

Clinical Research

What Factors Are Associated with Poor Shoulder Function and Serious Complications after Internal Fixation of Three-part and Four-part Proximal Humerus Fracture-dislocations?

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Abstract

Background Three-part and four-part fracture-dislocations of the proximal humerus are characterized by severe soft tissue disruptions that can compromise the viability of the humeral head. As a result, nonunion and avascular necrosis are more common in these injuries. In such injuries, surgical treatment (internal fixation or arthroplasty) is performed in most patients who are determined to be fit for surgery to potentially restore shoulder function. Although the decision to preserve or replace the humeral head is simple in young patients or those > 65 years, in most other patients, the decision can be complicated, and little is known about which patient-related and injury-related factors may be independently

associated with poor shoulder function or complications like avascular necrosis.

Questions/purposes (1) What proportion of fractures united after internal fixation of a three-part or four-part fracture-dislocation of the proximal humerus, what is the mean Constant score at a minimum of 2 years after this injury, and what proportion had serious complications (such as loss of fixation, nonunion, reoperation, or avascular necrosis)? (2) After controlling for potential confounding variables, what factors are independently associated with poor shoulder function (defined as a Constant score < 55 out of 100) and occurrence of serious complications such as loss of fixation or reduction resulting in revision surgery, nonunion, or radiographic evidence of avascular necrosis of the humeral head?

Methods Between 2011 and 2017, the senior author of this study (ASG) treated 69 patients with three-part or four-part proximal humerus fracture dislocations. During this time, indications for internal fixation in these patients were adequate humeral bone quality as determined by the surgeon on radiographs, adequate bone stock and volume available for fixation in the humeral head as determined on CT images, and the absence of a head split component as assessed on preoperative radiographs and CT images. On this basis, 87% (60 patients) underwent internal fixation with a locked plate and suture fixation of the tuberosities through a deltopectoral approach. Thirteen percent (nine patients) underwent either a hemiarthroplasty or a reverse total shoulder arthroplasty. Of the 60 patients who underwent internal fixation, four declined to participate in the study and two with brachial plexus palsy were not considered for inclusion. This study focused on the remaining 54 patients

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who were considered potentially eligible. To be included, a minimum follow-up of 2 years was required; 11% (6 of 54) were lost before that time, and the remaining 48 patients were analyzed at a mean of 48 months \pm 17 months in this retrospective study, which drew data from longitudinally maintained institutional databases. Fracture union was assessed by obliteration of fracture lines and the presence of bridging trabecular bone on plain radiographs. Shoulder function was assessed using the Constant score, which is scored from 0 to 100 points, with 0 indicating the most disability and 100 the least disability. The anchor-based minimal clinically important difference for the Constant score is 9.8 points. Twelve patient-related and injury-related factors were analyzed using a multivariate regression model to identify factors that are independently associated with poor results after internal fixation as measured by shoulder function and the occurrence of serious complications. We categorized results as poor if patients had one or more of the following: Constant score $<$ 55 out of 100 at the last follow-up examination (for patients who underwent revision surgery, the Constant score immediately before revision was considered) and loss of fixation or reduction resulting in revision surgery, nonunion, or avascular necrosis of the humeral head. Patients were screened for avascular necrosis at 6 and 12 months after surgery, then annually for another 2 years. Further assessments were made only based on symptoms.

Results Seventy-nine percent of the fractures united within 18 weeks of surgery (38 of 48), and an additional 13% united by 24 weeks (6 of 48), while 8% did not unite (4 of 48). The mean Constant score at the last follow-up was 68 ± 12 . Twenty-one percent (10 of 48) had a Constant score $<$ 55, indicating poor shoulder function. Twenty-one percent (10 of 48) experienced avascular necrosis, and 15% (7 of 48) with either nonunion or avascular necrosis underwent revision shoulder arthroplasty. Two patients who underwent arthroplasty had both nonunion and avascular necrosis. After controlling for potentially confounding variables, we found that being a woman (odds ratio 1.7 [95% confidence interval 1.4 to 2.1]; $p = 0.01$), four-part fracture dislocations (OR 2.1 [95% CI 1.5 to 2.7]; $p < 0.001$), absence of a metaphyseal head extension (OR 2.4 [95% CI 1.8 to 3.3]; $p < 0.001$), absence of active back-bleeding from the humeral head (OR 3.4 [95% CI 2.3 to 5.1]; $p < 0.001$), height of the head segment $<$ 2 cm (OR 2.3 [95% CI 1.8 to 2.8]; $p < 0.001$), and absence of capsular attachments to the head fragment (OR 2.2 [95% CI 1.6 to 2.9]; $p < 0.001$) were independently associated with poor shoulder function and the occurrence of complications such as nonunion and avascular necrosis.

Conclusion Internal fixation of three-part and four-part proximal humerus fracture dislocations resulted in poor shoulder function and complications in a high number of patients, although fracture union was achieved in most

patients. A nonunion proportion of 8%, 21% proportion of avascular necrosis, and 15% proportion of patients who underwent revision surgery suggests this is a fairly terrible injury. Being a woman and injury factors such as four-part fracture dislocation, absent metaphyseal head extension and back-bleeding from the head, height of the fractured head segment $<$ 2 cm, and absence of capsular attachments to the head were independently associated with poor function and complications. Our findings can help surgeons decide between internal fixation and arthroplasty for the surgical treatment of these injuries in patients across different age groups and functional demands.

Level of Evidence Level III, therapeutic study

Introduction

Three-part and four-part fracture-dislocations are the most severe injuries among proximal humerus fractures [5]. These injuries are usually treated surgically. Internal fixation or arthroplasty is performed in most patients who are determined to be fit for surgery to try to restore shoulder function [12, 16]. Surgical reduction of the dislocated head segment and stable internal fixation of the proximal humerus is typically performed, especially in younger patients, regardless of the complexity of the injury. Humeral head replacement with either hemiarthroplasty [2, 19] or reverse shoulder arthroplasty [21] can be considered in patients $>$ 65 years old, depending on their level of activity [10, 11].

Table 1. Demographic and baseline data (n = 48 patients)

Variables	Value
Age in years, mean \pm SD	48 \pm 15
% women (n)	44 (21)
% patients with dominant hand involvement (n)	56 (27)
% smokers (n)	19 (9)
% of patients sustaining high-energy injury (n)	77 (37)
% with posterior dislocations (n)	15 (7)
% with four-part dislocation (n)	21 (10)
% of fractures with no active back-bleeding from the humeral head (n)	25 (12)
% of fractures with no metaphyseal extension (n)	37 (18)
% of fractures with head segment measuring $<$ 2 cm in height (n)	23 (11)
% of fractures with absent capsular attachments (n)	23 (11)
Time from injury to surgery in days, mean \pm SD	2.2 \pm 1.4

In some middle-aged patients with complex fracture dislocations and in more-active patients > 65 years old, the decision between humeral head preservation and replacement can be more difficult. Earlier studies [8, 17, 18] reported on certain patient-related and injury-related factors (Table 1) that can influence fracture union, shoulder function, and the occurrence of complications such as nonunion, loss of fixation [1], and humeral head osteonecrosis [15] after internal fixation. However, in those previous reports, some of these factors were studied in patients with more diverse fracture patterns in the proximal humerus. No studies, to our knowledge, have adequately controlled for some of the confounding factors such as smoking, age, mechanism of injury, and hand dominance to assess which factors are more strongly and independently associated with poor outcome scores, avascular necrosis, nonunion, and performance of revision surgery. This information might help surgeons to decide on internal fixation or arthroplasty as the index intervention for this difficult-to-treat injury.

We therefore asked: (1) What proportion of fractures united after internal fixation of a three-part or four-part fracture-dislocation of the proximal humerus, what is the mean Constant score at a minimum of 2 years after this injury, and what proportion had serious complications (such as loss of fixation, nonunion, reoperation, or avascular necrosis)? (2) After controlling for potential confounding variables, what factors are independently associated with poor shoulder function (defined as a Constant score < 55 out of 100) and occurrence of serious complications such as loss of fixation or reduction resulting in revision surgery, nonunion, or radiographic evidence of avascular necrosis of the humeral head?

Patients and Methods

Study Design and Setting

This was a retrospective study drawing data from longitudinally maintained trauma databases at four different urban high-volume tertiary care trauma centers from June 2011 to September 2017.

Participants

Patients with a three-part or four-part proximal humerus fracture-dislocation considered amenable for internal fixation by one senior surgeon (ASG) were included in this study. Between 2011 and 2017, the senior author treated 69 patients with three-part or four-part proximal humerus fracture dislocations. During this time, indications for internal fixation in these patients were adequate humeral

bone quality as determined by the surgeon on radiographs, adequate bone stock or volume available for fixation in the humeral head as determined on CT images, and the absence of a head split component as assessed on preoperative radiographs and CT images. On this basis, 87% (60 of 69 patients) underwent internal fixation with a locked plate construct and suture fixation of the tuberosities using a deltopectoral approach. Thirteen percent (nine patients) underwent either hemiarthroplasty or reverse total shoulder arthroplasty. The indications for arthroplasty were patients with low demand and poor bone quality who > 65 years, inadequate bone stock in the humeral head for fixation, and patients with a head split component. Of the 60 patients who underwent internal fixation, four declined to participate in the study and two with brachial plexus palsy were not considered for inclusion. This study focused on the remaining 54 patients who were considered potentially eligible. To be included, a minimum follow-up of 2 years was required; 11% (six patients) were lost before that time, and the remaining 48 patients were included and their results were analyzed at a mean of 48 months \pm 17 months in this retrospective study, which drew data from longitudinally maintained institutional databases.

Patients' Baseline Data

The mean age was 48 years \pm 15 years. Fifty-six percent (27 of 48 patients) were men and 44% (21) were women (Table 1).

Preoperative Evaluation and Outcome Assessment

Fractures were classified according to Neer's system [22] using plain radiographs (shoulder AP and modified axial views) and CT images. The images were read and classified by the senior authors (ASG and PS). All patients underwent internal fixation using a locked plate construct augmented with suture fixation of the tuberosities. Fracture union was assessed by two authors (BJ and RVR) based on the obliteration of fracture lines and the presence of bridging trabecular bone on plain radiographs. The Constant score was used to measure shoulder function in these patients [9]. It is scored from 0 to 100 points, with 0 indicating the most disability and 100 the least disability. The anchor-based minimum clinically important difference for the Constant score is 9.8 points [20]. We categorized results as poor if patients had one or more of the following: Constant score < 55 or loss of fixation resulting in revision surgery, nonunion, or avascular necrosis (AVN) of the humeral head, which was diagnosed based on the presence of sclerotic changes with or without partial or complete collapse of the humeral head on plain radiographs [15]. We studied 12

patient-related and injury-related factors (Table 1) to identify their association with poor shoulder function and serious complications using a multivariate regression analysis model.

Surgical Technique

All patients underwent surgery through a conventional deltopectoral approach. Tuberosity fragments were controlled using heavy nonabsorbable sutures (Size 2 fiber wires, Arthrex). The head fragment was relocated with a lever and Schantz pin using a combination of disimpaction and derotation [23]. After the head fragment was retrieved and relocated, it was assessed for the presence of soft tissue attachments, active back-bleeding from the cancellous bone surface, and the presence or absence of an intact continuous medial metaphyseal extension. The height of the head fragment was measured using a K-wire drilled into the summit of the relocated humeral head under fluoroscopy, aiming for a center-center position on AP and axial views. Keeping the K-wire at the chondral level, the surgeon measured the protruding length of the wire using an identical-length K-wire to derive the head height. These four parameters were recorded in the patient's procedure notes. Fracture reduction was performed using standard techniques, followed by definitive fixation using laterally positioned locked plates (PHILOS, Depuy-Synthes). Fracture reduction and fixation was confirmed by the two senior surgeons (ASG and PS) based on the head-shaft alignment, position of the tuberosities, and cortical contact at the neck fracture on true AP view in the scapular plane and axial views. Suture fixation of the tuberosities was performed in all procedures. The impacted osteochondral defects were elevated and filled with cancellous autografts in four patients with large, engaging lesions. None of the labral lesions were primarily repaired.

Postoperative Rehabilitation and Follow-up

Postoperatively, patients were subjected to a standard rehabilitation program. Internal and external rotation was restricted in patients with posterior and anterior fracture dislocations, respectively. Pendulum movements were initiated on Day 1, followed by passive and active assisted movements at 3 weeks. Abduction beyond 90° was restricted for 6 weeks. Active movements and isometric strengthening exercises of the deltoid and cuff muscles were initiated at the end of Week 6.

Radiographs were taken at six weekly intervals to assess maintenance of reduction, loss of fixation, and fracture union. After union, further radiographs were only taken based on symptoms. The Constant score was recorded at 6 months,

12 months, and 24 months and every year thereafter for a further 3 years. The last Constant score available was used in this study to assess the patient's shoulder function. For patients who had undergone revision surgery to address nonunion or avascular necrosis, the last Constant score before the revision procedure was used for statistical analysis.

Primary and Secondary Study Outcomes

Our primary goals were to study the proportion of fractures that united after internal fixation of three-part and four-part proximal humerus fracture-dislocations, to measure shoulder function at a minimum follow up of 2 years using the Constant score, and to identify the incidence of serious complications such as nonunion, loss of fixation resulting in revision surgery, and AVN of the humeral head after internal fixation of these injuries.

Our secondary goal was to identify which of the 12 patient-related and injury-related factors we studied were independently associated with poor shoulder function (Constant score < 55 out of 100) and occurrence of serious complications such as nonunion, loss of fixation resulting in revision surgery, and AVN.

Ethical Approval

Ethical approval for this study was obtained from Rela Hospital, Chennai, India (number: ECR/1276/Inst/TN/2019/113). Written informed consent to participate in this study was obtained from all patients.

Statistical Analysis

The statistical analysis was performed using Python 3 software. A multivariate logistic regression model was created with the scikit-learn library sklearn.linear_model version (0.21.1)

There were 12 patient-related and injury-related factors (independent variables) (Table 1) that were studied for any association with poor results after internal fixation (dependent variable). A poor result was defined by presence of one or more of the following; Constant score < 55 out of 100, nonunion, AVN, and loss of fixation resulting in revision surgery. We performed an initial exploratory univariate analysis to understand the association between the independent variables and the dependent variable. Independent variables showing a strong association with a poor result after internal fixation in the univariate analysis, as evident by a p value < 0.05 and power > 80%, were advanced to a more definitive multivariate regression analysis. Multivariate logistic regression was performed

with nine of the 12 independent variables (age, gender, mechanism of injury, direction of the dislocation, Neer’s classification, humeral head height, active back bleeding from the head, capsular attachments, and metaphyseal extension) using the Enter methodology to adjust for confounding. Of the nine independent variables, all but age were categorical variables. The dependent variable (poor result after internal fixation) was also a binary categorical variable. The odds ratio and its 95% confidence interval were calculated. A two-tailed significance test was used, with the level of significance set at a p value of < 0.05 to define the independent association between the tested variables.

Results

Union, Outcomes Scores, and Serious Complications

A total of 79% of the fractures united within 18 weeks of the index procedure (38 of 48 fractures), and an additional 13% united by 24 weeks (6 of 48). Eight percent did not unite (4 of 48) and were treated with additional surgeries. The mean Constant score at the last follow-up was 68 ± 12. Sixty-three percent of the patients (30 of 48) returned to their full preinjury level of activity, while 37% (18 of 48) of patients had restrictions or needed to modify their work and activities. Twenty-five percent of patients (12 of 48) had poor shoulder function or encountered serious complications. Twenty-one percent of patients (10 of 48) had a Constant score of < 55 out of 100. Eight percent of patients (4 of 48) had nonunion; two of these patients underwent bone grafting. One patient successfully achieved fracture union after grafting. The remaining three patients underwent shoulder

arthroplasty. Twenty-one percent of patients (10 of 48) had radiographic evidence of AVN, six of whom underwent shoulder arthroplasty. Two patients who underwent arthroplasty had both AVN and nonunion. A total of 15% (of patients (7 of 48) underwent arthroplasty; hemiarthroplasty in three patients and reverse total shoulder arthroplasty in four patients.

Factors Independently Associated with Poor Shoulder Function and Serious Complications

After controlling for potentially confounding variables such as age, mechanism of injury, smoking and hand dominance, we found that being a woman (OR 1.7 [95% CI 1.4 to 2.1]; p = 0.01), four-part fracture dislocations (OR 2.1 [95% CI 1.5 to 2.7]; p < 0.001), absence of a metaphyseal head extension (OR 2.4 [95% CI 1.8 to 3.3]; p < 0.001), absence of active back-bleeding from the humeral head (OR 3.4 [95% CI 2.3 to 5.1]; p < 0.001), height of the head segment < 2 cm (OR 2.3 [95% CI 1.8 to 2.8]; p < 0.001), and absence of capsular attachments to the head fragment (OR 2.2 [95% CI 1.6 to 2.9]; p < 0.001) were independently associated with poor shoulder function and the occurrence of complications such as nonunion and AVN (Table 2).

Discussion

Three-part and four-part proximal humerus fracture-dislocations are terrible injuries characterized by severe osseous and soft tissue disruptions compromising the vascular supply to the humeral head [14]. These injuries are

Table 2. Logistic regression analysis of select variables to test for their independent association with poor results after internal fixation

Independent variables	Dependent variable (poor results after internal fixation)	
	OR (95% CI)	p value
Four-part dislocations ^a	2.1 (1.5-2.7)	< 0.001
No active back bleeding from the head ^a	3.4 (2.3-5.1)	< 0.001
Absent metaphyseal extension ^a	2.4 (1.8-3.3)	< 0.001
Head height < 2 cm ^a	2.3 (1.8-2.8)	< 0.001
Absent capsular attachments ^a	2.2 (1.6-2.9)	< 0.001
Age ^b	1.3 (1.1-1.6)	0.09
Women ^a	1.7 (1.4-2.1)	0.01
High-energy injury ^a	0.98 (0.83-1.1)	0.74
Posterior dislocation ^a	1.1 (0.83-1.2)	0.41

^aCategorical variable.
^bContinuous variable.

typically treated by internal fixation in active, younger patients, while arthroplasty is a reasonable choice in patients older than 65 years [6, 7, 11, 13, 14]. The decision to preserve or replace the humeral head cannot be made based on age alone and depends on several patient-related and injury-related factors [8, 17, 18] that can influence results after internal fixation. We studied some of those factors in exclusively three-part and four-part fracture dislocations across different age groups to identify specific factors that are independently associated with poor shoulder function and serious complications such as AVN and nonunion after internal fixation. We found that internal fixation of these injuries led to fracture union in most patients. We also encountered poor shoulder function and serious complications treated with revision surgery in a high number of patients. The study showed that being a woman and injury-related factors such as four-part fracture dislocations, small head segment (< 2 cm in height), absence of metaphyseal head extension, active back-bleeding, and capsular attachments were independently associated with poor shoulder function and the occurrence of serious complications after internal fixation of these injuries. These results from our analysis could help the surgeon decide between internal fixation and arthroplasty in select patients.

Limitations

The study has limitations. The study was retrospective, and interpretation of results is subject to bias. With a retrospective design, we could only study the strength of the association between the chosen patient-related and injury-related factors and a poor result after internal fixation but could not predict a poor result using these factors, which would require a prospective study design. The sample size may also have been inadequate, considering that very few posterior three-part and four-part fracture dislocations were included in the study. With the minimum follow-up for inclusion being 2 years, some complications such as AVN might not have occurred in some of these patients, and the long-term results in such patients could be different. There was no control group to know whether arthroplasty could have been a better option, especially in certain patients older than 65 years.

The preoperative assessment of bone quality and bone stock in the humeral head was done subjectively by the treating surgeons. This may not have been entirely accurate, and we did not use any validated indices. The 12 patient-related and injury-related factors we studied were chosen based on our surgical experience and published studies on the topic [8, 17, 18]. Some more-important factors might have been missed. Our statistical method of performing an exploratory (univariate) analysis first and subjecting only select variables showing a strong association to the multivariate model might have missed important variables. However, the

results can still be used as a template for future prospective comparative trials. The findings can also be used to choose either internal fixation or arthroplasty in treating injuries in patients across different age groups and demands.

Union, Outcomes Scores, and Serious Complications

Although most patients achieved osseous union, more than one in five experienced AVN, and 15% (7 of 48) underwent revision total shoulder arthroplasty. Given that our minimum follow-up was only 2 years, it seems likely that more patients will undergo conversion to arthroplasty in the future. Twenty-one percent of patients (10 of 48) also had poor Constant scores, indicating there was poor functional recovery in a high number of patients. The results from our study show the terrible nature of these injuries, and previous authors have reported similar outcomes. Soliman and Koptan [26] reported that 92% (36 of 39) of fractures united and 21% (8 of 39) had AVN in patients with four-part proximal humerus fracture-dislocations. The Constant score in their patients was, however, much higher, at 77 ± 6 , compared with 68 ± 12 in our study. This may have been because of the much younger cohort: 30 years \pm 6 years in their series compared with 48 years \pm 15 years in ours. Although age was not independently associated with poor shoulder function, patients with older age had progressively smaller Constant scores in our study [4]. Similar results have been reported after internal fixation of complex proximal humerus fracture-dislocations [24, 25].

Factors Independently Associated with Poor Clinical Outcomes

After controlling for potentially confounding variables such as age, smoking, hand dominance, and mechanism of injury, we identified that certain patient-related and injury-related factors were independently associated with serious problems after internal fixation (poor Constant scores, AVN, or conversion to arthroplasty). These included being a woman, four-part fracture-dislocations, the absence of a metaphyseal head extension and capsular attachments, height of the head segment < 2 cm, and absence of active back-bleeding from the fractured humeral head.

Bahrs et al. [3] reported that the complexity of proximal humerus fractures is gender-specific, and women especially tend to experience more complex fracture patterns than men do. In our study, women had more complex fracture patterns; 29% of women experienced a four-part fracture-dislocation compared with only 15% of men, which was the most probable reason for poor Constant scores and the higher incidence of serious complications in women.

Several intraoperative factors have been studied to prognosticate long-term results after internal fixation of proximal humerus fractures. Hertel et al. [18] described that the presence of a posteromedial extension from the head protects against humeral head osteonecrosis. Robinson et al. [24] classified their patients into two groups based on capsular attachments, head height > 2 cm, and back-bleeding from the humeral head. They found that results after internal fixation were less satisfactory if all these three parameters were absent. We considered these four variables described in the above two studies independently to study their individual effects on shoulder function and complications after internal fixation. Our results were different from those of Robinson et al. [24]; every one of these four intraoperative factors we studied were independently associated with poor Constant scores and the occurrence of serious complications.

Conclusion

We found that internal fixation for three-part and four-part fracture dislocations was associated with a high incidence of poor shoulder function and serious complications, despite the achievement of fracture union in most patients. Four-part fracture dislocations, fracture-related variables such as the absence of capsular head attachments, absence of a metaphyseal head extension, absence of active back-bleeding from the head, and humeral head height < 2 cm were independently associated with poor shoulder function and serious complications such as nonunion and AVN. Our results showed that except for gender, none of the patient-related factors were independently associated with poor function or complications, whereas several injury-related factors were independently associated with serious problems after surgery. The presence or absence of these factors can be used to decide between arthroplasty and internal fixation in the surgical treatment of these injuries in patients with different functional demands and across age groups.

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