preoperative pathomorphological factors with treatment failure. Significance was set at $p < 0.05$. Results were analyzed regardless of treatment, as well as individually for patient groups with primary ORIF, primary or secondary RTSA, and primary hemiarthroplasty at the time of follow-up.

Results

As confirmed with use of radiographs made immediately postoperatively, anatomical reduction was achieved in 16 patients (53%), whereas 11 patients (37%) had a minor malreduction and 3 patients (10%) had a major malreduction.

Among the 24 patients who underwent ORIF, radiographically detectable complications included 13 cases of malunion of the tuberosities (54%; 5 [21%] in the greater tuberosity and 8 [33%] in the lesser tuberosity), 7 cases of screw protrusion (29%), 5 cases of complete osteonecrosis (21%), 5 cases of partial osteonecrosis (21%), 5 cases of pseudarthrosis (21%), and 2 cases of glenoidal erosion (8%). Revision for implant removal was performed in 6 patients (25%): 3 because the patient requested implant removal with no radiological indication and 3 for screw protrusion, which, in addition to the 7 cases identified on radiographs, resulted in a total of 10 patients (42%) who experienced screw protrusion. Revision for screw protrusion was performed at an average of 36 ± 14 weeks postoperatively. Four patients (17%) underwent revision in the form of conversion to RTSA at an average of 38 ± 30 months postoperatively. Thus, excluding the 3 patients who underwent implant removal with no radiological indication, revision was performed in 7 (29%) of the 24 patients who underwent primary ORIF.

Among the 4 patients who underwent RTSA, there were 3 cases of radiographically detectable nonunion of both the greater and lesser tuberosities (75%). None of the patients who underwent primary RTSA underwent a subsequent revision procedure. Of the 4 patients who underwent RTSA secondary to ORIF, 3 (75%) had a malunion and 1 (25%) had a nonunion of the greater tuberosity, and 2 (50%) had a malunion of the lesser tuberosity, following the conversion procedure.

Of the 2 patients who underwent hemiarthroplasty, 1 (50%) experienced nonunion of both tuberosities and a decentering of the arthroplasty. Neither patient underwent a revision procedure.

The complication rate was 83% overall and 88% for primary ORIF, 75% for primary RTSA, and 50% for hemiarthroplasty. The revision rate was 29% for ORIF (excluding the 3 cases of implant removal performed at the request of the patient) and 0% for primary RTSA and hemiarthroplasty.

Table III details the type and number of long-term complications observed in each treatment group, as identified on radiographs at the follow-up examination.

ORIF and primary RTSA resulted in higher average clinical outcome scores than hemiarthroplasty and secondary RTSA (Table IV). On the basis of the criterion for failure of an adjusted Constant score <40, 15 patients (50%) were identified as experiencing clinical failure. The primary procedure was

TABLE III Type and Number of Long-Term Complications*

Complication	ORIF (N = 20)	Primary RTSA (N = 4)	Secondary RTSA (N = 4)	Hemiarthroplasty (N = 2)
Malunion (greater tuberosity)	5 (25%)	3 (75%)	3 (75%)	0
Minor	4 (20%)	3 (75%)	1 (25%)	0
Major	1 (5%)	0	2 (50%)	0
Nonunion (greater tuberosity)	0	0	1 (25%)	1 (50%)
Malunion (lesser tuberosity)	8 (40%)	3 (75%)	2 (50%)	0
Minor	4 (20%)	3 (75%)	0	0
Major	4 (20%)	0	2 (50%)	
Nonunion (lesser tuberosity)	0	0	0	1 (50%)
Complete osteonecrosis	5 (25%)	N/A	N/A	N/A
Partial osteonecrosis	5 (25%)	N/A	N/A	N/A
Screw protrusion	7 (35%)	N/A	N/A	N/A
Glenoidal erosion	2 (10%)	N/A	N/A	N/A
Pseudarthrosis	5 (25%)	N/A	N/A	N/A
Decentering	0	0	0	1 (50%)

*N/A = not applicable. For patients who underwent primary or secondary RTSA or hemiarthroplasty, imaging was not analyzed to assess for osteonecrosis, screw protrusion, glenoidal erosion, or pseudarthrosis, because of the nature of the procedures.

ORIF in 12 of those patients, hemiarthroplasty in 2 patients, and RTSA in 1 patient, leading to a clinical failure rate of 50% for primary ORIF, 100% for hemiarthroplasty, and 25% for primary RTSA. There were no significant differences in the patient characteristics between those who experienced clinical failure and those who did not (Table V). Similarly, there were no associations between clinical failure and patient factors or postoperative factors (Table VI). Overall, no factor was found to be associated with clinical failure except for a trend for worse outcomes in patients with higher BMI; however, patients who underwent revision procedures had worse clinical outcome scores overall (Table VII).

Discussion

Regardless of treatment type, the overall complication rate following surgical treatment of head-split fractures of the humerus was extremely high. The high complication and revision rate observed in the ORIF group was mostly related to tuberosity problems or osteonecrosis. Although arthroplasty patients also showed a high complication rate, mostly related to tuberosity problems, clinical outcomes were less affected and therefore no revisions were required in patients who underwent RTSA. Although patients with hemiarthroplasty did not undergo any revision procedures, tuberosity problems led to secondary decentering and poor clinical outcomes.

When comparing the results of the present study to those of other studies on proximal humeral fractures in general, a much higher rate of osteonecrosis (42%) was observed in the present study among patients who underwent ORIF. The reported rate of osteonecrosis after osteosynthesis of intra-articular fractures of the proximal aspect of the humerus ranges from 4% to 33%[20]. Jung et al. reported a necrosis rate of 2% after humeral head stabilization with locking plates[21], and Gerber et al. reported 35% following ORIF or minimally invasive fixation[22]. Although fractures with a head-split component were not explicitly excluded in those studies, these fracture types most likely comprised only a small percentage of the respective patient cohorts. Solberg et al. reported a rate of osteonecrosis of 16% in patients >55 years old who had a low-energy 3 or 4-part fracture of the proximal aspect of the

TABLE IV Clinical Outcome Scores at the Time of Follow-up*

Outcome	Overall (N = 30)	ORIF (N = 20)	Primary RTSA (N = 4)	Secondary RTSA (N = 4)	Hemiarthroplasty (N = 2)
SSV	58 ± 22	63 ± 22	61 ± 19	40 ± 18	35 ± 7
SST	5.7 ± 3.8	6.2 ± 4.2	6.5 ± 3.9	4 ± 0.8	3 ± 0
Adjusted CS	46 ± 24	47 ± 27	59 ± 16	35 ± 15	27 ± 13

*The values are given as the mean and standard deviation. SSV = Subjective Shoulder Value, SST = Simple Shoulder Test, and CS = Constant score.

TABLE V Comparison of Patient Characteristics by Occurrence of Clinical Failure

	Clinical Failure (N = 15)	No Clinical Failure (N = 15)	P Value
Age at the time of primary procedure* *(yr)*	65 ± 15	61 ± 11	0.339
BMI* *(kg/m²)*	32 ± 7	27 ± 5	0.059
Sex†			0.310
Female	10	6	
Male	5	9	
Primary intervention†			0.235
ORIF	12	12	
Primary RTSA	1	3	
Primary hemiarthroplasty	2	0	
ASA score†			1.000
1	8	7	
2	4	5	
3	3	3	
4	0	0	
5	0	0	
Time from injury to operation* *(days)*	4 ± 10.4	2 ± 1.6	0.746
Revision surgery†	5	2	0.203
Complication present†	13	17	0.203

*The values are given as the mean and standard deviation. †The values are given as the number of patients.

humerus[23]; however, patients with head-split fractures were initially treated with hemiarthroplasty and therefore not included in the analysis of head necrosis.

TABLE VI Association of Preoperative and Postoperative Pathomorphological Factors with Clinical Failure

	P Value
Sex	0.462
Classification according to Scheibel et al.[19]	0.642
Glenohumeral dislocation	0.340
Sagittal angulation	1.000
Coronal angulation	0.368
Impaction/avulsion/neutral	0.715
Fractured greater tuberosity	0.386
Fractured lesser tuberosity	1.000
Shaft dislocation	1.000
Metaphyseal extension	1.000
Medial hinge displacement	1.000
Classification according to Resch et al.[18]	0.596
Reduction	0.809
Healing of greater tuberosity	0.279
Healing of lesser tuberosity	0.525

The rate of tuberosity-related complications was also higher than those reported in other studies investigating general proximal humeral fractures. Brorson et al. reported a rate of 3% for nonunion and 5% for delayed union[20], Jung et al. reported a rate of 2% for tuberosity malunion following ORIF[21], and Gerber et al. reported a rate of malunion of 12% following either ORIF or minimally invasive fixation[22]. Solberg et al. observed nonunion of the greater tuberosity in 15% of patients following hemiarthroplasty, including patients with a head-split fracture[24]. In the present study, 43% of patients had a malunion or nonunion of the greater tuberosity and 47%, of the lesser tuberosity. However, the patient cohort in the present study likely represented a negative selection bias in terms of severity of the fractures, as only patients with a head-split fracture were included. Furthermore, the high rate of screw protrusion is likely linked to the high rate of osteonecrosis, which reduces the volume of the humeral head and thus leads to secondary protrusion of screws despite appropriate intraoperative length.

When comparing treatment groups at the time of follow-up, patients with primary RTSA had the highest Constant scores and similar Subjective Shoulder Value and Simple Shoulder Test scores compared with ORIF patients. Patients who underwent revision procedures had significantly lower Subjective Shoulder Value and Simple Shoulder Test scores, in addition to substantially lower Constant scores. Other than revision procedures, no risk factors for failure were identified; however, a trend toward an association between higher BMI

TABLE VII Comparison of Clinical Outcome Scores Between Patients Who Did and Did Not Undergo Revision*

Outcome	No Revision (N = 23)	Revision (N = 7)	P Value
SSV	64 ± 21	40 ± 20	0.014
SST	6.6 ± 3.8	2.8 ± 2	0.028
Adjusted CS	50 ± 24	31 ± 17	0.069

*Excluding the 3 patients who requested implant removal without an indication. The values are given as the mean and standard deviation. SSV = Subjective Shoulder Value, SST = Simple Shoulder Test, and CS = Constant score.

and clinical failure was observed. The number of days between fracture and intervention did not seem to have a significant influence on the outcome; however, most patients underwent procedures within a reasonable time frame, which might explain the contrast to the findings of Khmelnitskaya et al., who observed that intervention >2 weeks after injury is a risk factor for poor outcomes[6].

Other studies that focused on the factors influencing outcomes following surgical treatment of proximal humeral fractures have reported a correlation between varus angulation and poor outcome. Solberg et al. suggested a link between varus angulation of >20° and poor clinical outcomes, with significantly lower Constant scores in patients who underwent ORIF, and showed that an initial varus malreduction of >5° leads to progressive subsidence of the humeral head[23,24]. According to Tauber et al., varus malpositioning of >25° leads to a clinically relevant decrease in outcomes, with lower Constant scores compared with valgus malpositioning[25].

The known risk factors for ischemia as a pathomechanism for osteonecrosis of the humeral head include medial hinge displacement and short metaphyseal extension. Hertel et al. demonstrated that a calcar segment of <8 mm, a disrupted hinge, and the basic fracture pattern, looking at the location of the fracture line in relation to tuberosities, head, and shaft, represent a good predictor for humeral head ischemia[26]. Solberg et al. reported a significant correlation between a metaphyseal hinge of <2 mm and osteonecrosis[23], which we were not able to reproduce in the present study, possibly because head-split fractures could represent the most relevant risk factor for osteonecrosis and a poor clinical outcome. Although Hertel et al. did not find a significant correlation between a head-split component and ischemia[26], and although Gavaskar and Tummala showed that an isolated head-split fracture itself is not associated with an increased rate of ischemia, the latter study showed that a head-split fracture combined with tuberosity fracture does lead to a high rate of osteonecrosis[27].

One limitation of the present study is the relatively small cohort of patients available for analysis and the low follow-up rate; however, this specific fracture type is rare, and the achieved follow-up rate falls within the typical range of follow-up rates for elderly trauma patients. Overall, the imbalanced number of patients for treated with ORIF or arthroplasty and the differentiation between RTSA and hemiarthroplasty limited subgroup analysis. Other limitations include the likely presence of a selection bias, as many surgeons prefer to use ORIF (rather than arthroplasty) in younger, more active patients, and the lack of preoperative CT scans for detailed assessment of preoperative fracture characteristics in 47% of the patients. In particular, the lack of available CT scans did not allow us to retrospectively quantify the percentage of articular surface involvement. Although all available preoperative radiographs and CT scans were reevaluated in order to confirm the diagnosis of head-split fracture, a previous study has shown that even with available CT scans, there is poor interobserver reliability in identifying and categorizing head-split fractures[18]. Despite these limitations, the present study includes what is, to our knowledge, the largest cohort of patients with this rare pathology.

In conclusion, the surgical treatment of humeral head-split fractures is generally associated with a high rate of complications. Treatment with ORIF resulted in a high rate of complications (most notably osteonecrosis) and revision. Treatment with RTSA resulted in comparable clinical outcomes and complication rates; however, the observed complications were mostly related to tuberosity problems, which in this small series of patients did not require revision. Therefore, RTSA may be a viable treatment option for head-split fractures in elderly patients. ■

Paulina-Maria Peters[1]
Fabian Plachel, MD[1,2]
Victor Danzinger[1]
Michele Novi[3]
Sven Märdian, MD[1]
Markus Scheibel, MD[1,4]
Philipp Moroder, MD[1]

[1]Center for Musculoskeletal Surgery, Campus Virchow, Charité-Universitaetsmedizin Berlin, Berlin, Germany

[2]Institute of Tendon and Bone Regeneration, Paracelsus Medical University, Salzburg, Austria

[3]Azienda Ospedaliera Universitaria Pisana, Università di Pisa, Pisa, Italy

[4]Department of Shoulder and Elbow Surgery, Schulthess Clinic, Zurich, Switzerland

Email address for P.-M. Peters: paulina.peters@charite.de

ORCID iD for P.-M. Peters: 0000-0003-1850-703X
ORCID iD for F. Plachel: 0000-0002-3091-1556
ORCID iD for V. Danzinger: 0000-0003-1736-0259
ORCID iD for M. Novi: 0000-0003-4867-463X
ORCID iD for S. Märdian: 0000-0003-4220-2797
ORCID iD for M. Scheibel: 0000-0002-4485-0256
ORCID iD for P. Moroder: 0000-0003-4759-5390

References

1. Lind T, Krøner K, Jensen J. The epidemiology of fractures of the proximal humerus. Arch Orthop Trauma Surg. 1989;108(5):285-7.

2. Shrader MW, Sanchez-Sotelo J, Sperling JW, Rowland CM, Cofield RH. Understanding proximal humerus fractures: image analysis, classification, and treatment. J Shoulder Elbow Surg. 2005 Sep-Oct;14(5):497-505.

3. Panagopoulos A, Pantazis K, Iliopoulos I, Seferlis I, Kokkalis Z. Sword-like trauma to the shoulder with open head-splitting fracture of the head. Case Rep Orthop. 2016;2016:3539503. Epub 2016 Jul 5.

4. Tepass A, Rolauffs B, Weise K, Bahrs SD, Dietz K, Bahrs C. Complication rates and outcomes stratified by treatment modalities in proximal humeral fractures: a systematic literature review from 1970-2009. Patient Saf Surg. 2013 Nov 24;7(1):34.

5. Nowak LL, Dehghan N, McKee MD, Schemitsch EH. Plate fixation for management of humerus fractures. Injury. 2018 Jun;49(Suppl 1):S33-8.

6. Khmelnitskaya E, Lamont LE, Taylor SA, Lorich DG, Dines DM, Dines JS. Evaluation and management of proximal humerus fractures. Adv Orthop. 2012;2012: 861598. Epub 2012 Dec 18.

7. Spross C, Platz A, Erschbamer M, Lattmann T, Dietrich M. Surgical treatment of Neer Group VI proximal humeral fractures: retrospective comparison of PHILOS® and hemiarthroplasty. Clin Orthop Relat Res. 2012 Jul;470(7):2035-42. Epub 2011 Dec 13.

8. Greiwe RM, Vargas-Ariza R, Bigliani LU, Levine WN, Ahmad CS. Hemiarthroplasty for head-split fractures of the proximal humerus. Orthopedics. 2013 Jul;36(7): e905-11.

9. Gierer P, Simon C, Gradl G, Ewert A, Vasarhelyi A, Beck M, Mittlmeier T. [Complex proximal humerus fractures—management with a humeral head prosthesis? Clinical and radiological results of a prospective study]. Orthopade. 2006 Aug;35(8):834-40.

10. 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 Jan;22(1):32-7. Epub 2012 May 29.

11. Boileau P. Complications and revision of reverse total shoulder arthroplasty. Orthop Traumatol Surg Res. 2016 Feb;102(1)(Suppl):S33-43. Epub 2016 Feb 12.

12. Gilbart MK, Gerber C. Comparison of the subjective shoulder value and the Constant score. J Shoulder Elbow Surg. 2007 Nov-Dec;16(6):717-21.

13. Lippitt SB, Harryman DT, Matsen FA. A practical tool for evaluation of function: the Simple Shoulder Test. In: Matsen FA, Fu FH, Hawkins RJ, editors. The shoulder: a balance of mobility and stability. The American Academy of Orthopaedic Surgeons; 1993. p. 501-59.

14. Hsu JE, Russ SM, Somerson JS, Tang A, Warme WJ, Matsen FA 3rd. Is the Simple Shoulder Test a valid outcome instrument for shoulder arthroplasty? J Shoulder Elbow Surg. 2017 Oct;26(10):1693-700. Epub 2017 Jun 7.

15. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res. 1987 Jan;214:160-4.

16. Tavakkolizadeh A, Ghassemi A, Colegate-Stone T, Latif A, Sinha J. Gender-specific Constant score correction for age. Knee Surg Sports Traumatol Arthrosc. 2009 May;17(5):529-33. Epub 2009 Feb 28.

17. Booker S, Alfahad N, Scott M, Gooding B, Wallace WA. Use of scoring systems for assessing and reporting the outcome results from shoulder surgery and arthroplasty. World J Orthop. 2015 Mar 18;6(2):244-51.

18. Resch H, Tauber M, Neviaser RJ, Neviaser AS, Majed A, Halsey T, Hirzinger C, Al-Yassari G, Zyto K, Moroder P. Classification of proximal humeral fractures based on a pathomorphologic analysis. J Shoulder Elbow Surg. 2016 Mar;25(3):455-62. Epub 2015 Oct 23.

19. Scheibel M, Peters P, Moro F, Moroder P. Head-split fractures of the proximal humerus. Obere Extremität. 2019:14(2):93-102.

20. Brorson S, Rasmussen JV, Frich LH, Olsen BS, Hróbjartsson A. Benefits and harms of locking plate osteosynthesis in intraarticular (OTA Type C) fractures of the proximal humerus: a systematic review. Injury. 2012 Jul;43(7):999-1005. Epub 2011 Oct 2.

21. Jung SW, Shim SB, Kim HM, Lee JH, Lim HS. Factors that influence reduction loss in proximal humerus fracture surgery. J Orthop Trauma. 2015 Jun;29(6): 276-82.

22. Gerber C, Werner CM, Vienne P. Internal fixation of complex fractures of the proximal humerus. J Bone Joint Surg Br. 2004 Aug;86(6):848-55.

23. Solberg BD, Moon CN, Franco DP, Paiement GD. Surgical treatment of three and four-part proximal humeral fractures. J Bone Joint Surg Am. 2009 Jul;91(7): 1689-97.

24. Solberg BD, Moon CN, Franco DP, Paiement GD. Locked plating of 3- and 4-part proximal humerus fractures in older patients: the effect of initial fracture pattern on outcome. J Orthop Trauma. 2009 Feb;23(2):113-9.

25. Tauber M, Hirzinger C, Hoffelner T, Moroder P, Resch H. Midterm outcome and complications after minimally invasive treatment of displaced proximal humeral fractures in patients younger than 70 years using the Humerusblock. Injury. 2015 Oct;46(10):1914-20. Epub 2015 May 14.

26. Hertel R, Hempfing A, Stiehler M, Leunig M. Predictors of humeral head ischemia after intracapsular fracture of the proximal humerus. J Shoulder Elbow Surg. 2004 Jul-Aug;13(4):427-33.

27. Gavaskar AS, Tummala NC. Locked plate osteosynthesis of humeral head-splitting fractures in young adults. J Shoulder Elbow Surg. 2015 Jun;24(6):908-14. Epub 2014 Dec 1.