J Shoulder Elbow Surg (2019) 28, 1674–1684

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Complications after surgical treatment of proximal humerus fractures in the elderly—an analysis of complication patterns and risk factors for reverse shoulder arthroplasty and angular-stable plating

Alexander Klug, MD[a,*], Dennis Wincheringer, MD[a], Jasmin Harth, MS[b], Kay Schmidt-Horlohé, MD[c], Reinhard Hoffmann, MD[a], Yves Gramlich, MD[a]

[a]*Berufsgenossenschaftliche Unfallklinik Frankfurt am Main, Zentrum für Unfallchirurgie und orthopädische Chirurgie, Frankfurt am Main, Germany*
[b]*Johann Wolfgang Goethe-Universität Frankfurt am Main, Frankfurt am Main, Germany*
[c]*Orthopaedicum Wiesbaden—Praxis für Orthopädie, Unfallchirurgie und Sportmedizin, Zentrum für Ellenbogenchirurgie, Wiesbaden, Germany*

Background: To date, there is a lack of consensus regarding surgical treatment recommendations for complex proximal humerus fracture (PHF) patterns, especially between joint preservation and joint replacement techniques.
Methods: Between 2012 and 2017, 146 patients (aged 74.1 ± 8.0 years) with complex PHF were treated with locking plates (open reduction-internal fixation [ORIF]) or reverse total shoulder arthroplasty (RTSA). Complications and unplanned revision surgery were recorded in a mid-term follow-up. Potential patient and surgical risk factors for complications were extracted. Univariate and multivariate analyses were conducted.
Results: Follow-up data were available for 125 patients, 66 (52.8%) of whom were treated with locking plates, and 59 (41.2%) with RTSA. Both groups had comparable Charlson indices. The overall complication rate was 37.8% for ORIF and 22.0% for RTSA, with a revision rate of 12.1% and 5.1%, respectively, as driven primarily by persistent motion deficits. Multivariate analyses demonstrated no significant differences between the 2 procedures ($P = .500$). However, age was an independent protective factor against overall complications ($P = .018$). Risk factors for major complications in ORIF included osteoporosis, varus impaction fractures, posteromedial metaphyseal extensions <8 mm, head-shaft displacements >4 mm, and multifragmentary greater tuberosities. For RTSA, higher complication rates were seen in patients with higher Charlson indices, diabetes, or altered (greater) tuberosities. In contrast, Neer's classification system was not predictive in either group.

This study has been approved by the Ethical Committee of the Regional Medical Board of Hesse, Germany (under study ID: FF102/2017).

*Reprint requests: Alexander Klug, MD, Friedberger Landstraße 430, Frankfurt am Main 60389, Germany.
E-mail address: alexander.klug@bgu-frankfurt.de (A. Klug).

1058-2746/$ - see front matter
https://doi.org/10.1016/j.jse.2019.02.017

Conclusions: RTSA led to fewer complications than ORIF and thus can be considered a valuable option in complex PHF of the elderly. Paying attention to specific prognostic factors may help to reduce the complication rate.
Level of evidence: Level III; Retrospective Cohort Design; Treatment Study

Keywords: Proximal humerus fracture; complications; locking-plate; reverse shoulder arthroplasty; outcome; revision; elderly

Proximal humeral fractures account for approximately 6% of all adult fractures and are the third most common fracture seen in patients over 60 years of age.[12] According to Palvanen et al,[55] these numbers are expected to rise even more in the future, mainly as a result of an increase in osteoporotic fractures in the elderly. Almost 80% of these fractures are nondisplaced or minimally displaced and thus can successfully be treated nonoperatively.[20,32] Although the latest Cochrane review suggested a nonoperative approach even for patients with displaced fractures, the best treatment method for complex injuries (3- and 4-part fractures, dislocation-fractures, fractures with a head-split component), especially in the elderly, remains controversial.[9,17,29] If surgery is chosen, the surgeon has first to decide whether to fix or to replace the humeral head. Open reduction-internal fixation (ORIF) with locking plates preserves bone stock and the potential for anatomic healing, with complications including loss of reduction, screw cutout, intra-articular screw penetration, and avascular necrosis.[44,49,57,63] If reconstruction is not feasible, shoulder arthroplasty usually is the only surgical option. In recent years, there has been controversy as to which replacement method—hemiarthroplasty (HA) or reverse total shoulder arthroplasty (RTSA)—is the better treatment for proximal humeral fractures. However, RTSA seems to provide superior and more reliable functional results, facilitating a potentially more rapid recovery in the elderly.[45,65]

However, complications, such as scapular notching, hematoma, postoperative infection, glenoid loosening, and persistent instability, remain high and can be seen in up to 68% of the cases.[1-3,34]

To improve the preoperative decision making, the current study was designed to evaluate which surgical procedure (angular-stable plating or RTSA) leads to lower complication and revision rates, and to determine possible independent risk factors in an elderly population.

Methods

This is a retrospective study of the outcomes of surgical management of complex fractures of the proximal humerus in the elderly. Patients were selected by searching the clinic's patient management system (medico by Cerner Health Services GmbH, Idstein, Germany) of 1 level-I trauma center from 2011 to 2017 for all proximal humeral fractures, using the code S42.0 of the International Statistical Classification of Diseases and Related Health Problems, Tenth Edition. Data from all patients $\geq$60 years of age were analyzed, and those treated surgically by plate osteosynthesis or reverse shoulder prosthesis were identified. Ipsilateral injuries to the affected extremities were not exclusion criteria.

Plain radiographs and CT scans were reviewed by 2 orthopedic surgeons to identify 3- and 4-part fractures, head splits, and dislocation fractures defined by Neer for inclusion in the groups.[47] In addition, the status of each patient's metaphyseal medial hinge, tuberosities (single- or multifragmented), head-shaft angle, and displacement were evaluated.

The choice for the treatment method was based on individual criteria for every patient taking not only the actual age or fracture type, alone, but also a variety of different criteria, for example, biological age or functional demands of the patient into consideration.

All surgeries were performed by 1 of 4 experienced shoulder surgeons in a beach chair position under general anesthesia with preoperative single-shot antimicrobial prophylaxis using cefuroxime. A standard deltopectoral approach was used to enter the shoulder joint. The fracture was exposed, and the tuberosities were identified and grasped with No. 5 FiberWire sutures (Arthrex, Naples, FL, USA), if possible. The following implant systems were used: Reverse Shoulder Prosthesis (Delta Xtend, Depuy, Warsaw, IN, USA) (Fig. 1), the PHILOS-plate (Fa. Synthes, Umkirch, Germany) (Fig. 2), or the angular-stable Königsee plate system (Königsee Implantate GmbH, Allendorf, Germany). No statistical differences in outcome or complication rate were reported between these plate systems in a previous study at our institution.[40]

In case of RTSA, the glenoid was minimally reamed to conserve as much subchondral bone as possible. Then the glenoid baseplate was placed inferiorly on the glenoid with an inferior tilt to minimize scapular notching. After removal of the head fragments and preparation of the proximal humerus, a cemented stem was implanted at between 10° and 20° of retroversion to avoid tension on the greater tuberosity during internal rotation. Tension of the glenohumeral joint was considered ideal if the tip of the surgeon's fifth finger could pass between the trial glenosphere and the polyethylene. Finally, when possible, both tuberosities were reattached anatomically to the prosthesis and the humeral metaphysis with sutures. In case of ORIF, reduction was done under biplanar fluoroscopic control using temporary fixation with K-wires as needed. An angular stable plate was then chosen and positioned on the humeral bone so as to avoid impingement under the acromion. Screws were used as needed, including 2 inferomedial calcar screws. In all fractures, the tuberosities were reattached with additional FiberWire (Arthrex) cerclages knotted against the plate or additional screws in large

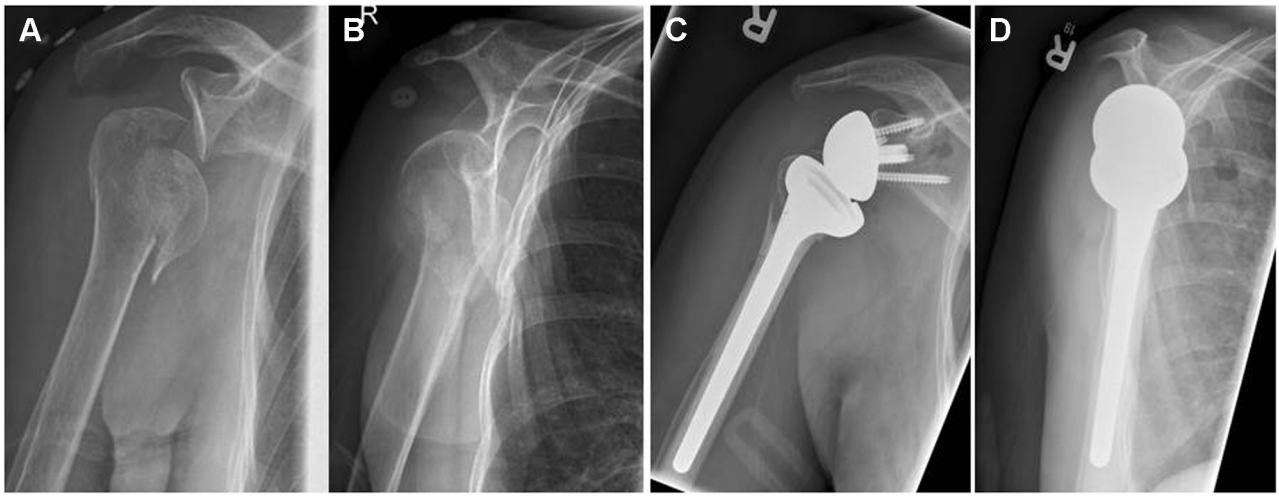

Figure 1 (**A**) Anteroposterior and (**B**) lateral radiograph of a 73-year-old man with a proximal humerus fracture after a fall from standing height. Because of the head-splitting aspect, the patient was treated with a reverse shoulder replacement as shown in the postoperative (**C**) anteroposterior and (**D**) lateral radiographs.

fragments. No bone grafts or cement augmentation was used to support the fixation.

Postoperatively, RTSA patients had to wear a protective sling and were treated with passive external and internal rotation and active-assisted elevation exercises for 6 weeks. ORIF patients began physiotherapy with active (without weight-bearing)/active-assisted and passive flexion/extension exercises on the first postoperative day for the first 6 weeks. No limitation in arc of motion was advised.

Depending on the radiographic findings after 6 weeks, patients were then allowed to increase weight-bearing to full load.

The medical records were reviewed for demographic characteristics, complications, and reoperations after at least 1 year of follow-up. The overall burden of comorbidities was compared between groups with the respective Charlson comorbidity indices. Complications were defined as adverse events directly related to the chosen treatment, and revision was defined as any subsequent surgical intervention related to the index procedure. We then differentiated between medical complications, such as pulmonary emboli or cardiac events, and operative complications that stemmed from the surgical site such as need for transfusions, wound complications, dislocations, avascular necrosis (AVN), or infections. According to Dindo et al,[16] surgical complications were graded as "minor" involving any deviation from the normal postoperative course requiring no secondary surgery, and "major" involving any event requiring pharmacologic treatment beyond 6 months or further surgical interventions. Persistent motor defects, defined as prolonged (>6 months) and painful active forward elevation (AFE) deficit <90°, were also classified as major complications.

All available radiographs were evaluated. In RTSA, implant position, inferior scapular notching, signs of loosening, and greater tuberosity healing were analyzed radiographically on standardized anteroposterior and axillary lateral radiographs at the final follow-up. Scapular notching was classified according to Sirveaux et al,[59] and humeral loosening was assessed with the method described by Sperling et al.[60]

For ORIF, follow-up radiographs were evaluated for successful union, loss of reduction and fixation, intra-articular screw perforation, AVN (graded according to Cruess[13]), and arthritic changes at the glenohumeral joint. Head-shaft alignment was graded as normal, varus (head-shaft angle <120°), or valgus malalignment (>150°). Loss of fixation was defined as a change in head-shaft angulation of >10° in the anteroposterior or lateral plane. Tuberosity malreduction was documented and classified as "insufficient," if displacement was more than 5 mm in any plane during follow-up.

The statistical analysis was performed using IBM software (SPSS version 21; IBM Corp., Armonk, NY, USA).

To determine the differences between ORIF and RTSA, categorical variables were compared using χ^2 or Fisher's exact tests. Continuous variables were compared using Mann-Whitney *U* tests, or Student's *t*-tests for normally distributed variables. Multivariate logistic regression analyses were performed to identify independent risk factors for complications and revision surgeries, with the type of procedure included as variables. For all tests, *P* values <.05 were considered to be significant.

Results

Between 2012 and 2017, 146 subjects met the inclusion criteria for this study, and a complete radiological and clinical data set including a follow-up period of at least 1 year was available for 125 cases, of whom 66 (45 females and 21 males) were treated by angular-stable plating (mean follow-up, 5.1 ± 1.9 years) and 59 (53 females and 6 males) by RTSA (mean follow-up, 3.5 ± 1.3 years). The average patient age was 74.1 years, with RTSA patients being older than the ORIF patients (Table I). The injury occurred on the dominant arm in 56% of the cases. In 115 subjects, the cause of the fracture was a fall or a low energy impact, and in 3 cases, the fractures resulted during polytraumatic events. No open fractures were reported.

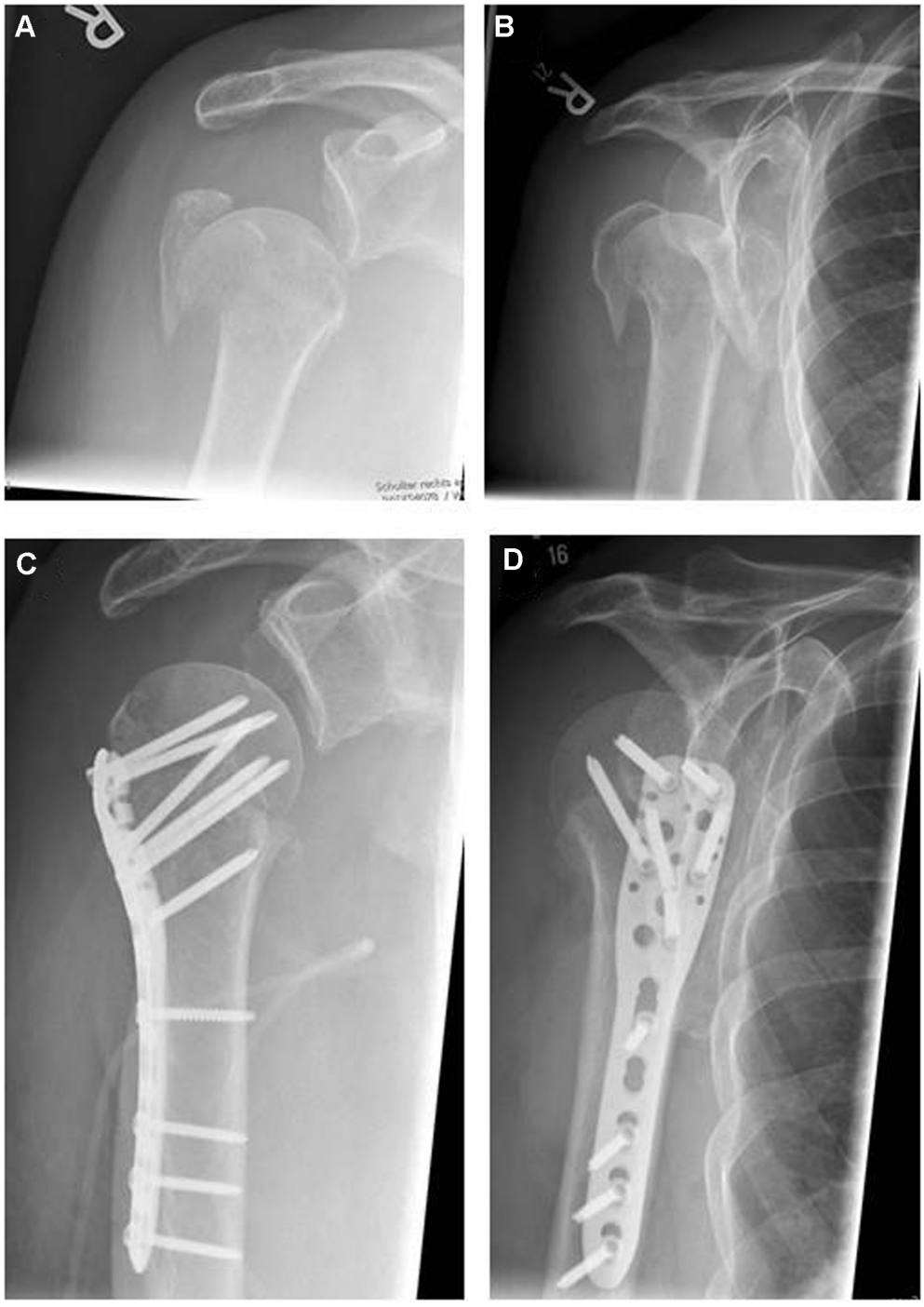

Figure 2 (**A**) Anteroposterior and (**B**) lateral radiograph of a76-year-old woman with a proximal humerus 4-part fracture after a bicycle accident. In this case, the proximal humerus was reconstructed using a PHILOS-plating system as shown in the postoperative (**C**) anteroposterior and (**D**) lateral radiographs.

All injuries were solitary lesions to the proximal humerus, but in 4 cases, a concomitant injury to the ipsilateral extremity (elbow, forearm) was seen.

According to Neer's classification system, 24 fractures were classified as 3-part (19.2%) and 73 (58.4%) were classified as 4-part fractures. A head split was seen in 25 cases (20%), and in 3 cases (2.4%), an anterior dislocation-fracture was apparent.

Both groups showed no significant differences in common comorbidities as well as in the Charlson index ($P = .208$).

The mean operation time was 140 $\pm$ 34 minutes for RTSA and 92 $\pm$ 31 minutes for ORIF.

Table I Study population and demographics

	RTSA	ORIF
N	59	66
Age, yr	77.4, SD 7.2	71.2, SD 7.4
Gender	45 F, 21 M	53 F, 6 M
NEER classification		
3-part	2	22
4-part	34	39
Head split	21	4
Dislocation fracture	2	1
Comorbidities		
Smoker	7	1
Diabetes	13	6
Osteoporosis	15	12
Malignoma	4	5
BMI, kg/m^2	30.1, SD 9.6	27.3, SD 6.5
Charlson index	1.44	0.98

RTSA, reverse total shoulder arthroplasty; *ORIF*, open reduction-internal fixation; *SD*, standard deviation; *BMI*, body mass index.

Reconstruction by locked plating

Postsurgical radiographic controls documented an anatomic reduction of the tuberosities and a correct restoration of the head-shaft angle (average, 135.4°; standard deviation, 9.7°) in all cases. During the follow-up period, a bony union was achieved in 65 of 66 patients with no signs of posttraumatic osteoarthritis on the final follow-up radiographs. However, superior migration of the greater tuberosity was documented in 4 cases, with 1 case of complete loss of fixation and a subsequent varus collapse during the first year.

Overall, we saw complications in approximately 37.8% of the cases, of which 12.1% required a surgical revision, including early hardware removal and arthrolysis. The primary cause of these complications was a persistent motion deficit seen in 25.8% of all patients and accounting for 62.5% of all revision procedures. Avascular necrosis of the humeral head (4 stage II, 2 stage III) was found in 6 cases (9%), 2 of which were revised for associated screw perforation. In 1 patient, a peri-implant infection with *Staphylococcus epidermidis* was successfully treated with a surgical débridement maintaining the hardware followed by a 4-week course. Because of a nonunion of the proximal humerus, a hemiarthroplasty was implanted in 1 patient, which had to be switched to a reverse prosthesis due to persistent motion deficit and subluxation of the prosthesis (Fig. 3). No axillary or radial nerve injuries were detected. Medical complications included pulmonary emboli in

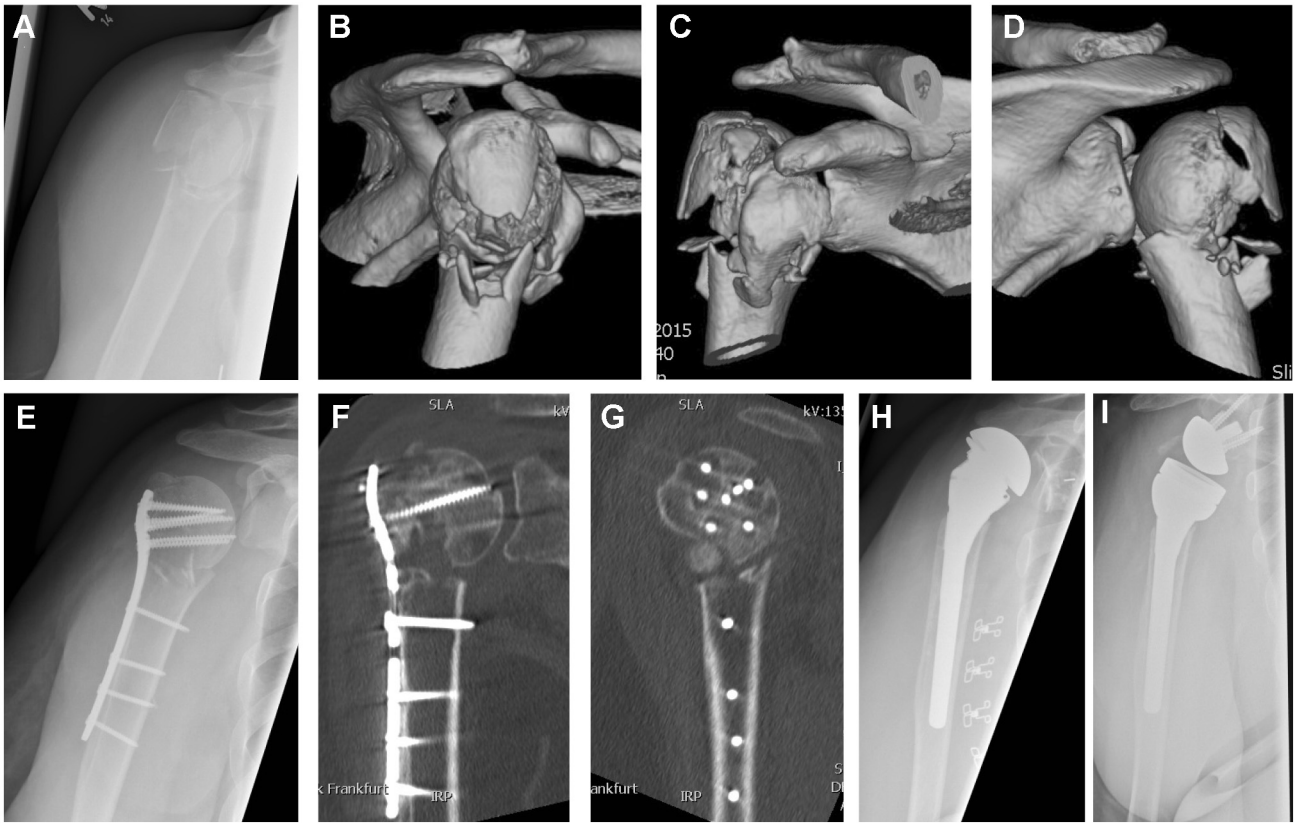

Figure 3 (**A**) Anteroposterior radiograph and (**B-D**) 3-dimensional computed tomography reconstruction of a 65-year-old woman (heavy smoker, body mass index: 54.7 kg/m^2, osteoporosis) with a 4-part fracture of the proximal humerus after a bicycle accident. (**E**) The fracture was initially fixed by a locking plate. However, a nonunion occurred after a follow-up of 8 months (**F, G**), leading to a revision surgery with implantation of a hemiarthroplasty. Unfortunately, because of subluxation of the prosthesis with persisting motion deficits (**H**), another revision surgery was performed after 3 months, including reverse shoulder arthroplasty (**I**).

2 cases (3%) and a postoperative anemia in 1 case. No perioperative blood transfusions were required.

In the multivariate regression model, several independent variables associated with negative outcomes could be identified (Supplementary Table S1), with varus impaction fractures being the greatest risk factor in this context. In addition, multifragmentary greater tuberosities, posteromedial metaphyseal extensions under 8 mm, preoperative head-shaft A-P displacement greater than 4 mm (distance measured in the sagittal plane), insufficiently reconstructed medial hinges, and osteoporosis were associated with significantly higher complication rates.

Replacement by RTSA

Major postoperative complications were reported in 13 cases (22.0%), of which 3 were treated by surgical revision (5%). These reoperations included open reduction for dislocation of RTSA, débridement and irrigation for infection, and open arthrolysis of adhesions for intractable stiffness. Persistent motion deficits and instability (n = 3) were seen in 15% of all cases (n = 9), and postoperative axillary nerve lesions were evident in 2 patients. During the follow-up period, no loosened glenoid baseplates or humeral stems were detected, although in 7 patients a discrete (grade I) scapular notching and in another 2 patients radiolucent areas occurred in zones 1 and 7. Furthermore, we documented 2 cases of a pulmonary embolism and 1 case of postoperative anemia requiring a blood transfusion.

The multivariate model revealed a higher risk for complications in patients with diabetes or a higher Charlson index, whereas, in contrast, increased age was associated with a decreased risk (Supplementary Table S2). Although not statistically significant, all patients with a body mass index (BMI) > 35 kg/m^2 had major or minor complications during the follow-up. Regarding surgical variables, the condition and healing of the tuberosities with (refixed-resected-resorbed) were directly associated with lower rates of motion deficits and instability. In contrast, the size of the metaglene was not correlated with a higher complication rate.

Comparison of RTSA vs. ORIF

After defining treatment-specific risk factors, we then ran a multivariate logistic regression analysis, containing age, gender, fracture classification, BMI, Charlson index, and the treatment method to determine independent risk factors for overall complications (Table ll), as well as whether the procedure type is an independent risk factor for complications. These analyses revealed that only the age ($P = .018$) can be considered as an independent risk factor. Gender ($P = .534$), BMI ($P = .646$), fracture type ($P = .870$), and procedure type ($P = .500$) were not statistically significant. This model explained 17.6% of the variance in the complication rate and correctly predicted the occurrence of complications in more than 70% of the cases.

Table II List of all complications for each surgical treatment method

Procedure	Complication	Number of patients	Percentage
ORIF		66	
	Motion deficits	17	25.8
	AVN	6	9.1
	Loss of fixation	4	6.1
	Screw cutout	2	3.0
	Infection	1	1.5
	Pulmonary embolism	2	3.0
	Postoperative anemia	1	1.5
RTSA		59	
	Motion deficits	9	15.3
	Instability	3	5.1
	Axillary nerve lesion	2	3.4
	Scapular notching	7	11.9
	Radiolucent lines (stem)	2	3.4
	Pulmonary embolism	2	3.4
	Postoperative anemia	1	1.5

ORIF, open reduction-internal fixation; *AVN*, avascular humeral head necrosis; *RTSA*, reverse total shoulder arthroplasty.

Discussion

The treatment of PHF in the elderly presents major challenges for the treating surgeon. Although no significant differences between surgical and nonoperative treatment have been reported in the recent literature,[29,51,52] there is still no consensus as to which patients will benefit from operative treatment.[28] Especially, complex fracture patterns regularly result in pain and loss of function,[17,53] an observation that has led many clinicians to consider 3- and 4-part fractures as indications for surgical management. In addition, there is some growing evidence that even after adjusting for age, gender, and comorbidities, surgical treatment of PHF is associated with significantly lower mortality rates.[5,56]

Surgical treatment options include ORIF, HA, and RTSA, but conflicting data exist on complication rates for these options.[14,26,46,62]

In our study, we analyzed the complication and revision rates of 125 consecutive elderly patients with a complex proximal humerus fracture undergoing surgical treatment either by locked plated osteosynthesis or by RTSA during 2011 and 2017 at a single-center institution. Although RTSA patients were substantially older and mostly female, the Charlson index between both groups showed no statistical difference.

Complications after ORIF

We identified postoperative shoulder stiffness and avascular humeral head necrosis as the 2 most common major complications after ORIF, with screw cut-out or complete loss of fixation described in only 3 cases. Similar complication rates have already been described by several authors.[6,23,27] However, unlike most previous studies, which reported a loss of fixation rate in up to 35%,[4,37,41,63] we saw only 1 secondary varus collapse during the observation period. We hypothesize that the reasons for this observation are multifactorial including improvements in the surgical technique with emphasis of the inferomedial calcar supporting screws,[22] treatment by shoulder specialists, increasing knowledge about potential factors for failure,[39] and the use of alternative techniques such as RTSA in more complex fracture patterns.

We identified several risk factors for complications including varus impaction, multifragmentary greater tuberosity, posteromedial metaphyseal extension under 8 mm, a preoperative head-shaft a-p displacement greater than 4 mm, and an insufficiently reconstructed medial hinge. These findings are consistent with the current literature. In a study of 252 patients, Jung et al[36] reported that a displaced varus fracture and a medial comminution were independent risk factors for reduction loss after PHF locking plate osteosynthesis. Hardeman et al[30] even reported the worst outcome in a significantly displaced varus articular fracture in the elderly. Although varus fractures were not associated with a loss of reduction in our study, we saw a higher number of complications, especially motion deficits, in these cases. A possible reason may be seen in the fact that varus deformity changes the pretension of the rotator cuff,[67] leading to decreased supraspinatus efficiency that ultimately requires significantly higher forces to achieve normal arm elevation. In addition, a multifragmentary greater tuberosity was found to negatively influence the complication rate. In 4 of these cases, we identified a secondary cranial tuberosity dislocation during the first 6 weeks after surgery, likely based on the difficulty of secure fixation with tuberosity comminution as has also been reported by Foruria et al.[19] Furthermore, we hypothesized that possible tuberosity resorption that may not be detected on radiographically can lead to tuberosity displacement.

In 2004, Hertel et al[31] reported a higher rate of humeral head ischemia in patients with a disrupted medial hinge and a posteromedial metaphyseal extension <8 mm, concluding that residual perfusion of the fractured head is dependent on the blood supply provided by the posterior circumflex vessels. Our results support these findings, as we also saw a higher rate of AVN in these cases. In addition, a head-shaft displacement >4 mm was found to be associated with a significantly higher complication rate, probably as a result of displacement-induced stripping of the periosteum (and vessels) around the anatomical neck. For this reason, special care has to be taken when restoring the functional anatomy of the humeral head and the medial hinge.

Interestingly, in contrast to prior studies,[7,30,35] the fracture type based on the Neer classification did not seem to interfere the results. This may be because of the proven low intra- and interobserver reliability of this classification system.[68]

Although several patient-derived risk factors (eg, age, smoking, steroid use, and diabetes) have been described in the recent literature,[6,49,61] we could only identify a correlation between osteoporosis and a higher surgical complication rate, which was attributed to a secondary loss of fixation during follow-up, as has been reported previously.[41,54,63]

Complications after RTSA

The most common complications were instability and intractable shoulder stiffness during follow-up, leading to an overall major complication rate of 22% and a revision rate of approximately 5%. These findings reflect the current literature, which reports complication rates ranging from 4.8% to 68% and revision rates mostly under 10%.[2,11,34,66] Depending on the classification of scapular notching, instability may be the most common complication after RTSA, with rates ranging from 2.4% to 31%.[8,11] In our study, instability was seen in one-third (n = 3) and scapular notching in 11.9% of all surgical complications. Our patients' advanced age and sedentary lifestyles as well as the short follow-up durations may explain the low frequency of scapular notching in our study. Furthermore, the clinical effects of notching remain controversial, as some authors report that notching does not affect range of motion (ROM) or functional scores, whereby other reports indicate that scapular notching could be an independent variable predictive of an adverse outcome and baseplate failure.[24,43,58]

Several patient-dependent variables for adverse outcomes after RTSA have been described in the literature. Farng et al[18] reported a higher 90-day complication rate after surgery for patients with high Charlson indexes or peripheral vascular disease. In addition, Jain et al[33] found that diabetes, hypertension, and obesity were predictors of increased postoperative complications in patients undergoing total hip, knee, or shoulder arthroplasty. Similarly, we found a significantly higher complication rate in this study for patients with higher Charlson indexes or diabetes. Furthermore, according to Gupta et al,[25] a BMI >35 kg/m leads to more complications in RTSA, presumably because of the added technical complexity and associated medical and surgical complications. Although not statistically significant, all of our patients with a BMI >35 kg/m^2 showed minor or major postoperative complications.

In contrast to that, our multivariate analysis revealed a protective effect of age on the complication rate in the RTSA group, confirming the report of Villacis

et al.[66] Similarly, Wagner et al[68] demonstrated a strong association between older age and decreased rates of revision surgery. In a study of 5494 consecutive patients undergoing TSA between 1970 and 2012, they demonstrated a 3% decrease in risk for revision surgery for every increase in 1 year of age. Because of a noticeable association with mechanical failure rates, the authors conjectured that the decreased functional demands of older patients would be a factor in this context.

Although union of the tuberosities and function of the rotator cuff are not as important in patients treated with RTSA, in contrast to hemiarthroplasty, we could demonstrate a significant reliance of the complication rate on the state of the tuberosities. We tried to reattach both tuberosities and can confirm that either resection (n = 14) or resorption (n = 7) of the greater tuberosity was associated with a higher risk of dislocation and prolonged motion deficits, consistent with the current literature. Gallinet et al[21] reported that anatomic fixation of the tuberosities over the prosthesis significantly improved rotational functions of the shoulder and can also lead to improved active anterior elevation as described by Grubhofer et al.24 In a recently published retrospective multicenter study of 420 elderly patients with a 4-part PHF, Ohl et al[50] concluded that anatomic healing of the greater tuberosity significantly improves active anterior elevation and external rotation, and its excision is associated with the worsened functional results and a high risk of postoperative shoulder instability. For this reason, some authors even advocate a graft augmentation of the tuberosities when performing RTSA in elderly patients.[64]

Comparison of RTSA vs. ORIF

To date, only few data exist regarding a comparison of ORIF and RTSA in the context of PHF. In a large systematic review of 92 studies, Gupta et al[26] reported the outcomes of more than 4500 patients with proximal humeral fractures after surgical management. Although ORIF and RTSA had a comparable rate of postoperative complications (15% for ORIF and 18% for RTSA), ORIF provided better functional results.[26] However, the revision rate was significantly higher for ORIF (13%) than for RTSA (5%), which is why the authors postulated that in patients older than 70 years, RTSA has the potential to be the most effective operative intervention.

In comparison, we detected higher overall major complication and revision rates for both procedures. However, in contrast to the previously mentioned study, we included only elderly patients with complex fracture types, who usually have a greater risk for postoperative complications and additionally classified persisting painful motion deficits as major complications, because of their high relevance for each patient. If motion deficits were excluded, the major complication rates decreased to 12.1% (ORIF) and 11.8% (RTSA), respectively.

In 2016, Cvetanovich et al[15] published the results of a national database study of 1791 patients with surgically treated PHF. Analyzing all medical complications within 30 days after surgery, they found that ORIF had a significantly lower complication rate (13.0%) than RTSA (23.2%), even after adjusting for several patient factors (age, gender, operative time, BMI, chronic obstructive pulmonary disease [COPD], American Society of Anaesthesiologists [ASA] class), primarily due to lower rates of blood transfusion. In their opinion, patient comorbidities, like a higher BMI, ASA class, or COPD, had a larger role than the procedures itself in predicting short-term complications. However, there were several limitations in this study, including the short follow-up period, the lack of fracture type classification or age group differentiation, and the focus on nonorthopedic specific complications. Similarly, our multivariate logistic regression analysis (age, gender, BMI, Charlson index, fracture type, surgical procedure) revealed that the type of procedure does not significantly affect the complication or revision rates after surgical treatment of a PHF, whereas only age was found to be an independent (protective) variable in this context.

In contrast to that, Neuhaus et al[48] presented a large US database (NHDS) study featuring more than 132,000 patients older than 65 years of age. Examining the medical adverse events after different treatment options, the authors found that ORIF is an independent risk factor for inpatient medical complications and mortality compared with TSA or nonoperative treatment. In addition, according to Zhang et al,[69] ORIF is also associated with a higher 90-day readmission rate (29%) from surgical complications than RTSA (20%). Although the authors reported that most readmissions were the result of medical complications, they presented significantly higher surgical complication rates for patients undergoing ORIF.[69] These were mainly associated with mechanical complications of the implant (ORIF) or instability (RTSA), which is consistent with the results of our study.

Although we did not assess functional outcomes in this study, some authors demonstrated that RTSA could also lead to better clinical results, especially in the elderly population.

In a matched-pair analysis, Chalmers et al[10] analyzed the outcomes of 27 patients with a displaced PHF treated either by RTSA, HA, or ORIF. They concluded that RTSA seems to provide a superior range of motion and more predictable functional outcomes than HA and ORIF. Likewise, we found persistent motion deficits in 10.2% of all RTSA and 28.7% of the ORIF patients, indicating that there could be a difference in function as well.

Our study has some limitations. Because we analyzed a number of consecutive patients with rather rare fracture entities at a single-center institution, our study population has some heterogeneity with respect to age and gender. Furthermore, the choice of the treatment method was not based on hard criteria, like actual age or fracture type, alone, as a variety of different criteria, for example, biological age

or functional demands of the patient may have influenced the surgeons' decision. In addition, we did not include functional scores, except for AFE <90°, in our results as our focus was solely on complication and revision rates in the context of predictive factors. However, several larger studies have confirmed that the inability to achieve AFE >90° may limit the patient's activities of daily living and could hamper independent living for some patients.[38,42] Although clinical and radiological follow-up did not differ in most of our patients, we did not routinely obtain radiographs in a few asymptomatic and low-risk patients (n = 11) after the first year to minimize their radiation exposure, which could have affected the rates of occult (minor) complications. Finally, the rate of late avascular necrosis of the humeral head as well as signs of humeral or glenoidal loosening in the RTSA patients may increase over time and thus have a significant effect on the outcome in the long-term.

Nevertheless, this study is one of only a few studies comparing the complication and revision rates of 2 concurrent surgical procedures for complex PHF in a population at risk.

Conclusions

Treating complex fractures of the proximal humerus in the elderly remains challenging. ORIF with locking plates and RTSA are 2 commonly used procedures, with no clear guidelines to justify the recommendation of one over the other yet.

In the present study, RTSA showed fewer complication and revision rates—although not statistically significant—compared with angular stable plating and it thus should be considered a viable option for treatment in these cases.

Careful analysis of the individual characteristics of the patients and fractures are necessary to minimize complications and revision rates. In older patients, knowledge of possible negative predictive factors becomes crucial for choosing between joint conservation and arthroplasty. As shown in our study, older patients with a varus impaction fracture, multi-fragmentary tuberosities, head-shaft displacement >4 mm, or osteoporosis may benefit from a primary RTSA.

Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jse.2019.02.017.

References

1. Abdelfattah A, Otto RJ, Simon P, Christmas KN, Tanner G, LaMartina J 2nd, et al. Classification of instability after reverse shoulder arthroplasty guides surgical management and outcomes. J Shoulder Elbow Surg 2018;27:e107-18. https://doi.org/10.1016/j.jse.2017.09.031
2. Acevedo DC, Vanbeek C, Lazarus MD, Williams GR, Abboud JA. Reverse shoulder arthroplasty for proximal humeral fractures: Update on indications, technique, and results. J Shoulder Elbow Surg 2014;23:279-89. https://doi.org/10.1016/j.jse.2013.10.003
3. Affonso J, Nicholson GP, Frankle MA, Walch G, Gerber C, Garzon-Muvdi J, et al. Complications of the reverse prosthesis: prevention and treatment. Instr Course Lect 2012;61:157-68.
4. Bahrs C, Kühle L, Blumenstock G, Stöckle U, Rolauffs B, Freude T. Which parameters affect medium- to long-term results after angular stable plate fixation for proximal humeral fractures? J Shoulder Elbow Surg 2015;24:727-32. https://doi.org/10.1016/j.jse.2014.08.009
5. Bell J-E, Cantu RV, Bynum JPW, Wang Q, Morgan T, Tosteson TD, et al. Mortality after proximal humerus fractures. J Shoulder Elbow Surg 2016;25:e174. https://doi.org/10.1016/j.jse.2015.11.031
6. Boesmueller S, Wech M, Gregori M, Domaszewski F, Bukaty A, Fialka C, et al. Risk factors for humeral head necrosis and non-union after plating in proximal humeral fractures. Injury 2016;47:350-5. https://doi.org/10.1016/j.injury.2015.10.001
7. Bonnevialle N, Tournier C, Clavert P, Ohl X, Sirveaux F, Saragaglia D. Hemiarthroplasty versus reverse shoulder arthroplasty in 4-part displaced fractures of the proximal humerus: multicenter retrospective study. Orthop Traumatol Surg Res 2016;102:569-73. https://doi.org/10.1016/j.otsr.2016.02.014
8. Bufquin T, Hersan A, Hubert L, Massin P. Reverse shoulder arthroplasty for the treatment of three- and four-part fractures of the proximal humerus in the elderly. J Bone Joint Surg Br 2007;89-B:516-20. https://doi.org/10.1302/0301-620X.89B4.18435
9. Cazeneuve JF, Cristofari D-J. The reverse shoulder prosthesis in the treatment of fractures of the proximal humerus in the elderly. J Bone Joint Surg Br 2010;92:535-9. https://doi.org/10.1302/0301-620X.92B4.22450
10. Chalmers PN, Slikker W 3rd, Mall NA, Gupta AK, Rahman Z, Enriquez D, et al. Reverse total shoulder arthroplasty for acute proximal humeral fracture: comparison to open reduction-internal fixation and hemiarthroplasty. J Shoulder Elbow Surg 2014;23:197-204. https://doi.org/10.1016/j.jse.2013.07.044
11. Cheung E, Willis M, Walker M, Clark R, Frankle MA. Complications in reverse total shoulder arthroplasty. J Am Acad Orthop Surg 2011;19:439-49.
12. Court-Brown CM, Garg A, McQueen MM. The epidemiology of proximal humeral fractures. Acta Orthop Scand 2001;72:365-71. https://doi.org/10.1080/000164701753542023
13. Cruess RL. Corticosteroid-induced osteonecrosis of the humeral head. Orthop Clin North Am 1985;16:789-96.
14. Cuff DJ, Pupello DR. Comparison of hemiarthroplasty and reverse shoulder arthroplasty for the treatment of proximal humeral fractures in elderly patients. J Bone Joint Surg Am 2013;95:2050-5. https://doi.org/10.2106/JBJS.L.01637
15. Cvetanovich GL, Chalmers PN, Verma NN, Nicholson GP, Romeo AA. Open reduction internal fixation has fewer short-term complications than shoulder arthroplasty for proximal humeral

fractures. J Shoulder Elbow Surg 2016;25:624-31.e3. https://doi.org/10.1016/j.jse.2015.09.011
16. Dindo D, Demartines N, Clavien P-A. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. Ann Surg 2004;240:205-13. https://doi.org/10.1097/01.sla.0000133083.54934.ae
17. Du S, Ye J, Chen H, Li X, Lin Q. Interventions for treating 3- or 4-part proximal humeral fractures in elderly patient: a network meta-analysis of randomized controlled trials. Int J Surg 2017;48:240-6. https://doi.org/10.1016/j.ijsu.2017.09.002
18. Farng E, Zingmond D, Krenek L, SooHoo NF. Factors predicting complication rates after primary shoulder arthroplasty. J Shoulder Elbow Surg 2011;20:557-63. https://doi.org/10.1016/j.jse.2010.11.005
19. Foruria AM, de Gracia MM, Larson DR, Munuera L, Sanchez-Sotelo J. The pattern of the fracture and displacement of the fragments predict the outcome in proximal humeral fractures. J Bone Joint Surg Br 2011;93:378-86. https://doi.org/10.1302/0301-620X.93B3.25083
20. Gaebler C, McQueen MM, Court-Brown CM. Minimally displaced proximal humeral fractures: epidemiology and outcome in 507 cases. Acta Orthop Scand 2003;74:580-5. https://doi.org/10.1080/00016470310017992
21. Gallinet D, Adam A, Gasse N, Rochet S, Obert L. Improvement in shoulder rotation in complex shoulder fractures treated by reverse shoulder arthroplasty. J Shoulder Elbow Surg 2013;22:38-44. https://doi.org/10.1016/j.jse.2012.03.011
22. Gardner MJ, Weil Y, Barker JU, Kelly BT, Helfet DL, Lorich DG. The importance of medial support in locked plating of proximal humerus fractures. J Orthop Trauma 2007;21:185-91. https://doi.org/10.1097/BOT.0b013e3180333094
23. Gomberawalla MM, Miller BS, Coale RM, Bedi A, Gagnier JJ. Meta-analysis of joint preservation versus arthroplasty for the treatment of displaced 3- and 4-part fractures of the proximal humerus. Injury 2013;44:1532-9. https://doi.org/10.1016/j.injury.2013.03.030
24. Grubhofer F, Wieser K, Meyer DC, Catanzaro S, Beeler S, Riede U, et al. Reverse total shoulder arthroplasty for acute head-splitting, 3- and 4-part fractures of the proximal humerus in the elderly. J Shoulder Elbow Surg 2016;25:1690-8. https://doi.org/10.1016/j.jse.2016.02.024
25. Gupta AK, Chalmers PN, Rahman Z, Bruce B, Harris JD, McCormick F, et al. Reverse total shoulder arthroplasty in patients of varying body mass index. J Shoulder Elbow Surg 2014;23:35-42. https://doi.org/10.1016/j.jse.2013.07.043
26. Gupta AK, Harris JD, Erickson BJ, Abrams GD, Bruce B, McCormick F, et al. Surgical management of complex proximal humerus fractures—a systematic review of 92 studies including 4500 patients. J Orthop Trauma 2015;29:54-9. https://doi.org/10.1097/BOT.0000000000000229
27. Haasters F, Siebenbürger G, Helfen T, Daferner M, Böcker W, Ockert B. Complications of locked plating for proximal humeral fractures—are we getting any better? J Shoulder Elbow Surg 2016;25:e295-303. https://doi.org/10.1016/j.jse.2016.02.015
28. Hageman MGJS, Jayakumar P, King JD, Guitton TG, Doornberg JN, Ring D. The factors influencing the decision making of operative treatment for proximal humeral fractures. J Shoulder Elbow Surg 2015;24:e21-6. https://doi.org/10.1016/j.jse.2014.05.013
29. Handoll HHG, Brorson S. Interventions for treating proximal humeral fractures in adults. Cochrane Database Syst Rev 2015;11:CD000434. https://doi.org/10.1002/14651858.CD000434.pub4
30. 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;43:153-8. https://doi.org/10.1016/j.injury.2011.04.003
31. 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;13:427-33. https://doi.org/10.1016/j.jse.2004.01.034
32. Iyengar JJ, Devcic Z, Sproul RC, Feeley BT. Nonoperative treatment of proximal humerus fractures: a systematic review. J Orthop Trauma 2011;25:612-7. https://doi.org/10.1097/BOT.0b013e3182008df8
33. Jain NB, Guller U, Pietrobon R, Bond TK, Higgins LD. Comorbidities increase complication rates in patients having arthroplasty. Clin Orthop Relat Res 2005;435:232-8.
34. Jiang JJ, Toor AS, Shi LL, Koh JL. Analysis of perioperative complications in patients after total shoulder arthroplasty and reverse total shoulder arthroplasty. J Shoulder Elbow Surg 2014;23:1852-9. https://doi.org/10.1016/j.jse.2014.04.008
35. Jost B, Spross C, Grehn H, Gerber C. Locking plate fixation of fractures of the proximal humerus: analysis of complications, revision strategies and outcome. J Shoulder Elbow Surg 2013;22:542-9. https://doi.org/10.1016/j.jse.2012.06.008
36. Jung S-W, Shim S-B, Kim H-M, Lee J-H, Lim H-S. Factors that influence reduction loss in proximal humerus fracture surgery. J Orthop Trauma 2015;29:276-82. https://doi.org/10.1097/BOT.0000000000000252
37. Kralinger F, Blauth M, Goldhahn J, Käch K, Voigt C, Platz A, et al. The influence of local bone density on the outcome of one hundred and fifty proximal humeral fractures treated with a locking plate. J Bone Joint Surg Am 2014;96:1026-32. https://doi.org/10.2106/JBJS.M.00028
38. Kralinger F, Schwaiger R, Wambacher M, Farrell E, Menth-Chiari W, Lajtai G, et al. Outcome after primary hemiarthroplasty for fracture of the head of the humerus. A retrospective multicentre study of 167 patients. J Bone Joint Surg Br 2004;86:217-9.
39. Krappinger D, Bizzotto N, Riedmann S, Kammerlander C, Hengg C, Kralinger FS. Predicting failure after surgical fixation of proximal humerus fractures. Injury 2011;42:1283-8. https://doi.org/10.1016/j.injury.2011.01.017
40. Kuhlmann T, Hofmann T, Seibert O, Gundlach G, Schmidt-Horlohé K, Hoffmann R. Vergleich Philos- vs. Königseeplattenosteosynthese bei der operativen versorgung von 4-fragment-frakturen des proximalen humerus bei über 65-jährigen patienten. Z Orthop Unfall 2012;150:149-55. https://doi.org/10.1055/s-0031-1280365 [in German].
41. Lee C-W, Shin S-J. Prognostic factors for unstable proximal humeral fractures treated with locking-plate fixation. J Shoulder Elbow Surg 2009;18:83-8. https://doi.org/10.1016/j.jse.2008.06.014
42. Lenarz C, Shishani Y, McCrum C, Nowinski RJ, Edwards TB, Gobezie R. Is reverse shoulder arthroplasty appropriate for the treatment of fractures in the older patient? Early observations. Clin Orthop Relat Res 2011;469:3324-31. https://doi.org/10.1007/s11999-011-2055-z
43. Lévigne C, Boileau P, Favard L, Garaud P, Molé D, Sirveaux F, et al. Scapular notching in reverse shoulder arthroplasty. J Shoulder Elbow Surg 2008;17:925-35. https://doi.org/10.1016/j.jse.2008.02.010
44. Martetschläger F, Siebenlist S, Weier M, Sandmann G, Ahrens P, Braun K, et al. Plating of proximal humeral fractures. Orthopedics 2012;35:e1606-12. https://doi.org/10.3928/01477447-20121023-17
45. Mata-Fink A, Meinke M, Jones C, Kim B, Bell J-E. Reverse shoulder arthroplasty for treatment of proximal humeral fractures in older adults: a systematic review. J Shoulder Elbow Surg 2013;22:1737-48. https://doi.org/10.1016/j.jse.2013.08.021
46. Namdari S, Horneff JG, Baldwin K. Comparison of hemiarthroplasty and reverse arthroplasty for treatment of proximal humeral fractures: a systematic review. J Bone Joint Surg Am 2013;95:1701-8. https://doi.org/10.2106/JBJS.L.01115
47. Neer CS. Displaced proximal humeral fractures. Part I. Classification and evaluation. By Charles S. Neer, I, 1970. Clin Orthop Relat Res 1987:3-10.
48. Neuhaus V, Bot AGJ, Swellengrebel CHJ, Jain NB, Warner JJP, Ring DC. Treatment choice affects inpatient adverse events and mortality in older aged inpatients with an isolated fracture of the proximal humerus. J Shoulder Elbow Surg 2014;23:800-6. https://doi.org/10.1016/j.jse.2013.09.006

49. Ockert B, Siebenbürger G, Kettler M, Braunstein V, Mutschler W. Long-term functional outcomes (median 10 years) after locked plating for displaced fractures of the proximal humerus. J Shoulder Elbow Surg 2014;23:1223-31. https://doi.org/10.1016/j.jse.2013.11.009
50. Ohl X, Bonnevialle N, Gallinet D, Ramdane N, Valenti P, Decroocq L, et al. How the greater tuberosity affects clinical outcomes after reverse shoulder arthroplasty for proximal humeral fractures. J Shoulder Elbow Surg 2018;27:2139-44. https://doi.org/10.1016/j.jse.2018.05.030
51. Olerud P, Ahrengart L, Ponzer S, Saving J, Tidermark J. Hemiarthroplasty versus nonoperative treatment of displaced 4-part proximal humeral fractures in elderly patients: a randomized controlled trial. J Shoulder Elbow Surg 2011;20:1025-33. https://doi.org/10.1016/j.jse.2011.04.016
52. Olerud P, Ahrengart L, Ponzer S, Saving J, Tidermark J. Internal fixation versus nonoperative treatment of displaced 3-part proximal humeral fractures in elderly patients: a randomized controlled trial. J Shoulder Elbow Surg 2011;20:747-55. https://doi.org/10.1016/j.jse.2010.12.018
53. Ong C, Bechtel C, Walsh M, Zuckerman JD, Egol KA. Three- and four-part fractures have poorer function than one-part proximal humerus fractures. Clin Orthop Relat Res 2011;469:3292-9. https://doi.org/10.1007/s11999-011-1864-4
54. Owsley KC, Gorczyca JT. Fracture displacement and screw cutout after open reduction and locked plate fixation of proximal humeral fractures corrected. J Bone Joint Surg Am 2008;90:233-40. https://doi.org/10.2106/JBJS.F.01351
55. Palvanen M, Kannus P, Niemi S, Parkkari J. Update in the epidemiology of proximal humeral fractures. Clin Orthop Relat Res 2006;442:87-92.
56. Rotman D, Giladi O, Senderey AB, Dallich A, Dolkart O, Kadar A, et al. Mortality after complex displaced proximal humerus fractures in elderly patients: conservative versus operative treatment with reverse total shoulder arthroplasty. Geriatr Orthop Surg Rehabil 2018;9. https://doi.org/10.1177/2151459318795241. 2151459318795241.
57. Schliemann B, Siemoneit J, Theisen C, Kösters C, Weimann A, Raschke MJ. Complex fractures of the proximal humerus in the elderly—outcome and complications after locking plate fixation. Musculoskelet Surg 2012;96(Suppl 1):S3-11. https://doi.org/10.1007/s12306-012-0181-8
58. Simovitch RW, Zumstein MA, Lohri E, Helmy N, Gerber C. Predictors of scapular notching in patients managed with the Delta III reverse total shoulder replacement. J Bone Joint Surg Am 2007;89:588-600. https://doi.org/10.2106/JBJS.F.00226
59. Sirveaux F, Favard L, Oudet D, Huquet D, Walch G, Molé D. Grammont inverted total shoulder arthroplasty in the treatment of glenohumeral osteoarthritis with massive rupture of the cuff. Results of a multicentre study of 80 shoulders. J Bone Joint Surg Br 2004;86:388-95.
60. Sperling JW, Cofield RH, O'Driscoll SW, Torchia ME, Rowland CM. Radiographic assessment of ingrowth total shoulder arthroplasty. J Shoulder Elbow Surg 2000;9:507-13.
61. Spross C, Platz A, Rufibach K, Lattmann T, Forberger J, Dietrich M. The PHILOS plate for proximal humeral fractures—risk factors for complications at one year. J Trauma Acute Care Surg 2012;72:783-92. https://doi.org/10.1097/TA.0b013e31822c1b5b
62. Sproul RC, Iyengar JJ, Devcic Z, Feeley BT. A systematic review of locking plate fixation of proximal humerus fractures. Injury 2011;42:408-13. https://doi.org/10.1016/j.injury.2010.11.058
63. Südkamp N, Bayer J, Hepp P, Voigt C, Oestern H, Kääb M, et al. Open reduction and internal fixation of proximal humeral fractures with use of the locking proximal humerus plate. Results of a prospective, multicenter, observational study. J Bone Joint Surg Am 2009;91:1320-8. https://doi.org/10.2106/JBJS.H.00006
64. Uzer G, Yildiz F, Batar S, Binlaksar R, Elmadag M, Kus G, et al. Does grafting of the tuberosities improve the functional outcomes of proximal humeral fractures treated with reverse shoulder arthroplasty? J Shoulder Elbow Surg 2017;26:36-41. https://doi.org/10.1016/j.jse.2016.05.005
65. van der Merwe M, Boyle MJ, Frampton CMA, Ball CM. Reverse shoulder arthroplasty compared with hemiarthroplasty in the treatment of acute proximal humeral fractures. J Shoulder Elbow Surg 2017;26:1539-45. https://doi.org/10.1016/j.jse.2017.02.005
66. Villacis D, Sivasundaram L, Pannell WC, Heckmann N, Omid R, Hatch GF III. Complication rate and implant survival for reverse shoulder arthroplasty versus total shoulder arthroplasty: results during the initial 2 years. J Shoulder Elbow Surg 2016;25:927-35. https://doi.org/10.1016/j.jse.2015.10.012
67. Voigt C, Kreienborg S, Megatli O, Schulz A-P, Lill H, Hurschler C. How does a varus deformity of the humeral head affect elevation forces and shoulder function? A biomechanical study with human shoulder specimens. J Orthop Trauma 2011;25:399-405. https://doi.org/10.1097/BOT.0b013e31820beb80
68. Wagner ER, Houdek MT, Schleck CD, Harmsen WS, Sánchez-Sotelo J, Cofield R, et al. The role age plays in the outcomes and complications of shoulder arthroplasty. J Shoulder Elbow Surg 2017;26:1573-80. https://doi.org/10.1016/j.jse.2017.01.020
69. Zhang AL, Schairer WW, Feeley BT. Hospital readmissions after surgical treatment of proximal humerus fractures: is arthroplasty safer than open reduction internal fixation? Clin Orthop Relat Res 2014;472:2317-24. https://doi.org/10.1007/s11999-014-3613-y