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Research article

Assessment of surgical management for locked fracture-dislocations of the proximal humerus in patients of different ages

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ABSTRACT

Background: Locked fracture-dislocation of the proximal humerus (LFDPH) is a very severe complex injury; neither arthroplasty nor internal plating are fully satisfactory. This study aimed to evaluate different surgical treatments for LFDPH to determine the optimal option for patients of different ages.
Methods: From October 2012 to August 2020, patients who underwent open reduction and internal fixation (ORIF) or shoulder hemiarthroplasty (HSA) for LFDPH were retrospectively reviewed. At follow-up, radiologic evaluation was performed to evaluate bony union, joint congruence, screw cut-out, avascular necrosis of the humeral head, implant failure, impingement, heterotopic ossification, and tubercular displacement or resorption. Clinical evaluation comprised the Disability of the Arm, Shoulder, and Hand (DASH) questionnaire and Constant–Murley and visual analog scale (VAS) scores. Additionally, intraoperative and postoperative complications were assessed.
Results: Seventy patients (47 women and 23 men) with final evaluation results qualified for inclusion. Patients were divided into three groups: group A: patients aged under 60 years who underwent ORIF; group B: patients aged ≥60 years who underwent ORIF; and group C: patients who underwent HSA. At a mean follow-up of 42.6 ± 26.2 months, function indicators, namely shoulder flexion, and Constant–Murley and DASH scores, in group A were significantly better than those in groups B and C. Function indicators in group B were slightly but not significantly better compared with group C. Regarding operative time and VAS scores, there were no significant differences between the three groups. Complications occurred in 25%, 30.6%, and 10% of the patients in groups A, B, and C, respectively.
Conclusions: ORIF and HSA for LFDPH provided acceptable but not excellent results. For patients aged <60 years, ORIF might be optimal, whereas, for patients aged ≥60 years, both ORIF and HSA provided similar results. However, ORIF was associated with a higher rate of complications.

Level of evidence: Level IV, Case Series, Treatment Study.

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Abbreviations

LFDPH	Locked fracture-dislocation of the proximal humerus
ORIF	open reduction and internal fixation
HSA	hemiarthroplasty
AVN	avascular necrosis
DASH	Disability of the Arm, Shoulder, and Hand questionnaire
VAS	visual analog scale

1. Introduction

Proximal humeral fractures are a common injury, comprising 4–5% of all fractures [1,2]. Most of these fractures occur in people older than 65 years of age and in those with osteopenia or osteoporosis, and the incidence is increasing. Locked fracture-dislocation of the proximal humerus (LFDPH) is a very rare but more severe complex injury. In this type of injury, fractures often occur in the surgical neck, and the humeral head is completely disengaged from the humeral shaft and displaced and locked onto the glenoid rim [3–7]. LFDPH is most often caused by a high-energy axial loading force with the arm adducted, flexed, and internally rotated; thus, the majority of these injuries occur in young patients [7,8]. The humeral head can dislocate anteriorly, posteriorly, or inferiorly, although the latter two directions are extremely rare.

Because most of the fractures involve the surgical neck, and the humeral head is locked onto the glenoid rim, it is difficult to achieve reasonable shoulder function by conservative treatment; thus, surgical management is necessary [9]. Owing to the rarity of LFDPH, only a small series of cases have been reported [3–8], and the treatment experience is limited and unique challenges remain. Both arthroplasty and open reduction and internal fixation (ORIF) are not fully satisfactory and are associated with higher complication rates [5,10]. Previously, technical difficulties in re-dislocation and rigid fixation because of a cartilage shell associated with a thin layer of bone, and the risk of nonunion and osteonecrosis of the humeral head after osteosyntheses, indicated arthroplasty over ORIF, especially for older patients with lower postoperative demands [4,11,12]. However, several authors chose internal plate fixation to treat LFDPH and achieved splendid results. These authors advocate that it is worth preserving the humeral head even if osteonecrosis develops. This is because necrosis might be asymptomatic owing to the non-weight-bearing nature of the glenohumeral joint [6,7,10]. Therefore, it remains unknown which surgical option is optimal for LFDPH.

LFDPH is infrequently reported, and the literature does not contain clear, widespread guidelines for the operative management. Hence, it is crucial for surgeons to determine the optimal surgical option for patients with LFDPH. This study aimed to evaluate the clinical results of surgical treatment for LFDPH, as well as humeral head necrosis, non-union, and other possible complications after operative managements for such injuries. Additionally, we hypothesized that the optimal surgical strategy for younger patients with LFDPH is internal fixation.

2. Methods

This was a single-center retrospective case series study. The medical records of patients who underwent surgical treatment for LFDPH between October 2012 and August 2020 were reviewed. In this study, LFDPH was defined as disengagement of the humeral head from the shaft and fully dislocated from contact with the glenoid fossa and locked onto the glenoid rim [7]. Among these patients, there was either an isolated fracture through the neck of the humerus or a neck fracture associated with fractures of one or both tuberosities. The inclusion criteria were patients who had a closed LFDPH treated surgically and had a minimum 12 months post-operative follow-up. The exclusion criteria were: (1) proximal humeral fracture without the humeral head fully displaced and locked; (2) adolescents with unclosed epiphyses; (3) pathological fractures; (4) patients with a previous injury or surgery in the ipsilateral shoulder; (5) concomitant ipsilateral fracture of the distal upper limb; and (6) partial osteochondral fracture of the humeral head or an isolated tuberosity fracture.

Prior to surgery, the patients' characteristics data were collected. In addition to anteroposterior and axial projection radiographic views, each patient routinely underwent computed tomography and reconstruction to improve the surgeons' understanding of the fragment displacement and bone quality in both the humeral head and glenoid, and to help determine the treatment strategy. We used the Neer classifications [13] to describe the displacement of the fracture fragments, and glenohumeral dislocation was classified as inferior, anterior, or posterior. Magnetic resonance imaging was not routinely performed unless there was a suspicion of rotator cuff injury and labral tears.

The study was approved by the Ethics Committee of Hong Hui Hospital, Xi'an Jiaotong University School of Medicine (No. 202205007) and was conducted in accordance with the Declaration of Helsinki. All patients provided written informed consent to participate in this study, and for the publication of their clinical data and accompanying images.

2.1. Operative technique

All patients underwent a similar operative procedure and postoperative rehabilitation program. The surgical indications for ORIF were a displaced LFDPH that could not be reduced by conservative treatment and/or appeared prone to recurrence after conservative treatment. The indications for shoulder hemiarthroplasty (HSA) were a displaced comminuted LFDPH in an older patient with low postoperative demands that could not be managed by plating. A single dose of third-generation cephalosporin was administered to each patient 30 min preoperatively. After inducing general anesthesia, each patient was placed in the beach chair position. Dissection was performed via a shoulder strap skin incision and deltopectoral approach to gain excellent visualization of the humeral head fragment and the empty glenoid through the rotator cuff interval. A direct arthrotomy was made along the long head of the biceps tendon, which is located between the subscapularis and supraspinatus tendons.

In ORIF, after directly identifying the displacement of the humeral head and irrigating the area, the humeral head was freed from the glenoid rim and relocated by forceps under direct vision. During this procedure, we tried to preserve the residual capsule attachments and the muscles of the rotator cuff as much as possible, then anatomically reduced and provisionally stabilized the humeral head using two or three Kirschner wires. Metaphyseal defects were packed with an allograft or auto-iliac crest bone graft, then definitive fixation with a locking plate was performed. Screws were placed meticulously in the humeral head within 5 mm of the subchondral layer (Fig. 1). For more complex three- and four-part fractures, non-resorbable sutures were used predominantly through the insertion of the rotator cuff to secure the reduction of the tubercles, and the rotator cuff was repaired. Finally, the fracture reduction and correct implant position were verified by fluoroscopy.

In HSA, after excision of the humeral head, the humeral component (the proximal area that was retained for the tubercles was press-fit and the remaining was cemented) with cement was inserted and press-fit when there was enough bone to obtain a firm fit of the component proximally. Next, the greater and lesser tubercles were fixed anatomically with wires or non-resorbable sutures, and the prosthetic humeral head was placed (Fig. 2). Before arthrotomy closure, any scarring around the subscapularis was released and necessary joint lysis was performed to facilitate the ability to regain active movement.

2.2. Postoperative management

Cephalosporin antibiotics were continued for 24 h postoperatively, and a drain was maintained for 48 h. A sling was not routinely prescribed unless there was a suspicion of residual joint instability. The postoperative protocol differed between the patients who underwent ORIF vs HSA. For patients treated with ORIF, supervised rehabilitation comprising gentle pendulum shoulder exercises and active elbow flexion and extension started immediately after surgery. Rehabilitation included limited active abduction and external rotation of the shoulder in the first 4 weeks in cases where the greater tubercle was fractured and active internal rotation and passive external rotation of the shoulder in the first 4 weeks in cases where the lesser tubercle was fractured. Gentle shoulder active movements

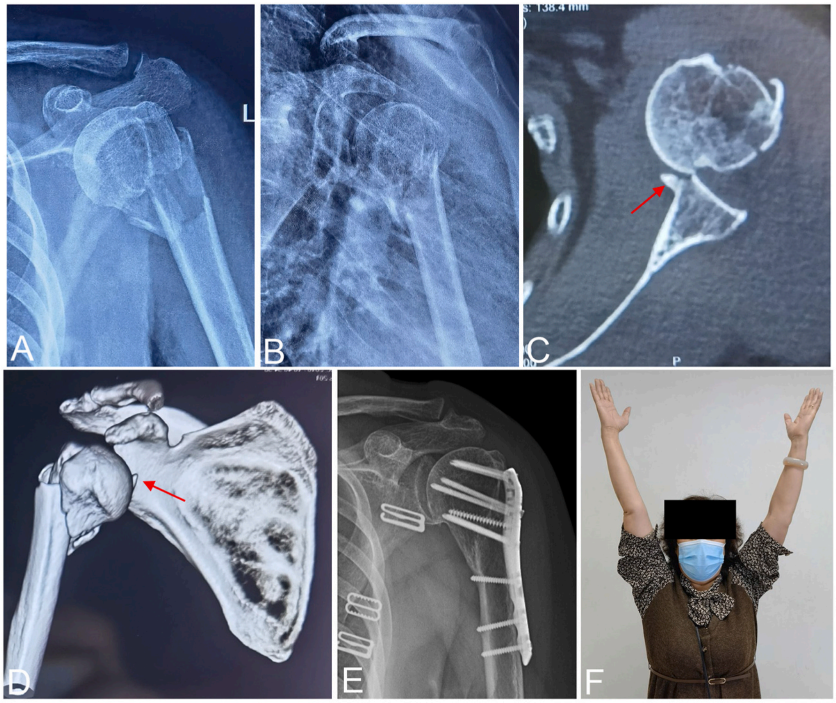

Fig. 1. A 56-year-old female patient with locked fracture-dislocation of the proximal humerus treated by open reduction and internal fixation. Preoperative plain radiographs (a, b) of the left shoulder showing an anteriorly dislocated shoulder and an associated fracture of the humeral surgical neck. Computed tomography images (c, d) showing the displaced humeral head and anterior glenoid rim fracture ("bony Bankart" lesion, red arrow). At the 57-month follow-up, the patient had solid bone union and a full range of shoulder motion (e). She was able to return to her preinjury work, and she was highly satisfied with the treatment (f). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

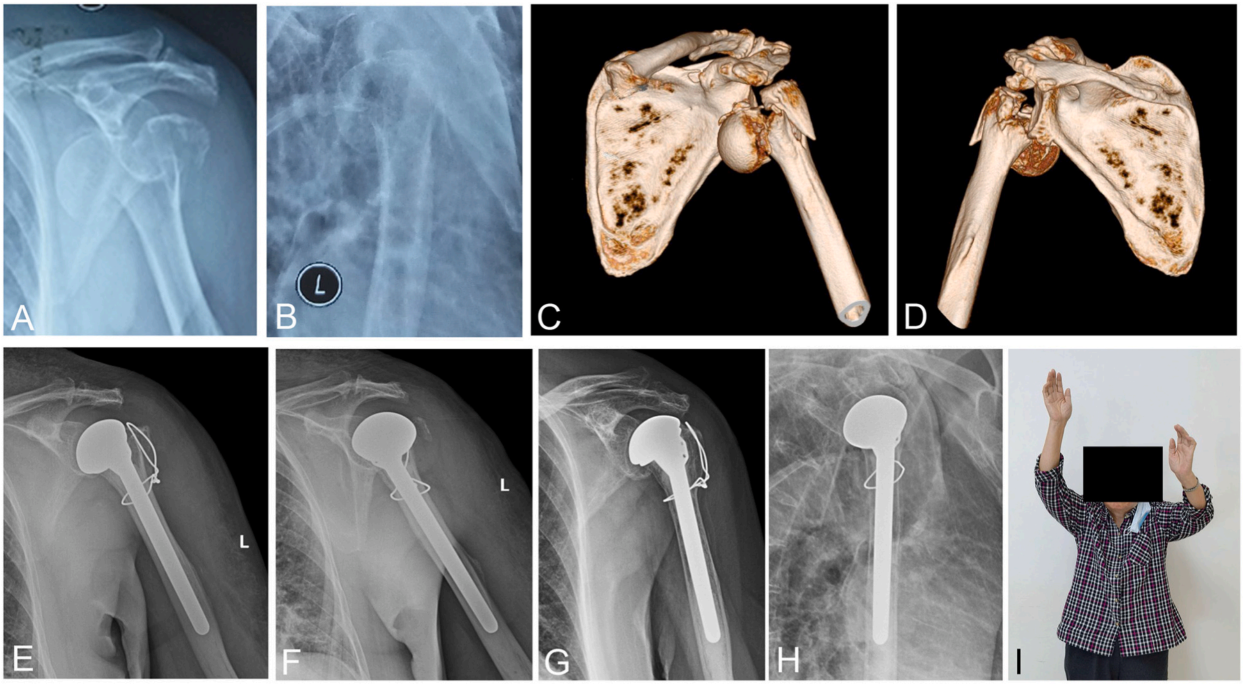

Fig. 2. Locked fracture-dislocation of the proximal humerus in a 77-year-old female patient treated by shoulder hemiarthroplasty. Anteroposterior (a) and axial projection view (b) radiographs and three-dimensional computed tomography images (c, d) showing a three-part Neer fracture of the proximal humerus with the humeral head displaced anteriorly and locked onto the glenoid rim. Postoperative radiographs after hemiarthroplasty (e, f) showing the major tubercle fixed anatomically with wires. X-rays 50 months postoperatively (g, h) showing good joint congruence with no complications. (i) Photograph showing the clinical outcome 50 months after surgery.

started 4 weeks postoperatively, resistance exercises began at 6 weeks, and strengthening exercises began at 3 months. As with ORIF, patients who underwent HSA were encouraged to perform gentle pendulum shoulder exercises and active elbow flexion and extension immediately after surgery. Then, patients gradually began to perform passive forward flexion and horizontal external rotation of the shoulder. Resistance exercises began at 6 weeks, and strengthening exercises began at 2 months. Additionally, activating the deltoid muscle with assisted physiotherapy was helpful.

2.3. Data collection and outcome measures

Patients were encouraged to undergo follow-up in our institute 1, 3, 6, and 12 months postoperatively and every 6 months thereafter. Patients for whom it was inconvenient to attend in person were followed by telephone or email. Radiologic evaluation was performed to evaluate bony union, joint congruence, screw cut-out, avascular necrosis (AVN) of the humeral head, implant failure (migration, loosening, or breakage), impingement, and heterotopic ossification, tubercular displacement, or resorption. Reduction quality was determined by the three criteria defined by Schnetzke et al. [14] medial head shaft displacement <5 mm, greater tuberosity cranialization <5 mm, and neck-shaft angle between 120° and 150°. The Constant–Murley scale was applied to evaluate shoulder function [15]. Screw cut-out was defined as protruded screws into the glenohumeral joint not initially seen on the first postoperative radiographs [16]. Upper limb function was evaluated using the Disability of the Arm, Shoulder, and Hand (DASH) questionnaire, which is scored from 0 to 100, with a high score indicating a high level of dysfunction [17]. Pain was assessed using a visual analog scale (VAS) ranging from 0 to 10, with a high score representing a high level of pain. Additionally, any other complications were recorded, such as infection, nerve injury, or rotator cuff tear.

2.4. Statistical analysis

Statistical analysis was performed using SPSS (version 23.0; SPSS Inc., IBM Corp., Armonk, NY, USA). The results were reported as the mean with 95% confidence interval (CI) in each group. First, we assessed whether the measurement data were normally distributed using the Shapiro–Wilk test. We then analyzed the data using the Kruskal–Wallis test. Differences were considered statistically significant with $P < 0.05$. If there was a significant difference between the three groups, we performed pairwise comparisons.

Table 1
Patients data and outcomes.

	Group A (n = 24)	Group B (n = 36)	Group C (n = 10)
Age (years)	Mean 46.6 ± 11.0, min 21, max 58	Mean 71.3 ± 8.1, min 60, max 89	Mean 73.5 ± 10.0, min 59, max 90
Gender			
Female	11 (45.8%)	29 (80.6%)	7 (70%)
Male	13 (54.2%)	7 (19.4%)	3 (30%)
Injured Side			
Left	12 (50%)	22 (61.1%)	7 (70%)
Right	12 (50%)	14 (38.9%)	3 (30%)
Injury Mechanism			
Accident	11 (45.8%)	4 (11.1%)	2 (20%)
High falling	4 (16.7%)	3 (8.3%)	1 (10%)
Slipping	9 (37.5%)	29 (80.6%)	7 (70%)
Fracture type			
2-part	1 (4.2%)	2 (5.6%)	0
3-part	12 (50%)	12 (33.3%)	1 (10%)
4-part	11 (45.8%)	22 (61.1%)	9 (90%)
Direction of dislocated humeral head			
Anterior	22 (91.7%)	34 (94.4%)	9 (90%)
Posterior	2 (8.3%)	2 (5.6%)	0
Inferior	0	0	1 (10%)
Multi-injuries	One acromion fracture, 1 acetabular fracture, 3 scapular glenoid fractures (2 cases underwent fixation)	Two scapular glenoid fractures, 1 patella fracture	One acetabular fracture, 1 case with bilateral scapular glenoid fracture and contralateral shoulder joint dislocation, 1 lumbar fracture, 1 case with pelvic fracture and lumbar fracture
Comorbidities	6 (25%)	23 (63.9%)	8 (80%)
Hypertension	3 (12.5%)	13 (36.1%)	4 (40%)
Diabetes	0	3 (8.3%)	1 (10%)
Arrhythmia	3 (12.5%)	15 (41.7%)	6 (60%)
Cerebral infarction	0	3 (8.3%)	0
Emphysema	0	1 (2.8%)	0
Parkinson's disease	0	1 (2.8%)	1 (10%)
Smoking	4 (16.7%)	0	0
Alcohol	4 (16.7%)	0	0
Time to surgery(days)	mean 5.3 ± 6.6, min 2, max 35	Mean 5.8 ± 4.2, min 2, max 21	Mean 15.4 ± 27.4, min 3, max 92
Operative time(mins)	mean 151.0 ± 48.7, min 80, max 240 (95% CI, 131.3 to 172.7)	Mean 151.1 ± 46.8, min 80, max 300 (95% CI, 136.5 to 165.8)	Mean 156.5 ± 56.2, min 90, max 270 (95% CI, 124.5 to 191.5)
Bone graft	6 (25%) (5 allograft, 1 auto-iliac crest bone graft)	19 (52.9%) (all were allograft)	0
Blood transfusion(U)	mean 1.8 ± 1.2, min 0, max 4 (95% CI, 1.4 to 2.3)	mean 1.8 ± 1.1, min 0, max 4 (95% CI, 1.4 to 2.1)	mean 2.8 ± 1.0, min 2, max 4 (95% CI, 2.2 to 3.4)
Follow-up time (months)	mean 44.83 ± 30.71, min 12, max 108	Mean 37.4 ± 21.9, min 12, max 97	Mean 56.1 ± 25.8, min 15, max 93
Shoulder flexion (°)	Mean 132.3 ± 42.5, min 50, max 180 (95% CI, 115.4 to 148.1)	Mean 101.8 ± 39.9, min 30, max 180 (95% CI, 89.7 to 115.6)	Mean 82.0 ± 41.6, min 40, max 150 (95% CI, 58.0 to 108.0)
Constant–Murley score	Mean 87.3 ± 11.5, min 47, max 98 (95% CI, 82.2 to 91.2)	Mean 76.1 ± 14.3, min 36, max 94 (95% CI, 71.6 to 80.7)	Mean 75.1 ± 10.5, min 60, max 92 (95% CI, 68.8 to 81.6)
DASH score	Mean 8.6 ± 8.2, min 0, max 29.1 (95% CI, 5.6 to 12.0)	Mean 19.2 ± 10.3, min 0, max 39 (95% CI, 15.8 to 22.6)	Mean 19.5 ± 10.0, min 5.8, max 36.7 (95% CI, 13.5 to 25.7)
VAS	Mean 0.5 ± 1.1, min 0, max 5 (95% CI, 0.1 to 1.0)	Mean 0.9 ± 1.3, min 0, max 4 (95% CI, 0.5 to 1.3)	Mean 0.8 ± 1.3, min 0, max 4 (95% CI, 0.1 to 1.7)
Complications	6 (25%)	11 (30.6%)	1 (10%)
AVN	3 (12.5%)	7 (19.4%)	
Non-union	0	0	
Screw cut out	2 (8.3%)	7 (19.4%)	
Greater tuberosity resorption	1 (4.2%)	2 (5.6%)	
Arthritis	0	0	1 (10%)
Reoperation			
Implant removal	11 (45.8%)	5 (13.9%)	0

DASH, Disability of the Arm, Shoulder, and Hand. VAS, visual analog scale. AVN, avascular necrosis.

3. Results

From October 2012 to August 2020, 82 cases of LFDPH were treated operatively in our institution. Seven patients were lost to follow-up because of death, and 5 patients refused to participate in further follow-up; thus, 70 patents (47 females and 23 males) with final evaluation results qualified for inclusion. The patients' mean age was 63.1 ± 15.2 years (range: 21–90 years) (Table 1). All 70 patients had sustained closed fractures, and 60 (85.7%) underwent ORIF and 10 (14.3%) underwent HSA.

We divided the patients into three groups: group A comprised patients aged <60 years who underwent ORIF; group B comprised patients aged ≥60 years who underwent ORIF; and group C comprised patients who underwent HSA. Specifically, there were 24 patients (34.3%) in group A (mean age: 46.6 ± 11.0 years; range: 21–58 years), 36 (51.4%) in group B (mean age: 71.3 ± 8.1 years; range: 60–89 years), and 10 (14.3%) in group C (mean age: 73.5 ± 10.0 years; range: 59–90 years). Women constituted 45.8% (11/24), 80.6% (29/36), and 70% (7/10) of the patients in groups A, B, and C, respectively. The most affected side was the left in each group, and the most common injury mechanism was an accident in group A and slipping in both group B and group C. Three-part Neer fracture was the most common fracture type in group A, with four-part Neer most common in groups B and C. Anterior dislocation of the humeral head comprised over 90% of the dislocations in each group. There were two patients with posterior dislocation in both group A and group B, and one inferior dislocation in group C. Multiple injuries occurred in 5 cases in group A, 3 in group B, and 4 in group C, and the comorbidity rate in the three groups was 25%, 66.7%, and 80%, respectively. Surgery was performed an average of 5.3 ± 6.6 days after injury in group A; 5.8 ± 4.2 days in group B, and 15.4 ± 27.4 days in group C. The average operative time was 151.0 ± 48.7 min (range: 80–240 min) in group A, 151.1 ± 46.8 min (range: 80–300 min) in group B, and 156.5 ± 56.2 min (range: 90–270 min) in group C, with no significant difference between the three groups (P = 0.955). Six (25%) patients in group A and 29 (52.9%) patients in group B received bone grafts.

According to the quality of the reduction as described by Schnetzke et al. [14], overall anatomical or acceptable fracture reduction was achieved in 19 (79.2%) patients in group A and 21 (58.3%) patients in group B. The mean follow-up period was 42.6 ± 26.2 months (range: 12–108 months), and functional outcomes differed significantly according to the treatment modality. The function indicators, shoulder flexion and Constant–Murley and DASH scores in Group A were significantly better than those in groups B or C (Tables 1 and 2). In comparison, the function indicators in group B were slightly better compared with the indicators in group C, but there was no significant difference (Table 2). Regarding the Constant–Murley scores in group A, 16 patients (66.7%) had excellent scores (>86 points), 6 (25%) had good scores (71–85 points), 1 (4.2%) had a fair score (56–70 points), and 1 (4.2%) had a poor score (<56 points) [18]. In group B, there were 11 (30.1%) excellent cases, 16 (44.4%) good cases, 5 (13.9%) fair cases, and 4 (11.1%) poor cases. In group C, there were 3 (30%) excellent cases, 3 (30%) good cases, and 4 (40%) fair cases. The mean DASH score in groups A, B, and C was 8.6 ± 8.2 (range, 0–29.1), 19.2 ± 10.3 (range, 0–39), and 19.5 ± 10.0 (range, 5.8–36.7), respectively. The mean VAS score in group A was 0.5 ± 1.1 (range, 0–5), 0.9 ± 1.1 (range, 0–4) in group B, and 0.8 ± 1.3 (range, 0–4) in group C, with no significant differences between the three groups (P = 0.312).

The overall complication rate was 22.9% (16/70). In group A, complications were observed in 6 cases (25%), with 3 cases (12.5%) of AVN of the humeral head, 2 cases (8.3%) of screw cut-out, and 1 case (4.2%) of greater tuberosity resorption. In group B, complications were observed in 11 cases (30.6%), namely AVN in 7 cases (19.4%), screw cut-out due to collapse of the humeral head in 7 patients (19.4%), and greater tuberosity resorption in 2 cases (5.6%). We observed only one complication (10%) (arthritis) in group C. No other complications, such as neurovascular structure injury, infection, nonunion, and implant failure occurred. Eleven patients (45.8%) in group A and 5 patients (13.9%) in group B underwent secondary plate removal after fracture healing, including one patient aged 67 years who developed AVN 3 years after plate removal.

Table 2
Pairwise comparison of results.

	Comparison	Z	Adjusted P
Blood transfusion	Group A-Group B	0.179	1.000
	Group B-Group C	−2.419	0.047
	Group A-Group C	−2.173	0.089
Shoulder flexion	Group A-Group B	2.701	0.021
	Group B-Group C	1.375	0.508
	Group A-Group C	3.197	0.004
Constant–Murley score	Group A-Group B	3.647	0.001
	Group B-Group C	0.603	1.000
	Group A-Group C	3.126	0.005
DASH score	Group A-Group B	−3.943	<0.001
	Group B-Group C	−0.114	1.000
	Group A-Group C	−2.869	0.012

DASH, Disability of the Arm, Shoulder, and Hand.

4. Discussion

LFDPH represents a challenging and increasingly prevalent problem without a clear best treatment strategy. LFDPH is an uncommon injury with only a few case series reported in the literature [3,4,6–8]. Wooten et al. [11] treated 32 patients with chronic locked posterior dislocation of the shoulder with anatomical shoulder arthroplasty. In a report of 26 cases of posterior fracture-dislocation of the shoulder by Robinson et al. [7], all cases were treated with internal fixation. Additionally, Robinson et al. [6] reported 58 cases of anterior LFDPH, namely 30 cases treated by ORIF and 28 by cemented HSA. In this study, we reported 70 LFDPH cases, in which 65 patients had anterior dislocation, 4 had posterior dislocation, and only 1 had inferior dislocation. To the best of our knowledge, only one study's sample size was larger than ours: Schirren et al. [19] treated 81 anterior fracture-dislocations with surgery. However, none of these previous studies compared the results after ORIF between patients $<$60 years vs $\geq$ 60 years of age.

In this study, four cases with anatomical neck fracture who were initially misdiagnosed on plain radiographs and who unsuccessfully underwent attempted closed manipulation of the dislocation in the emergency department were confirmed with obvious displacement on post-closed reduction X-ray. It is often difficult to distinguish this type of injury from a two-part greater tuberosity fracture dislocation (Fig. 3). Additionally, surgeons should note that it is generally difficult to diagnose posterior LFDPH, and that this dislocation is frequently missed in the initial evaluation, with misdiagnosis rates ranging from 60% to 80% [3]. Therefore, computed tomography should be performed routinely when there is a high suspicion of this type of injury. Although one patient with LFDPH who had obvious displacement of the humeral head from the shaft underwent successful closed reduction of the glenohumeral joint in a local hospital, closed manipulation of this type of injury should be avoided, especially for patients with fragility fractures, not to mention the high risk of further damage to the dislocated epiphysis and neurovascular structures with closed reduction.

Most LFDPH cases involve surgical neck fractures of the humerus with the humeral head locked onto the glenoid rim, which frequently causes devascularization of the humeral head and neurovascular damage. Therefore, LFDPH is considered among the most severe forms of proximal humeral fracture. LFDPH treatment comprises multiple challenges for surgeons. Previously, technical difficulties in re-dislocation and rigid fixation because of a cartilage shell associated with a thin layer of bone and the risk of nonunion and osteonecrosis of the humeral head after osteosyntheses indicated arthroplasty instead of ORIF [4]. However, recent studies have suggested that arthroplasty as the better choice is debatable [3,5,6]. Wooten et al. [11] found that shoulder arthroplasty for LFDPH was inferior to arthroplasty for glenohumeral osteoarthritis. Additionally, although ORIF is associated with a greater risk of AVN, it allows for preservation of the humeral head. Furthermore, overall shoulder function might not be compromised and symptoms of AVN of the humeral head might not appear even if AVN develops because the glenohumeral joint is a non-weight-bearing joint [5]. Consequently,

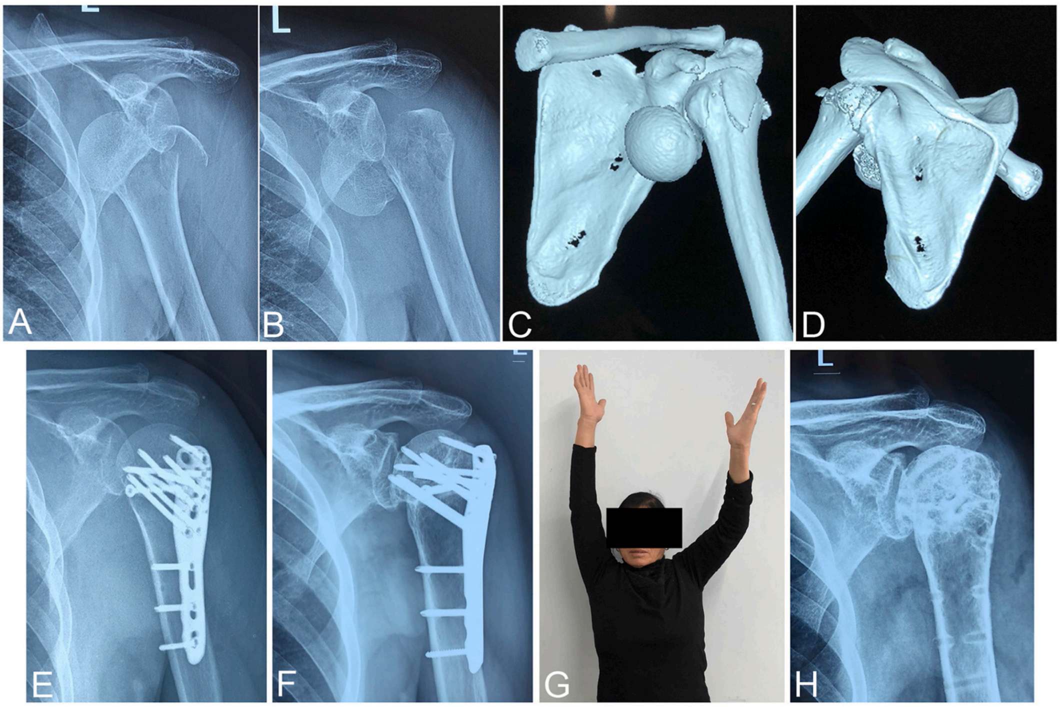

Fig. 3. Anteroposterior radiograph (a) of the left shoulder taken immediately after injury in a 60-year-old female patient showing anterior fracture dislocation of the proximal humerus with a non-obvious anatomical neck fracture. After failed closed reduction in a local hospital, the humeral head was completely disengaged from the shaft (b–d). Plain radiograph (e) taken immediately after open reduction and internal fixation (ORIF) showing that both the fracture and the joint were anatomically reduced. X-ray 18 months postoperatively showing avascular necrosis (AVN) and screw cut-out (f). The patient had mild shoulder range of motion limitation with no pain (g). She refused joint replacement and underwent simple implant removal (h).

it remains unknown which surgical option is optimal for LFDPH, especially for patients older than 60 years of age.

This study showed that both ORIF and HSA can effectively treat locked fracture-dislocations of the proximal humerus, but the results were not excellent. Additionally, outcomes after ORIF in patients <60 years of age were better than those after ORIF in patients ≥60 years and those in patients who underwent HSA. Furthermore, the outcomes in patients over 60 years of age who underwent ORIF or HSA were similar. Evaluation indicators, such as operative time, blood transfusion, shoulder flexion, and Constant–Murley scores in patients over 60 years of age who underwent ORIF were slightly better than those in patients over 60 years of age who underwent HSA, but with no significant difference. Additionally, patients over 60 years of age who underwent ORIF had a higher rate of complications. Our outcomes were similar or better than those reported in other studies. Schirren et al. [19] treated 81 anterior fracture-dislocations, and 40 were treated with ORIF, 19 with HSA, and 22 with reverse shoulder arthroplasty. At a mean follow-up of 3.4 ± 2.9 years, the average Constant-Murley score was 63.4 ± 10.3 after ORIF, 52.4 ± 12.9 after HSA, and 74.5 ± 11.1 after reverse shoulder arthroplasty. In a retrospective study of 58 cases of LFDPH, Robinson et al. [6] treated 30 cases (23 with retained capsular attachments and 7 without) with ORIF and the remaining 28 with cemented HSA, and the outcomes were favorable. In a case series of six locked posterior fracture-dislocations of the shoulder, Park et al. [8] treated four patients with an internal PHILOS plate and the remaining two patients with arthroplasty (one HSA and one reverse shoulder arthroplasty). The patients' mean Constant–Murley, American Shoulder and Elbow Surgeons, and VAS scores at the postoperative final visit were 66.7, 65.5, and 2.2 points. AVN of the humeral head and screw penetration occurred in two cases, with an incidence rate of AVN of the humeral head of 50%. However, none of these three previous studies compared the results after ORIF between patients aged <60 years vs ≥ 60 years.

AVN and screw cut-out are the most severe complications after ORIF for proximal fractures. The incidence of AVN after plating for proximal humeral fractures was as high as 68%, and even reached 80% in three- and four-part fracture cases [20]. The risk factors for humeral head necrosis after plating are related to the fracture type (AO type C and Neer four-part fractures), length of the dorsomedial metaphyseal extension, degree of fracture fragment displacement, and integrity of the medial hinge [16,21]. In this study, the rates of both AVN and screw cut-out after ORIF in patients ≥60 years of age were higher than those in patients <60 years, with an AVN rate of 19.4% and screw cut-out rate of 19.4% in the former, and 12.5% for AVN and 8.3% for screw cut-out in the latter. In group A, in the four patients who developed AVN or screw cut-out or both, malreduced fracture reduction was seen in two patients in accordance with the quality of reduction advocated by Schnetzke et al. [14], whereas malreduced fracture reduction was seen in 3 of the 9 patients with AVN or screw cut-out or both in group B. In a study by Robinson et al. [6], the incidence of osteonecrosis was 2/23 (8.7%) in type I injuries (patients with retained capsular attachments ≥2 cm in length and arterial bleeding) and 4/7 (57.1%) in type II injuries (no demonstrable arterial bleeding) 2 years post-injury. In Schirren et al.'s study [19], AVN after ORIF occurred in 7 cases (17.5%), and in a study of ORIF for proximal humeral fracture dislocations by Padegimas et al. [10], 2/20 cases (10%) developed AVN.

This study showed that ORIF is optimal for LFDPH in patients <60 years of age. The possible reasons are as follows: first, according to Robinson et al. [6], most patients with anterior fracture-dislocations of the proximal humerus who were <60 years of age had retained capsular attachments of the humeral head ≥2 cm in length, and arterial bleeding, and the opposite periosteal sleeve hinge was intact, indicating a higher possibility of success in preserving the humeral head. Second, patients <60 years of age are often medically fit and might have advanced prospects to preserve the humeral head. Additionally, younger patients may prefer plate osteosynthesis to preserve the humeral head. Furthermore, even if AVN develops, owing to the non-weight-bearing characteristic of the upper limb, the AVN may be incomplete or relatively asymptomatic. Finally, although shoulder arthroplasty can provide pain relief and improved shoulder external rotation, and it is associated with a low risk of recurrent instability, the overall outcomes in primary HSA for LFDPH are inferior compared with arthroplasty for glenohumeral osteoarthritis [11]. Thus, in patients aged <60 years, we recommend ORIF to maintain the integrity and vitality of the humeral head. Internal locking plate fixation offers excellent biomechanical stability even in osteoporotic bone and restores the anatomy of the proximal humerus, which permits early exercise and results in good joint function [2]. In China, most patients with LFDPH wish to preserve their humeral head. In this study, 13 patients developed AVN or screw cut-out after ORIF, and although they had pain or shoulder function limitation, these patients refused joint replacement and elected simple implant removal (Fig. 3).

This study had limitations. First, this was a single-center retrospective case study with a small sample size and short follow-up period. In particular, the number of patients with posterior locked fracture-dislocations and the number undergoing HSA were small. Second, patients in this study were treated by different medical groups. Although these well-trained surgeons had high levels of experience, the surgical technique, implant selection, and rehabilitation protocols were not standardized. Furthermore, even though questionnaires were validated, owing to inconvenience in attending follow-up examinations in person, in older patients, some of the outcome data were obtained by self-reported mailed questionnaires or by telephone. Additionally, we obtained the final follow-up outcomes only for some patients. Last but not least, there was no control group of patients treated by reverse total shoulder replacement, and biomechanical experiments were lacking. Recent studies showed that reverse total shoulder arthroplasty provides better shoulder function than HSA and plate fixation for displaced complex proximal humeral fractures in older patients [22–24]. However, LFDPH is a very rare but also severe form of proximal humeral fracture. With more patients and a comparison of reverse total shoulder arthroplasty and HSA for LFDPH in future studies, our results will be more convincing and useful.

5. Conclusion

For LFDPH in patients <60 years of age, ORIF might be optimal. In contrast, for patients aged ≥60 years, both ORIF and HSA achieved acceptable and similar outcomes. In our study, in the older age group, the function indicators after ORIF were slightly better, but ORIF was associated with a higher complication rate.

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Ethics approval

The study was approved by the Ethics Committee of Hong Hui Hospital, Xi'a Jiaotong University School of Medicine (No. 202205007) and was conducted in accordance with the Declaration of Helsinki. All patients provided written informed consent to participate in this study, and for the publication of their clinical data and accompanying images.

Author contribution statement

Zhan Wang: conceived and designed the experiments; performed the experiments; analyzed and interpreted the data. Dongxu Feng: analyzed and interpreted the data; performed the experiments; wrote the paper. Yuxuan Jiang and Xiaomin Kang: analyzed and interpreted the data; contributed reagents, materials, analysis tools or data. Zhe Song, Yangjun Zhu, Jun Zhang and Kun Zhang: performed the experiments, analyzed and interpreted the data.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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