J Shoulder Elbow Surg (2020) 29, 1796–1803

ELSEVIER

Journal of Shoulder and Elbow Surgery

www.elsevier.com/locate/ymse

Surgical treatment of complex proximal humeral fractures in elderly patients: a matched-pair analysis of angular-stable plating vs. reverse shoulder arthroplasty

Alexander Klug, MD*, Jasmin Harth, MS, Reinhard Hoffmann, MD, Yves Gramlich, MD

Berufsgenossenschaftliche Unfallklinik Frankfurt am Main, Zentrum für Unfallchirurgie und Orthopädische Chirurgie, Frankfurt am Main, Germany

Background: To date, there is a lack of consensus regarding the type of surgical treatment for complex proximal humeral fractures (PHFs) in elderly patients, especially between joint preservation and joint replacement techniques.

Materials and methods: We matched 60 patients (aged 73.2 ± 6.4 years) with complex PHFs in terms of sex, age, and Charlson Comorbidity Index, who underwent locking-plate open reduction–internal fixation (ORIF) or reverse shoulder arthroplasty (RSA) (2011-2017). Postoperative range of motion and functional outcome were assessed using the American Shoulder and Elbow Surgeons shoulder score, Oxford Shoulder Score, Constant-Murley score, and Disabilities of the Arm, Shoulder and Hand score at a mean follow-up of 49 months (ORIF group) and 38 months (RSA group). Complications and unplanned revision surgery were recorded, and all radiographs were analyzed.

Results: ORIF resulted in numerically, although not statistically significantly, greater mean shoulder motion vs. RSA. Significantly better outcome was reported for the Oxford Shoulder Score ($P = .034$) and Disabilities of the Arm, Shoulder and Hand score ($P = .026$) in the ORIF group, although no significant differences were observed in the American Shoulder and Elbow Surgeons shoulder score and Constant-Murley score. The complication rate (30% vs. 10%) and revision rate (20% vs. 3%) were significantly higher in the ORIF group ($P = .028$), with patients who had complications or required revision having worse functional results.

Conclusion: Favorable results are achievable through both angular-stable plating and RSA. Although ORIF may be associated with a superior functional outcome, exceeding the minimal clinically important difference, RSA was linked to significantly fewer complications and revisions.

Level of evidence: Level III; Retrospective Cohort Comparison; Treatment Study

Keywords: Proximal humeral fracture; locking plate; reverse shoulder arthroplasty; outcome; revision; elderly

Proximal humeral fractures (PHFs) are among the most common fractures in adults, and they represent the third most common fracture in patients older than 60 years.[9] Because of the close association of PHFs with osteoporosis, their number is expected to increase further in the future.[45] Although nonsurgical treatment is a reasonable

The study was approved by the Ethical Committee of the Regional Medical Board of Hesse, Germany (under study identification no. FF102/2017).

*Reprint requests: Alexander Klug, MD, Berufsgenossenschaftliche Unfallklinik Frankfurt am Main, Zentrum für Unfallchirurgie und Orthopädische Chirurgie, Friedberger Landstraße 430, 60389 Frankfurt am Main, Germany.

E-mail address: alexander.klug@bgu-frankfurt.de (A. Klug).

1058-2746/$ - see front matter
https://doi.org/10.1016/j.jse.2020.01.073

option for most of these fractures,[13,21] the best treatment method for complex injuries (ie, 3- and 4-part fractures, dislocation-fractures, and fractures with a head-splitting component), especially in elderly patients, remains controversial.[32] Whereas some studies indicated that surgical treatment might be associated with a favorable outcome[43] and lower mortality rate,[49] most recent studies have failed to find any benefit of surgical treatment in PHFs.[34,47] However, an increasing interest in surgical intervention has developed since the introduction of angular-stable implants[4] and the recent use of reverse shoulder arthroplasty (RSA) for fracture treatment.[5]

To date, limited data are available regarding the comparison of different treatment options, especially between open reduction–internal fixation (ORIF) and RSA, in the context of PHF.[11,19,38,65] 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.[35,39,51,59] RSA, on the other hand, seems to provide good and reliable functional results, facilitating a potentially more rapid recovery in elderly patients.[36,62]

However, complications such as scapular notching, hematoma, postoperative infection, glenoid loosening, and persistent instability continue to show high rates and can be seen in up to 68% of the cases.[1-3,26,46] This study was designed to evaluate which surgical procedure (ie, angular-stable plating or RSA) leads to a more favorable functional and clinical outcome and is associated with lower complication and revision rates in an elderly population. The purpose of the study was to compare the 2 options. Our primary hypothesis was that RSA would provide better functional results than ORIF in complex fracture patterns (independent of fracture type).

Materials and methods

This was a retrospective comparative study of the outcomes of surgical management of complex PHFs in elderly patients. The study was conducted in a single level I trauma center from 2011 to 2017. All patients aged 65 years or older and treated surgically by either plate osteosynthesis or a reverse shoulder prosthesis were identified and selected through the patient management system of the clinic (medico; Cerner Health Services, Idstein, Germany).

Plain radiographs and computed tomography scans were reviewed by 2 orthopedic surgeons to identify 3- and 4-part fractures, with or without head splitting, and/or dislocation-fractures (as defined by Neer) for inclusion in the groups.[37] All patients with an acute, complex PHF, according to the aforementioned fracture patterns, and immediate surgical treatment were included. Patients with delayed (>14 days from injury) or secondary surgical treatment (including initial nonoperative treatment) were excluded. The choice of treatment method was based on the individual criteria for each patient (ie, actual age or fracture type) and a variety of different criteria (ie, biological age or functional demands of the patient) but ultimately remained the surgeon's choice.

All surgical procedures were performed by 1 of 4 experienced shoulder surgeons with the patient in the beach-chair position under general anesthesia with preoperative single-shot antimicrobial prophylaxis. 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, depending on the surgeon's choice: Reverse Shoulder Prosthesis (Delta Xtend; DePuy Synthes, Umkirch, Germany), PHILOS plate (DePuy Synthes), or angular-stable Königsee plate system (Königsee Implantate, Allendorf, Germany). In a previous study performed at our institution, no statistically significant differences were reported in outcomes or complication rates between these 2 plate systems.[30]

In RSA patients, the glenoid baseplate was placed inferiorly on the glenoid with an inferior tilt to minimize scapular notching. After removal of the head fragments, a cemented stem was implanted at between 10° and 20° of retroversion. 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 ORIF patients, reduction was performed under biplanar fluoroscopic control using temporary fixation with K-wires, as required. An angular-stable plate was subsequently selected and positioned on the humeral bone 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 cerclage stitches knotted against the plate or additional screws in large fragments. Bone grafts or cement augmentation was not used to support the fixation.

Postoperatively, patients who underwent RSA wore a protective sling in neutral rotation to avoid secondary avulsion or tuberosity nonunion, and were treated with passive external and internal rotation and active-assisted elevation exercises for 6 weeks. Patients who underwent ORIF initiated physiotherapy with active (without weight bearing) or active-assisted and passive flexion-extension exercises on the first postoperative day and continued for 6 weeks. No limitation in the arc of motion was advised. Depending on the radiographic findings after 6 weeks, patients were subsequently allowed to increase weight bearing to full load.

After a minimum follow-up period of 1 year, the patients were clinically evaluated by an independent experienced orthopedic surgeon. The range of motion (ROM) of both shoulder joints was tested using a standard goniometer. Postoperative functional outcome was assessed using the German-language version of the American Shoulder and Elbow Surgeons (ASES) shoulder score[18]; the German-language version of the Oxford Shoulder Score (OSS; range, 0-48)[22]; the Constant-Murley score[8]; and the German-language Disabilities of the Arm, Shoulder and Hand (DASH) questionnaire (range, 0-100, with 0 representing a perfectly functioning arm).[40]

All available radiographs were evaluated. In RSA patients, implant position, inferior scapular notching, signs of loosening, and greater tuberosity healing were radiographically analyzed on standardized anteroposterior and axillary lateral radiographs at the final follow-up. Scapular notching was classified according to

Sirveaux et al,[55] and humeral loosening was assessed with the method described by Sperling et al.[57] In ORIF patients, follow-up radiographs were evaluated for successful union, loss of reduction and fixation, intra-articular screw perforation, avascular necrosis (graded according to Cruess[10]), and arthritic changes at the glenohumeral joint. Loss of fixation was defined as a change in head-shaft angulation greater than 10° in the anteroposterior or lateral plane. 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. Post-traumatic shoulder stiffness—defined as a prolonged (>6 months) and painful active forward elevation and external rotation deficit in the absence of a radiologic correlate—was also classified as a complication because of its high relevance for each patient, as previously described.[28,48]

For better comparability, we matched each patient who underwent shoulder arthroplasty with a patient who underwent angular-stable plating. Patients were matched by sex, age at the time of the operation (±2 years), and the respective age-related Charlson Comorbidity Index. If all 3 parameters were matched by more than 2 controls, we used the control with a date of birth closest to that of the case.[14] To calculate the sample size, we used the primary outcomes of the OSS (range, 0-48 points) and ASES score (range, 0-100). A medium effect size was used, and the minimal clinically important difference (MCID) was determined to equal 6.4 points for the ASES score and 5.1 points for the OSS.[56,61] The level of significance (α) equaled .05. Given a power of 0.80 (β), the number of patients required in each group was 21. Because of a predicted loss of included patients during follow-up, we aimed to find at least 30 matched patients for each group.

Statistical analysis was performed using SPSS software (version 25.0; IBM, Armonk, NY, USA). Continuous variables were compared using the paired Wilcoxon signed rank test or paired Student *t* test for normally distributed variables to determine the differences between ORIF and RSA. For all tests, $P < .05$ denoted a statistically significant difference. In addition, we compared our outcome variables based on the MCID as reported in the literature,[12,31,50,54,56,61] which has been increasingly used to evaluate treatment effectiveness in recent years. Simple linear regression analyses were performed to identify independent risk factors for complications and revision surgery for each treatment method.

Results

A total of 112 patients older than 65 years with complex PHFs were identified, with 84 patients returning for follow-up. Of those, 30 matched pairs were included in this analysis based on the aforementioned criteria (Table I). The average follow-up period was 49 months (range, 12-83 months) in the ORIF group and 38 months (range, 12-50 months) in the RSA group.

In the ORIF group, postsurgical radiographic controls documented anatomic reduction of the tuberosities and correct restoration of the head-shaft angle (average, 138.1°; range, 120°-155°) in all cases. During the follow-up period, bony union was achieved in all patients, without signs of post-traumatic osteoarthritis observed on the final follow-up radiographs. However, secondary cranialization of the greater tuberosity was documented in 3 cases, with 1 case demonstrating complete loss of fixation and subsequent varus collapse during the first year. The most frequent complication in the plating group was post-traumatic shoulder stiffness (n = 6), followed by avascular necrosis (n = 2, stage II), and secondary perforation of the head screws into the glenohumeral joint (n = 1). In 1 patient, a peri-implant infection was successfully treated with surgical débridement maintaining the hardware, followed by a 4-week antibiotic course.

In the RSA group, the 3 complications observed were a postoperative lesion to the axillary nerve; a recurrent dislocation of the prosthesis; and a postoperative infection that was successfully treated with local débridement and administration of oral antibiotics. However, resorption of the greater tuberosity was apparent in 6 patients. No signs of humeral loosening were observed in any of the patients at the time of last radiographic follow-up. However, moderate scapular notching (grade II) was evident in 2 patients.

Overall, the clinical and radiographic rate of complications was markedly higher in the ORIF group than in the RSA group at last follow-up. Complication rates were 30% (10 of 30 patients) in the plate group and 10% (3 of 30 patients) in the RSA group (relative risk, 3.3; $P = .028$).

In addition, a higher number of revision surgical procedures, including early hardware removal and arthrolysis, were performed in the ORIF group vs. the RSA group, leading to revision rates of 20% (n = 6) vs. 3% (n = 1) (relative risk, 6.0; $P = .045$). None of the patients who underwent ORIF required conversion to secondary prosthesis during follow-up.

At the final follow-up, patients who underwent ORIF had numerically greater mean shoulder motion in all directions than patients who underwent RSA (Table II). Furthermore, functional outcomes tended to be better in patients who underwent reconstruction vs. those who underwent joint replacement, as all outcome variables exceeded the MCID. However, statistical significance was only detected in the OSS and DASH score (Table II). For further analysis, we conducted a subanalysis of 2 main score domains (pain and activities of daily living [ADL]) of each outcome instrument. Although pain showed no difference between both procedure types in all outcome variables, patients with RSA reached significantly reduced scores for ADL.

Overall, neither the different fracture subtypes (ie, 3- and 4-part and head-splitting fractures) nor a higher Charlson Comorbidity Index significantly affected the functional outcome within each treatment group or between both procedures. However, in the RSA group, status of the greater tuberosity on the latest radiographic examination had a significant influence on the result. Patients showed significantly greater motion in abduction and external rotation when the greater tuberosity was still present (Table III).

Although different patient-specific parameters (ie, diabetes, body mass index, osteoporosis, and smoking) did not affect the clinical outcome in patients who underwent RSA,

Table I Study population and demographic characteristics

	RSA	ORIF	*P* value
n	30	30	
Age (SD), yr	73.9 (6.7)	72.5 (6.3)	.50
Sex: F/M, n	25/5	25/5	
Neer classification, n			
3-Part fracture	1	10	
4-Part fracture	17	18	
Head-splitting fracture	12	2	
Comorbidities, n			
Smoking	5	5	>.99
Diabetes	7	1	.02
Osteoporosis	9	11	.58
Pathologic fracture	2	3	.64
BMI (SD), kg/m^2	30.3 (9.5)	26.1 (4.0)	.08
Charlson Comorbidity Index (SD)	3.5 (0.9)	3.3 (1.2)	.77

RSA, reverse shoulder arthroplasty; *ORIF*, open reduction–internal fixation; *SD*, standard deviation; *BMI*, body mass index.

osteoporosis seemed to be associated with an inferior outcome ($P < .001$ for DASH score) in the ORIF group. Moreover, less favorable outcomes were noted in patients with complications after both procedures, whereas the negative effect of follow-up complications on final functional outcome was greater for ORIF patients (Table IV).

Discussion

PHFs in elderly patients represent an increasingly prevalent injury based on recent trend analyses.[27] Emerging data on nonoperative treatment have sparked a debate regarding the optimal treatment of this injury in elderly patients.[24,25] Although no significant differences between surgical and nonoperative treatment have been reported in the recent literature,[21,42,43] there is no consensus regarding the subset of patients who would benefit from operative treatment.[20,64] Notably, complex fracture patterns regularly result in pain and loss of function,[13,44] which has led numerous clinicians to consider 3- and 4-part fractures as indications for surgical management, even in elderly patients.[7,17,29] Surgical treatment options include ORIF, hemiarthroplasty (HA), and RSA. There is growing evidence that RSA provides superior and more reliable functional results, potentially facilitating a more rapid recovery in elderly patients, compared with HA.[36,62] However, there are almost no data regarding the comparison of locked plating and RSA. In our study, ORIF tended to provide a better functional outcome, as evidenced by higher clinical scores and ROM, which exceeded the MCID. However, these advantages did not reach statistical significance for some outcome variables (ASES and Constant scores), which could be associated with the properties of these outcome instruments. On the basis of the current literature, each instrument has a limited amount of evidence to support its use in shoulder trauma populations.

Currently, psychometric evaluations in isolated shoulder fracture populations are almost completely missing, and clinicians must remember that an instrument's properties are defined for the population tested.[56] Pain and ADL are 2 commonly reported score domains of most outcome scores, with the percentage contribution to the final score markedly differing between the outcome instruments. However, there is growing evidence that in particular, psychosocial factors may play an important role in affecting patient outcomes after total shoulder arthroplasty.[60] Within our 4 outcome scores tested, the ASES and Constant scores both have the lowest ADL percentage reported,[56] which has to be considered when interpreting our data. However, the possible benefits of a better functional outcome were offset by significantly higher complication and revision rates in the ORIF group.

These findings are consistent with those reported in the current literature. In a large systematic review of 92 studies, Gupta et al[19] reported the outcomes of more than 4500 patients with PHFs following surgical management. Although ORIF provided better functional results (ie, DASH and Constant-Murley scores), the revision rate was significantly higher for ORIF (13%) than for RSA (5%). Although their hypothesis that RSA would lead to the best overall outcome was not confirmed, Gupta et al postulated that in patients older than 70 years, RSA has the potential to be the most effective operative intervention, as also reported by Chalmers et al,[6] who analyzed the outcomes of 27 age- and sex-matched patients with a displaced PHF treated with either RSA, HA, or ORIF. They concluded that RSA provided superior ROM and more predictable functional outcomes than HA or ORIF. In this context, we could detect a higher complication rate associated with plating of the proximal humerus compared with RSA; the functional outcome seems to be more favorable, though. However, especially in elderly patients, rates of complications and revision surgery should be kept as low as possible in our opinion.[58] Still, good to

Table II Comparison of final outcome variables between angular-stable plating (ORIF) and RSA

	RSA (SD)	ORIF (SD)	Δ (SD)	*P* value
Anteversion, °	133 (45)	146 (31)	13 (54)*	.232
Abduction, °	118 (55)	135 (39)	17 (68)*	.206
Internal rotation, °	79 (15)	85 (13)	6 (17)	.060
External rotation, °	39 (25)	52 (23)	13 (39)*	.082
ASES score	74.6 (21.6)	83.4 (15.8)	8.8 (27.2)*	.156
OSS	37.7 (10.3)	42.8 (5.7)	5.1 (11.8)*	.034†
Constant score	69.9 (26.0)	81.4 (17.2)	11.5 (31.3)*	.067
DASH score	25.3 (20.0)	14.3 (14.7)	−11.0 (24.6)*	.026†

ORIF, open reduction–internal fixation; *RSA*, reverse shoulder arthroplasty; *SD*, standard deviation; *ASES*, American Shoulder and Elbow Surgeons; *OSS*, Oxford Shoulder Score; *DASH*, Disabilities of the Arm, Shoulder and Hand.
* Exceeding minimal clinically important difference.
† Statistically significant ($P < .05$).

Table III Influence of greater tuberosity status on outcome after reverse shoulder arthroplasty

Outcome variable	Tuberosity status (0, non-existing; 1, existing)	n	Average	SD	*P* value
ASES score	1	14	76.5	23.1	.654
	0	16	72.9	20.7	
DASH score	1	14	22.7	20.6	.514
	0	16	27.6	19.7	
OSS	1	14	38.0	11.1	.897
	0	16	37.5	9.9	
CMS	1	14	70.4	29.3	.931
	0	16	69.5	23.9	
Anteversion	1	14	133.9°	49.5°	.932
	0	16	132.5°	41.9°	
Abduction	1	14	127.1°	55.5°	.041*
	0	16	110.0°	54.5°	
Internal rotation	1	14	80.4°	17.6°	.741
	0	16	78.4°	13.9°	
External rotation	1	14	30.4°	22.7°	.047*
	0	16	15.9°	26.8°	

SD, standard deviation; *ASES*, American Shoulder and Elbow Surgeons; *OSS*, Oxford Shoulder Score; *CMS*, Constant-Murley score.
* Statistically significant ($P < .05$).

excellent outcomes with relatively low complication rates may be achieved through locking-plate osteosynthesis, even in elderly patients, following careful patient selection.[20,48] Especially in patients with a varus impaction fracture, disruption of the medial hinge, multifragmentary tuberosities, head-shaft displacement greater than 4 mm, or osteoporosis, plate fixation may lead to a higher complication rate,[28] which is associated with a less favorable outcome as confirmed in our study population. Furthermore, surgeons must be aware that the postoperative result after plate osteosynthesis requires a skill set based on a learning curve and is dependent on the quality of fracture reduction.[53] Südkamp et al[59] reported a 34% complication rate in their ORIF group. Of these complications, 40% were associated with an incorrect surgical technique. In addition, several technical advancements, such as medial calcar screws, cement augmentation,[52] or fibular allografts,[33] have been shown to improve the individual outcome, providing better humeral head support and maintenance of reduction while possibly reducing the incidence of complications associated with fixation using a locking plate alone.

In contrast, outcome following RSA appeared to be more predictable and independent of the initial fracture pattern. Moreover, status of the rotator cuff, which regularly shows asymptomatic degenerative changes in elderly individuals,[63] is expected to be less important in postoperative shoulder function than in ORIF or HA. As shown in our study, good functional scores and ROM with low complication rates may be achieved even in complex fractures in elderly patients, without significant differences in most outcome variables compared with patients who underwent ORIF. However, clinical results tend to deteriorate following the resection or resorption of the tuberosities during follow-up.[15] In our study, patients who underwent tuberosity reattachment showed significantly better ROM in abduction and external rotation, although the functional scores did not differ, matching the findings of previous studies.[41] Even after failed osteosynthetic repair, RSA is reported to improve outcomes and pain, although patients should be aware of a less favorable result compared with primary RSA and the possibility of major complications after this technically demanding procedure.[16,23]

This study had several limitations, mainly owing to its retrospective nonrandomized design. Despite age, sex, and comorbidity matching, bias is likely to be present between the study cohorts that could contribute to differences between the groups. We speculated that there may be surgeon bias in choosing a certain treatment method because this choice is usually not based on hard criteria (ie, actual age or fracture type) alone, as a variety of different criteria (eg, biological age or functional demands of the patient) were taken into consideration. This problem has been previously described.[32] Accordingly, the classification of fracture

Table IV Outcome variables for patients with and without follow-up complications

	Follow-up complications		*P* value
	Yes	No	
ORIF			
N	10	20	
ASES score (SD)	74.8 (13.9)	87.8 (15.2)	.031*
OSS (SD)	40.1 (4.8)	44.1 (5.8)	.071
Constant score (SD)	73.0 (17.8)	73.0 (17.8)	.057
DASH score (SD)	20.7 (10.6)	11.1 (15.6)	.092
RSA			
n	3	27	
ASES score (SD)	69.4 (20.8)	75.2 (21.2)	.372
OSS (SD)	37.0 (5.9)	37.8 (10.5)	.436
Constant score (SD)	54.0 (29.6)	71.7 (24.5)	.249
DASH score (SD)	27.6 (14.9)	25.1 (20.1)	.417

ORIF, open reduction–internal fixation; *ASES*, American Shoulder and Elbow Surgeons; *SD*, standard deviation; *OSS*, Oxford Shoulder Score; *DASH*, Disabilities of the Arm, Shoulder and Hand; *RSA*, reverse shoulder arthroplasty.
* Statistically significant ($P < .05$).

subtypes had no influence on the final outcome of each procedure in our study. We also could not match every patient according to specific fracture patterns, as our ''primary'' matching was made in terms of sex, age at the time of the operation, and the respective age-related Charlson Comorbidity Index as the so-called patient-specific criteria. Therefore, some heterogeneity regarding the chosen treatment procedure, such as a higher rate of RSA in head-splitting fractures, has to be acknowledged. Still, more than half of our patients also showed respective fracture-pattern matching.

We also did not have preinjury functional data available, which could have improved cohort matching and minimized confounders of our results. All patients presented with acute fractures and were included consecutively; thus, it was not possible to obtain a preinjury data point. Furthermore, we did not routinely obtain dual-energy x-ray absorptiometry scans to detect osteoporosis in all of our patients, which might explain the relatively low number of osteoporotic fractures in our patient cohort. Finally, the rate of late-onset complications (eg, late avascular necrosis of the humeral head and signs of humeral or glenoid loosening of RSA) may increase over time, exerting a significant effect on the outcomes and complication rate in the long term. Nevertheless, this study is one of only a few comparing the functional outcomes of 2 most common surgical procedures for complex PHF in a population at risk.

Conclusion

The treatment of PHFs in elderly patients is challenging, and the optimal surgical option remains controversial. Favorable results may be achieved through both angular-stable plating and RSA, although the findings of this study suggest higher functional outcome scores and ROM for angular-stable plating. The complication and revision rates were significantly higher in these patients, regularly leading to inferior results. Although it appears justifiable to perform osteosynthetic repair of complex PHFs in specific elderly patients, surgeons have to be aware of the associated limitations, which may regularly result in inferior outcomes. Therefore, RSA may be the more predictable treatment option in these patients.

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.

References

1. Abdelfattah A, Otto RJ, Simon P, Christmas KN, Tanner G, LaMartina J, 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. Bell J-E, Leung BC, Spratt KF, Koval KJ, Weinstein JD, Goodman DC, et al. Trends and variation in incidence, surgical treatment, and repeat surgery of proximal humeral fractures in the

elderly. J Bone Joint Surg Am 2011;93:121-31. https://doi.org/10.2106/JBJS.I.01505
5. 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: a prospective review of 43 cases with a short-term follow-up. J Bone Joint Surg Br 2007;89:516-20. https://doi.org/10.1302/0301-620X.89B4.18435
6. Chalmers PN, Slikker W, 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
7. Chivot M, Lami D, Bizzozero P, Galland A, Argenson J-N. Three- and four-part displaced proximal humeral fractures in patients older than 70 years: reverse shoulder arthroplasty or nonsurgical treatment? J Shoulder Elbow Surg 2019;28:252-9. https://doi.org/10.1016/j.jse.2018.07.019
8. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res 1987:160-4.
9. Court-Brown CM, Caesar B. Epidemiology of adult fractures: a review. Injury 2006;37:691-7. https://doi.org/10.1016/j.injury.2006.04.130
10. Cruess RL. Corticosteroid-induced osteonecrosis of the humeral head. Orthop Clin North Am 1985;16:789-96.
11. 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
12. Dabija DI, Jain NB. Minimal clinically important difference of shoulder outcome measures and diagnoses: a systematic review. Am J Phys Med Rehabil 2019;98:671-6. https://doi.org/10.1097/PHM.0000000000001169
13. 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
14. Fernández-Cortiñas AB, Vidal Campos J, Paredes-Carnero X, Marco Martinez F. Is the Charlson comorbidity index a good predictor of mortality and adverse effects in proximal humerus fractures? Orthop Traumatol Surg Res 2019;105:301-5. https://doi.org/10.1016/j.otsr.2018.11.016
15. 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
16. García-Fernández C, Lopiz Y, Rizo B, Serrano-Mateo L, Alcobía-Díaz B, Rodríguez-González A, et al. Reverse total shoulder arthroplasty for the treatment of failed fixation in proximal humeral fractures. Injury 2018;49(Suppl 2):S22-6. https://doi.org/10.1016/j.injury.2018.06.042
17. Goch AM, Christiano A, Konda SR, Leucht P, Egol KA. Operative repair of proximal humerus fractures in septuagenarians and octogenarians: does chronologic age matter? J Clin Orthop Trauma 2017;8:50-3. https://doi.org/10.1016/j.jcot.2017.01.006
18. Goldhahn J, Angst F, Drerup S, Pap G, Simmen BR, Mannion AF. Lessons learned during the cross-cultural adaptation of the American Shoulder and Elbow Surgeons shoulder form into German. J Shoulder Elbow Surg 2008;17:248-54. https://doi.org/10.1016/j.jse.2007.06.027
19. 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
20. 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
21. Handoll HHG, Brorson S. Interventions for treating proximal humeral fractures in adults. Cochrane Database Syst Rev 2015:CD000434. https://doi.org/10.1002/14651858.CD000434.pub4
22. Huber W, Hofstaetter JG, Hanslik-Schnabel B, Posch M, Wurnig C. The German version of the Oxford Shoulder Score—cross-cultural adaptation and validation. Arch Orthop Trauma Surg 2004;124:531-6. https://doi.org/10.1007/s00402-004-0716-z
23. Hussey MM, Hussey SE, Mighell MA. Reverse shoulder arthroplasty as a salvage procedure after failed internal fixation of fractures of the proximal humerus: outcomes and complications. Bone Joint J 2015;97-B:967-72. https://doi.org/10.1302/0301-620X.97B7.35713
24. 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
25. Jia Z, Li W, Qin Y, Li H, Wang D, Zhang C, et al. Operative versus nonoperative treatment for complex proximal humeral fractures: a meta-analysis of randomized controlled trials. Orthopedics 2014;37:e543-51. https://doi.org/10.3928/01477447-20140528-54
26. 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
27. Klug A, Gramlich Y, Wincheringer D, Schmidt-Horlohé K, Hoffmann R. Trends in surgical management of proximal humeral fractures in adults: a nationwide study of records in Germany from 2007 to 2016. Arch Orthop Trauma Surg 2019;139:1713-21. https://doi.org/10.1007/s00402-019-03252-1
28. Klug A, Wincheringer D, Harth J, Schmidt-Horlohé K, Hoffmann R, Gramlich Y. 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. J Shoulder Elbow Surg 2019;28:1674-84. https://doi.org/10.1016/j.jse.2019.02.017
29. de Kruijf M, Vroemen JPAM, de Leur K, van der Voort EAM, Vos DI, van der Laan L. Proximal fractures of the humerus in patients older than 75 years of age: should we consider operative treatment? J Orthop Traumatol 2014;15:111-5. https://doi.org/10.1007/s10195-013-0273-8
30. 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. [Operative treatment of proximal humeral four-part fractures in elderly patients: comparison of two angular-stable implant systems]. Z Orthop Unfall 2012;150:149-55 [in German]. https://doi.org/10.1055/s-0031-1280365
31. Kukkonen J, Kauko T, Vahlberg T, Joukainen A, Äärimaa V. Investigating minimal clinically important difference for Constant score in patients undergoing rotator cuff surgery. J Shoulder Elbow Surg 2013;22:1650-5. https://doi.org/10.1016/j.jse.2013.05.002
32. LaMartina J, Christmas KN, Simon P, Streit JJ, Allert JW, Clark J, et al. Difficulty in decision making in the treatment of displaced proximal humerus fractures: the effect of uncertainty on surgical outcomes. J Shoulder Elbow Surg 2018;27:470-7. https://doi.org/10.1016/j.jse.2017.09.033
33. Lee SH, Han SS, Yoo BM, Kim JW. Outcomes of locking plate fixation with fibular allograft augmentation for proximal humeral fractures in osteoporotic patients. Bone Joint J 2019;101-B:260-5. https://doi.org/10.1302/0301-620X.101B3.BJJ-2018-0802.R1
34. Lopiz Y, Alcobía-Díaz B, Galán-Olleros M, García-Fernández C, Picado AL, Marco F. Reverse shoulder arthroplasty versus nonoperative treatment for 3- or 4-part proximal humeral fractures in elderly patients: a prospective randomized controlled trial. J Shoulder Elbow Surg 2019;28:2259-71. https://doi.org/10.1016/j.jse.2019.06.024

35. 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
36. 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
37. Neer CS. Displaced proximal humeral fractures. Part I. Classification and evaluation. By Charles S. Neer, I, 1970. Clin Orthop Relat Res 1987:3-10.
38. 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
39. 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
40. Offenbächer M, Ewert T, Sangha O, Stucki G. Validation of a German version of the 'Disabilities of Arm, Shoulder and Hand' questionnaire (DASH-G). Z Rheumatol 2003;62:168-77. https://doi.org/10.1007/s00393-003-0461-7
41. 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
42. 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
43. 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
44. 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
45. Palvanen M, Kannus P, Niemi S, Parkkari J. Update in the epidemiology of proximal humeral fractures. Clin Orthop Relat Res 2006;442:87-92. https://doi.org/10.1097/01.blo.0000194672.79634.78
46. Peters P-M, Plachel F, Danzinger V, Novi M, Märdian S, Scheibel M, et al. Clinical and radiographic outcomes after surgical treatment of proximal humeral fractures with head-split component. J Bone Joint Surg Am 2020;102:68-75. https://doi.org/10.2106/JBJS.19.00320
47. Roberson TA, Granade CM, Hunt Q, Griscom JT, Adams KJ, Momaya AM, et al. Nonoperative management versus reverse shoulder arthroplasty for treatment of 3- and 4-part proximal humeral fractures in older adults. J Shoulder Elbow Surg 2017;26:1017-22. https://doi.org/10.1016/j.jse.2016.10.013
48. Robinson CM, Stirling PHC, Goudie EB, MacDonald DJ, Strelzow JA. Complications and long-term outcomes of open reduction and plate fixation of proximal humeral fractures. J Bone Joint Surg Am 2019;101:2129-39. https://doi.org/10.2106/JBJS.19.00595
49. 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;9:2151459318795241. https://doi.org/10.1177/2151459318795241.
50. Roy J-S, MacDermid JC, Woodhouse LJ. Measuring shoulder function: a systematic review of four questionnaires. Arthritis Rheum 2009;61:623-32. https://doi.org/10.1002/art.24396
51. 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
52. Schliemann B, Wähnert D, Theisen C, Herbort M, Kösters C, Raschke MJ, et al. How to enhance the stability of locking plate fixation of proximal humerus fractures? An overview of current biomechanical and clinical data. Injury 2015;46:1207-14. https://doi.org/10.1016/j.injury.2015.04.020
53. Schnetzke M, Bockmeyer J, Porschke F, Studier-Fischer S, Grützner P-A, Guehring T. Quality of reduction influences outcome after locked-plate fixation of proximal humeral type-C fractures. J Bone Joint Surg Am 2016;98:1777-85. https://doi.org/10.2106/JBJS.16.00112
54. Simovitch R, Flurin P-H, Wright T, Zuckerman JD, Roche CP. Quantifying success after total shoulder arthroplasty: the minimal clinically important difference. J Shoulder Elbow Surg 2018;27:298-305. https://doi.org/10.1016/j.jse.2017.09.013
55. 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. https://doi.org/10.1302/0301-620x.86b3.14024
56. Slobogean GP, Slobogean BL. Measuring shoulder injury function: common scales and checklists. Injury 2011;42:248-52. https://doi.org/10.1016/j.injury.2010.11.046
57. 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.
58. 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
59. 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
60. Vajapey SP, Cvetanovich GL, Bishop JY, Neviaser AS. Psychosocial factors affecting outcomes after shoulder arthroplasty: a systematic review. [Epub ahead of print] J Shoulder Elbow Surg 2019. https://doi.org/10.1016/j.jse.2019.09.043
61. van de Water ATM, Shields N, Davidson M, Evans M, Taylor NF. Reliability and validity of shoulder function outcome measures in people with a proximal humeral fracture. Disabil Rehabil 2014;36:1072-9. https://doi.org/10.3109/09638288.2013.829529
62. 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
63. Yamaguchi K, Ditsios K, Middleton WD, Hildebolt CF, Galatz LM, Teefey SA. The demographic and morphological features of rotator cuff disease. A comparison of asymptomatic and symptomatic shoulders. J Bone Joint Surg Am 2006;88:1699-704. https://doi.org/10.2106/JBJS.E.00835
64. Yang T-C, Su Y-P, Chang M-C. The elderly have similar outcomes compared to younger patients after ORIF with locking plate for comminuted proximal humerus fracture. Acta Orthop Traumatol Turc 2019;53:1-5. https://doi.org/10.1016/j.aott.2018.12.001
65. 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