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ORIGINAL PAPER

Long-term outcomes of shoulder hemiarthroplasty for acute proximal humeral fractures

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Abstract

Purpose Shoulder hemiarthroplasty (HA) is now rarely indicated for complex proximal humeral fractures due to its unpredictable characteristic of the greater tuberosity (GT) healing. Despite the increasing popularity of reverse shoulder arthroplasty (RSA) in fracture treatment, there are still concerns about failure revision and its application in young populations. The complete negation of HA for fracture treatment is still under debate.

Methods Eighty-seven out of 135 patients with acute proximal humeral fractures treated with HA were enrolled. Clinical and radiographic evaluations were performed.

Results With a mean follow-up time of 14.7 years, the 10-year prosthetic survival rate was 96.6%. The mean ASES score and Constant score were 79.3 and 81.3, respectively, the mean VAS was 1.1, the average forward flexion was 125.9°, external rotation was 37.2°, and internal rotation was at the L4 level. Nineteen patients (21.8%) displayed GT complications and showed significantly worse outcomes. Glenoid erosion was observed in 64.9% of the patients and resulted in inferior outcomes. The patients who showed good postoperative two year functional outcomes and good acromiohumeral distances usually maintained their results without deterioration over time.

Conclusions With strict patient selection, a proper surgical technique and closely supervised postoperative rehabilitation, HA could achieve a 96.6% ten year survival rate and good pain relief at an average follow-up of 15 years. Although rarely indicated, HA should have a role in the treatment of acute complex proximal humeral fractures in relatively young and active patients with good GT bone and intact cuff.

Keywords Shoulder hemiarthroplasty · Proximal humeral fracture · Shoulder reconstruction · Radiographs

Introduction

Shoulder hemiarthroplasty (HA) used to be the major treatment option for complex proximal humeral fractures that are impossible to achieve good reduction and reliable fixation. Although Neer first reported satisfactory results after HA for 3-part and 4-part fractures in 1970 [1], variable results [2–9] were published afterward and Neer's excellent results have been rarely reproduced or surpassed. Multiple factors including age, sex, comorbidities, tuberosity reconstruction, and rehabilitation [3, 10–12] are all associated with the final outcome. Since the unpredictable characteristic of the greater tuberosity (GT) healing and subsequent cuff insufficiency are major concerns [3, 8–10], HA is now rarely indicated for complex proximal humeral fractures. Reverse shoulder arthroplasty (RSA) has become more favored in the past ten to 15 years. A similar trend also exists in our department. Most of our HA surgeries were performed before 2009, when the reverse prosthesis was first introduced into our country. The number of HA cases has decreased dramatically ever since. Although most published results of RSA are more predictable and better than those of HA [13–16], the complete negation of HA as one of the treatment options for complex proximal humeral fractures is still under debate.

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Moreover, there have been very few reports of long-term results of HA on exclusive acute fracture case series in the literatures.

The aim of this study was to assess the long-term clinical and radiological outcomes, and survivorship of HA in the treatment of acute fracture of the proximal humerus.

Materials and methods

This is a retrospective study with institutional review board approval. The inclusion criteria were as follows: (1) proximal humeral fractures treated by HA, (2) acute fractures treated within three weeks after injury, and (3) a minimum clinical follow-up of ten years. The exclusion criteria were as follows: (1) previous surgery on the same shoulder, (2) delayed fractures with nonunion or malunion, (3) concomitant neurovascular deficit, and (4) concomitant rotator cuff tear identified during surgery.

The indications of HA for acute proximal humeral fractures at that time were as follows: (1) complex fracture types (3-part, 4-part and/or with dislocation, head-splitting fracture) in senior patients or in patients with severe osteoporotic conditions; (2) complex fractures that anatomic reduction and reliable fixation cannot be achieved; and (3) normal functional deltoid.

Surgical technique

All surgeries were performed by the senior surgeon. The deltopectoral approach was adopted in all cases. Any fractures of the glenoid rim were treated with anchor fixation. The retroversion angle was set to 20° in all patients. All humeral stems were cemented at an appropriate height. The tuberosity fragments were then attached to the proximal part on the stem by preset heavy nonabsorbable sutures and/or titanium cable (Cable-ready, Zimmer, Warsaw, IN, USA) in a cerclage fashion. Bicep tenodesis was carried out in all cases.

Rehabilitation

The arm was placed in a neutral rotation brace for six weeks. Passive range of motion (ROM) exercises started at the third week after surgery. Assisted active ROM exercises were allowed six weeks after surgery. Strengthening exercises were instituted at least three months after surgery until tuberosity healing was confirmed by radiography. All patients were informed preoperatively that the rehabilitation therapy should be supervised by therapist on a regular visit basis and would last at least one year after surgery.

Clinical evaluation

Patients were evaluated at three weeks, six weeks, three months, six months,one year, two years, and five years postoperatively and then at the final follow-up (minimum 10 years). Functional outcomes were obtained by clinical visits or visual telephone interviews, which included the patient-derived Constant score (CS) [17], the American Shoulder and Elbow Surgeons (ASES) score [18], and a visual analog score (VAS) with values between zero (no pain) and 10 (maximum pain). Active forward flexion, external rotation with arm at side, and internal rotation were measured by the surgeon with a goniometer or were measured with special software on a snapshot taken during the visual chat under instruction (Fig. 1). Muscle power was measured by the surgeon with a dynamometer or by the patients themselves with multiple 2.5-kilo rice bags and 500 mL beverage bottles during the visual chat (Fig. 2). Internal rotation was converted to a number: T1-T12 was converted to 1–12, L1-L5 to 13–17, the sacrum to 18, and the buttock to 19 [19].

Radiographic assessment

Standardized radiographs were obtained at the routine follow-up, which included AP view in internal and external rotation, a lateral Y view and an axillary view. The humeral head superior migration, GT position, and glenoid erosion were evaluated. To correct the magnification effect of the radiographs, all quantitative measurements were adjusted according to the diameter of the humeral stem.

Humeral head superior migration

Acromiohumeral distance (AHD) was used to measure the extent of superior head migration. An AHD < 7 mm indicated abnormal superior migration, which implicated rotator cuff failure [6, 10, 20]. AHD was measured on AP view taken at the postoperative two year, five year, and final follow-up.

GT complication

GT displacement can be divided into GT malposition (immediately after surgery as surgical error) and later GT malunion/nonunion. The initial GT position was evaluated by the head to tuberosity distance (HTD) on the AP view. An HTD of 3 to 20 mm was considered anatomic reconstruction [20]. GT malposition was defined as an HTD > 20 mm or < 3 mm [20, 21]. Later GT malunion/

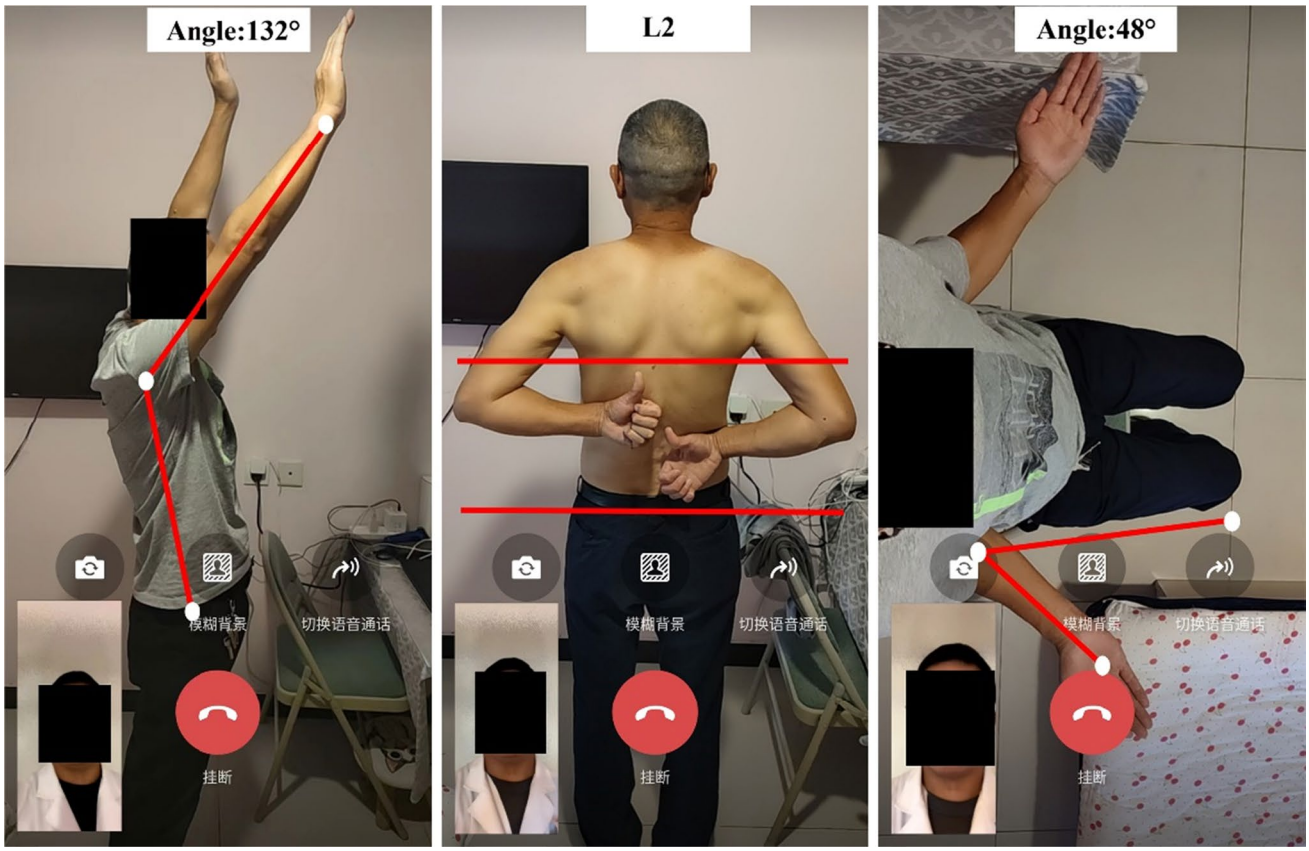

Fig. 1 Measurement of range of motion with special software on the snapshot taken during the visual chat under instruction

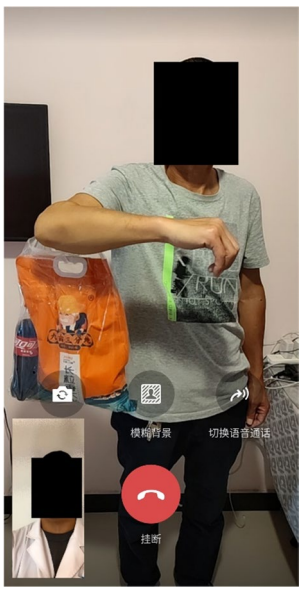

Fig. 2 Measurement of muscle power with multiple 2.5-kilo rice package bags and 500 ml water bottles during the visual chat

nonunion was defined as the GT being absent on the follow-up AP view in neutral rotation but visible on the internal rotation AP view and axillary view. The presence of immediate postoperative GT malposition or later malunion/nonunion was considered a GT complication.

GT resorption was only evaluated in the patients with a well-healed tuberosity. It was defined as follows: GT was visible on the AP view in neutral rotation at the final follow-up, but its contour decreased compared to postoperative two year. GT resorption was not considered a GT complication.

Glenoid erosion

Glenoid erosion was classified into eccentric erosion and concentric erosion. Glenoid eccentric erosion was defined as superior-medial step-off medialization of the glenoid on the AP view (Fig. 3). Glenoid concentric erosion was measured and quantified by the distance of a tangent line at the lateral edge of the acromion parallel to the line connecting the superior and inferior poles of the glenoid on the AP view (Fig. 4). An increase in this distance during the follow-up indicated glenoid erosion.

Statistical analysis

Categorical variables were reported as frequencies and percentages, whereas continuous variables were reported as the means and standard deviations. The Kolmogorov–Smirnov test was used to test the normal distribution of characteristics

Fig. 3 A 51-year-old man who had HA showed glenoid eccentric erosion 16 years postoperatively

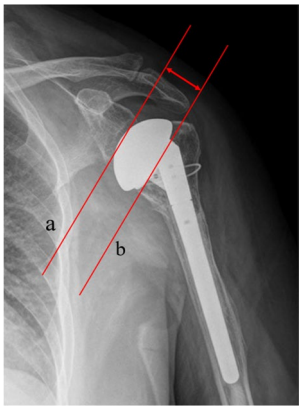

Fig. 4 Measurement of glenoid concentric erosion: A line a was drawn by connecting the superior and inferior poles of the glenoid margin. Line b was perpendicular to Line a and tangent to the lateral edge of the acromion. Glenoid erosion was quantified using the distance from Line a to Line b. All quantitative measurements were adjusted according to the diameter of the humeral stem

and outcome variables. For continuous variables, Student's *t*-test was used. Variables measured on a categorical scale were compared with the chi-square analysis. Functional outcomes at two, five and ten years postoperatively were analyzed using repeated measures analysis of variance. Prosthesis survivorship was defined as no reoperation on the same shoulder for any cause and was calculated using the Kaplan–Meier method. The level of significance was set at $P < 0.05$, and SPSS software (version 25, IBM, USA) was used for all statistical analyses.

Results

Demographic characteristics

From January 2002 to December 2010, 1038 patients underwent surgical treatment for proximal humeral fractures in our department, of which 192 patients received HA and 135 patients met the inclusion criteria. At the final follow-up, 28 patients had passed away, three patients refused to participate, and 17 patients could not be contacted. Finally, 87 shoulders in 87 patients who had a minimum ten year follow-up were enrolled in this study (Fig. 5). A conventional prosthesis (Bigliani/Flatow; Zimmer, Warsaw, IN, USA) was implanted in 53 patients, a low-profile fracture prosthesis (Tornier, Saint-Ismier, France) in six, and a bone ingrowth prosthesis (Trabecular Metal Humeral Stem; Zimmer, Warsaw, IN, USA) in 28.

The mean follow-up was 14.7 years (10–20 years). Bony Bankart lesion was found in one patient and was treated with open bony Bankart repair. The baseline characteristics of the 87 patients are shown in Table 1.

Survivorship and complications

There were no intraoperative complications recorded. Three of the 87 patients (3.4%) required reoperation: two

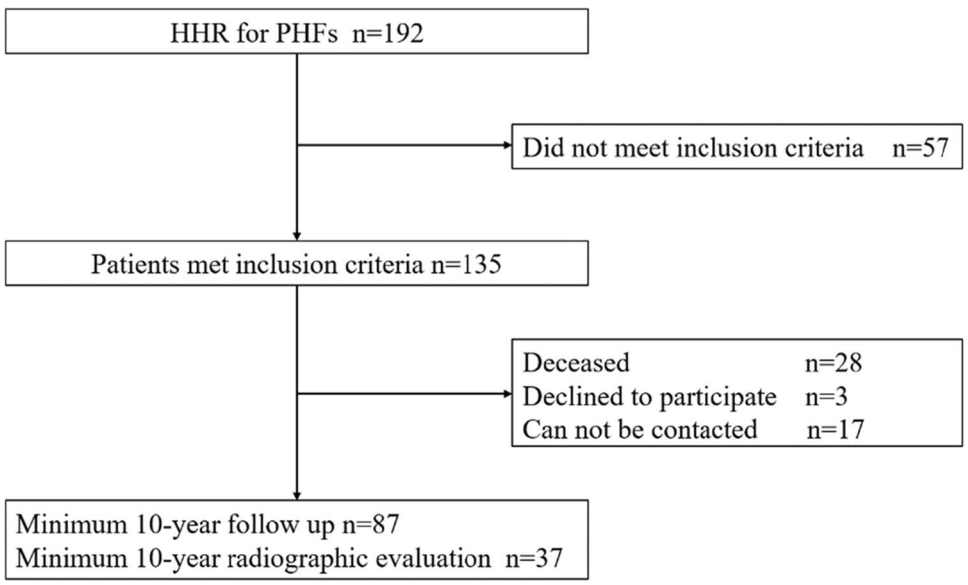

Fig. 5 Flow chart demonstrating the 87 patients enrolled in this study

Table 1 Demographic characteristics ($n=87$)

Variable	
Age at surgery (yr)	59.8 ± 12.2
Sex, male/female (*n*)	32/55
Dominant arm involvement (*n* (%))	52(59.8%)
Fracture pattern (*n* (%))	
3 part/dislocation	26(29.9%)
4 part/dislocation	46(52.9%)
Head splitting	15(17.2%)
Time to surgery (d)	9.5 ± 5.7

patients were stage-revised to RSA due to infection within two years after surgery, and one patient underwent multiple debridement for infection four years postoperatively (the patient refused implant removal). One patient developed locked anterior dislocation due to severe glenoid erosion at five years postoperatively and refused any further surgery. The overall prosthetic survival rate at two years postoperatively was 97.7% (95% confidence interval, 92.2% to 99.7%), which decreased to 96.6% (95% confidence interval, 90.6% to 99.3%) at five years and at ten years (Fig. 6).

Overall functional results

The ASES score and CS score for the 85 patients who still had the humeral head implant in place were 79.3 ± 13.3 and 81.3 ± 11.2, respectively. The average forward flexion was 125.9° ± 22.8°, the external rotation was 37.2° ± 9.8°, and the internal rotation was 15.7 ± 2.7 (Table 2). No significant difference was found regarding the functional scores and pain scores at any time-point from two years postoperatively to the final follow-up

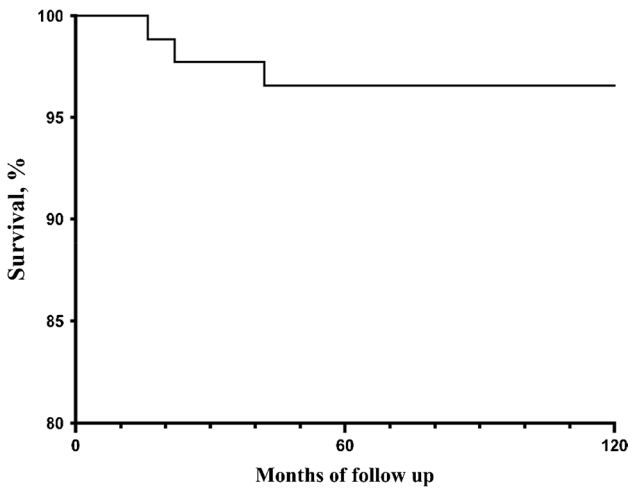

Fig. 6 Kaplan–Meier curve demonstrating prosthetic survivorship at different follow-up time-points

Table 2 Clinical outcomes after HA ($n=85$ *)

	2-year FU	5-year FU	Final FU	*P* value
ASES	80.8 ± 13.7	82.7 ± 14.7	79.3 ± 13.3	0.078
CS	82.4 ± 12.7	80.5 ± 13	81.3 ± 11.2	0.265
VAS	1.0 ± 1.4	0.9 ± 1.2	1.1 ± 1.2	0.562
ROM				
FF	131.2 ± 29.1	128.2 ± 27.2	125.9 ± 22.8	0.100
ER	39.5 ± 13.4	37.9 ± 11.5	37.2 ± 9.8	0.154
IR	12.9 ± 3.6	13.8 ± 3.4	15.7 ± 2.7	< 0.001

FU follow-up, *HA* hemiarthroplasty, *ASES* American Shoulder and Elbow Surgeons, *CS* Constant score, *VAS* visual analog score, *ROM* range of motion, *FF* forward flexion, *ER* external rotation, *IR* internal rotation

*Only the 85 patients who still had the humeral head implant in place were evaluated

(Table 2). Of the 85 patients, 77.6% (66) had a forward flexion greater than 120°, 54.1% (46) had an ASES greater than 80, and 61.2% (52) had a CS greater than 80. Patients aged younger than 70 had significantly better CS scores, ASES scores, forward flexion and internal rotation than the patients aged 70 and older. The same scores were significantly better in the males than in the females (Table 3).

Radiographic results

Radiographic evaluations immediately postoperatively and at two years postoperatively were available for all 87 patients. Postoperative five year radiographs were available in 44 patients, among whom 37 patients were still available at the final radiographic follow-up (Table 4). All radiographic evaluations except GT complications were carried out on these 37 patients.

GT complications

Of all 87 patients, immediate postoperative malposition of the GT was observed in nine patients (10.3%): the GT was placed too low in 8 (HTD > 20 mm) and too high in one (HTD < 3 mm). Of all the 78 patients who achieved anatomic GT reconstruction, ten patients showed GT malunion/nonunion within the postoperative two year follow-up (Table 4). Of the 30 patients who achieved anatomic healed GT, nine patients were found to have GT resorption (Table 4). Patients with anatomic GT healing had significantly higher functional scores and better ROM than the patients with GT complications (Table 5). There were no significant differences between the patients with or without GT resorption (Table 5).

Table 3 Functional outcomes regarding age and gender ($n=85$ *)

	Age			Gender		
	< 70 yr ($n=64$)	≥ 70 yr ($n=21$)	*P* value	Male ($n=31$)	Female ($n=54$)	*P* value
ASES	81 ± 12.3	74.2 ± 15.2	0.042	83.6 ± 11.8	76.9 ± 13.6	0.025
CS	82.8 ± 11.0	76.7 ± 10.7	0.029	84.9 ± 10.5	79.3 ± 11.1	0.024
VAS	1.0 ± 1.1	1.2 ± 1.6	0.670	0.9 ± 1.1	1.2 ± 1.3	0.346
ROM						
FF	128.8 ± 22.2	117.4 ± 23.1	0.047	136.8 ± 23.4	119.7 ± 20.2	0.001
ER	38.2 ± 9.2	34 ± 11.0	0.092	40.8 ± 8.1	35.1 ± 10.2	0.006
IR	15.4 ± 2.8	16.8 ± 2.3	0.036	15.5 ± 3.1	15.9 ± 2.6	0.589

ASES American Shoulder and Elbow Surgeons, *CS* Constant score, *VAS* visual analog score, *ROM* range of motion, *FF* forward flexion, *ER* external rotation, *IR* internal rotation

*Only the 85 patients who still had the humeral head implant in place were evaluated

Table 4 Radiographic outcomes after HA

	Initial postoperative	2-year FU	5-year FU	Final FU	*P* value
HTD between 3 and 20 mm, *n* (%), $n=87$	78 (89.7%)				
AHD (mm), $n=37$		5.7 ± 2.8	5.3 ± 2.1	4.9 ± 3.3	0.974
Glenoid erosion (mm), $n=34$ *		1.4 ± 3.5	1.5 ± 0.3	2.8 ± 1.4	0.681
GT resorption (*n* (%)), $n=30$ #				9(30.0%)	
GT complication (*n* (%)), $n=87$		19(21.8%)			

HA hemiarthroplasty, *FU* follow-up, *HTD* the head to tuberosity distance, *AHD* acromiohumeral distance, *GT* greater tuberosity

AHD, glenoid erosion, and GT resorption were measured only in the 37 patients who were available for radiographic evaluation at the final follow-up

*Three patients with glenoid eccentric erosion were excluded

#Seven patients with GT complications were excluded

Table 5 Functional outcomes regarding GT complication and GT resorption

	GT complication ($n=87$)				GT resorption ($n=30$)	
	No ($n=68$)	Yes ($n=19$)	*P* value	No ($n=21$)	Yes ($n=9$)	*P* value
ASES	81.8 ± 12.6	68.4 ± 14.7	< 0.001	79.5 ± 13.6	75.8 ± 14	0.504
CS	82.8 ± 10.4	74.1 ± 13.8	0.004	85.7 ± 11.2	80.2 ± 12.3	0.244
VAS	0.9 ± 1.2	1.8 ± 1.4	0.003	1.5 ± 0.9	1.8 ± 1.3	0.476
ROM						
FF	129.9 ± 21.1	110.8 ± 22.8	0.001	135.2 ± 18.1	123.9 ± 19.5	0.135
ER	37.1 ± 10.2	37.6 ± 8.6	0.846	40.7 ± 11	33.9 ± 12.4	0.145
IR	15.7 ± 2.7	16.0 ± 2.8	0.665	15.0 ± 3.3	16.4 ± 2.3	0.248

GT greater tuberosity, *ASES* American Shoulder and Elbow Surgeons, *CS* Constant score, *VAS* visual analog score, *ROM* range of motion, *FF* forward flexion, *ER* external rotation, *IR* internal rotation

Glenoid erosion

At the final follow-up, concentric erosion of the glenoid was found in 21 patients (56.8%), and eccentric erosion was found in 3(8.1%). Patients with glenoid erosion had worse outcomes than those without erosion (Table 6).

Humeral head superior migration

Twenty-five out of 37 patients were found to have an AHD > 7 mm at two years postoperatively. All but 2 of these patients (23/37) maintained an AHD > 7 mm at the final follow-up. At the final follow-up, the patients with an AHD < 7 mm

Table 6 Functional outcomes regarding glenoid erosion and humeral head superior migration ($n=37$)

	Glenoid erosion			Humeral head superior migration		
	No ($n=13$)	Yes ($n=24$)	*P* value	No ($n=23$)	Yes ($n=14$)	*P* value
ASES	82.9 ± 10.4	72.2 ± 15.1	0.029	81.3 ± 10.6	67.1 ± 16	0.008
CS	87.8 ± 7.4	80.6 ± 13.2	0.039	87.8 ± 8.2	75.5 ± 13.3	0.006
VAS	1.5 ± 1.0	2.0 ± 1.3	0.316	1.4 ± 0.9	2.4 ± 1.4	0.028
ROM						
FF	134.6 ± 10.1	128.1 ± 21.7	0.224	138.5 ± 11.5	117.1 ± 20.6	0.002
ER	40.0 ± 9.6	38.8 ± 11.9	0.747	41.3 ± 11.1	35.7 ± 10.4	0.137
IR	14.5 ± 2.4	15.9 ± 3.4	0.190	14.4 ± 3.1	17 ± 2.3	0.011

ASES American Shoulder and Elbow Surgeons, *CS* Constant score, *VAS* visual analog score, *ROM* range of motion, *FF* forward flexion, *ER* external rotation, *IR*, internal rotation

demonstrated significantly worse functional scores and limited ROM (except for external rotation) (Table 6).

Discussion

HA has long been a recommended treatment for complex proximal humeral fractures in senior patients [3, 4, 6]. However, due to the very inconsistent results (mean CS scores ranging from 33 to 72 points [22]) and the emergence of RSA, HA has been rarely indicated in the past ten to 15 years. There has been an increasing popularity of RSA over HA in the treatment of proximal humeral fractures for the past two decades, especially in patients aged 70 years or older [23]. To date, there have been three randomized controlled studies comparing HA and RSA in the treatment of fractures. In one of these studies, Sebastiá-Forcada et al. [24] found that the RSA group showed significantly higher Constant score (56.1 vs 40.0), but worse disabilities of the arm, shoulder, and hand score (17.5 vs 24.4). Jonsson et al. [13] compared 43 HA and 41 RSA patients with a minimum follow-up period of two years, and a recent study by Laas et al. [14] assessed 14 HA and 17 RSA patients, with the RSA groups in both studies reported superior clinical outcomes and flexion in patients with RSA than HA. Despite the favorable results of RSA, its complication and revision rates are still a serious concern [25, 26]. Gallinet et al. [15] reported a higher overall complication rate after RSA than HA. Moreover, RSA in relatively young patients showed a higher complication rate than that in senior patients in long-term follow-up [27]. The result of RSA revision is very unpredictable, and a high complication rate has been reported [28, 29]. Therefore, the question is as follows: is RSA the only option for the treatment of unreconstructable complex proximal humeral fractures in a relatively young population? Does HA still have a role in it?

There are limited published data on the long-term results of HA on fractures [2, 4, 7]. Both Antuña et al. [4] and Giovale et al.'s [2] five to seven year follow-up studies showed satisfactory long-term pain relief but less predictable healing of GT. In a registry study from the Danish Shoulder Arthroplasty Registry [7], the 14-year cumulative revision rate was 5.7% without any radiological evaluation. Our case series is by far the longest follow-up study of HA for the treatment of acute proximal humeral fractures that has been reported. At an average of 15-year follow-up, good pain relief with a mean CS score of 81.3 and an average ASES score of 79.3 was observed. The ten year prosthetic survival rate was 96.6%. Our results suggest that although rarely indicated, with strict patient selection, proper surgical techniques, and closely supervised postoperative rehabilitation, there should still be a place for HA in the treatment of acute proximal humeral fractures (Fig. 7).

By deeply examining our data, several risk factors were identified for a good long-term outcome after HA.

Age and gender

Age was an important factor affecting the results. Patients in this study were relatively young with a mean age of 59.8 years. Young individuals have been reported to have a better prognosis after HA for acute fractures than elderly patients [3, 4, 8]. Our results also showed significantly lower CS scores and ASES scores and less forward flexion angles in female patients.

Greater tuberosity and cuff status

Studies have shown that lack of rotator cuff integrity and poor bone quality of tuberosities negatively affect outcome after HA [4, 30, 31]. GT displacement was the most common complication after HA for proximal humeral fractures [5, 8, 32–34]. In the current study, 19 patients (21.8%) displayed GT complications (malposition in 9 and malunion/nonunion

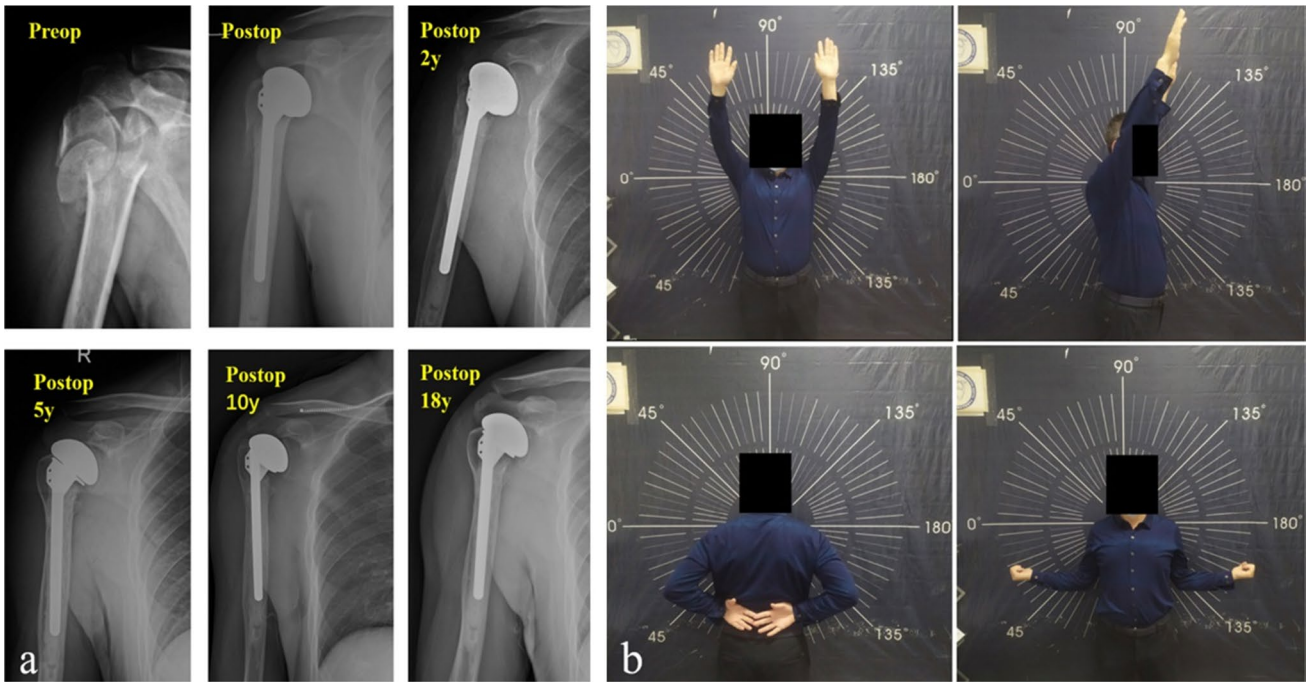

Fig. 7 Radiographic and clinical evaluation of a patient after HA at the age of 53. **a** Radiographic evaluation. **b** Clinical evaluation at the final follow-up

in 10). The importance of anatomical healing of the GT for the clinical outcome has been described by Boileau et al. [10] and other authors [4, 5, 30]. Consistent with these studies, our data demonstrated that patients with anatomical GT healing had significantly higher CS, ASES scores, and forward flexion.

Later complications related to long-term follow-up

Glenoid erosion after HA is commonly reported for degenerative problems [35]. However, limited research has evaluated the occurrence rate and the effect of glenoid erosion on functional outcome after HA in fracture situations. Grönhagen et al. [31] found that 35% of 82 HA patients had glenoid erosion, which led to a low CS but without significant difference. Glenoid erosion was observed in 64.9% (24/37) of the patients in our study and resulted in less satisfactory outcomes (Table 6). One patient even developed locked anterior dislocation due to the severe glenoid defect caused by erosion. Our higher glenoid erosion rate might be caused by the longer-term follow-up than other studies. Similarly, humeral head superior migration is also one of the key issues during long-term follow-up. Humeral head superior migration was found in 37.8% (14/37) of the patients with significantly lower ASES and CS scores and less forward flexion and external rotation (Table 6).

Interestingly, the postoperatively two year seemed to be an important time-point for functional outcome, since the ROM and functional scores were not deteriorating over time, and 92% of the patients could maintain their AHD until the final follow-up if they had an AHD > 7 mm at the postoperative two year follow-up.

There are several limitations in this study. First, selection bias inherently existed due to its retrospective nature. Second, we had no control group of patients treated with RSA or other treatment modalities. Third, due to the long-term nature of this study, the loss to follow-up rate was 35.6%, and only 37 out of the 87 patients were available for the final radiographic evaluation. Finally, this was a high-volume subspecialized single-surgeon case series report with a well-informed rehabilitation team supervising all of the patients' postoperative exercises. Therefore, our results might not be generalizable.

Conclusion

With strict patient selection, proper surgical technique, and closely supervised postoperative rehabilitation, HA could achieve a 96.6% ten year survival rate at an average follow-up of 15 years. Good pain relief can be expected even in patients with poor functional outcomes. Glenoid erosion and humeral head superior migration are common during long-term follow-up and have a negative impact on functional outcome. Patients who showed good postoperative two year functional outcomes and good AHD usually maintained their

results without deterioration over time. Although rarely indicated, HA should still have a role in the treatment of acute complex proximal humeral fractures in relatively young and active patients with good GT bone and intact cuff.

Author contribution Y. Z.: conceptualisation, measurements, and writing of the manuscript. YM. Z.: measurements and writing of the manuscript. Y. L.: measurements and proofreading of the manuscript. FL. L.: statistics and proofreading of the manuscript. CY. J.: conceptualisation and writing of the manuscript.

Data availability The datasets used in this study are not publicly available because of patient confidentiality but are available from the corresponding author on reasonable request.

Code availability Not applicable.

Declarations

Ethics approval Ethical approval for this study was received from the Institutional Review Board of Beijing Jishuitan Hospital (IRB 202102–18).

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent for publication The authors affirm that participants provided informed consent for publication of the images in Figs. 1, 2, and 7.

Conflict of interest The authors declare no competing interests.

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