Surgical Treatment of Three and Four-Part Proximal Humeral Fractures

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Surgical Treatment of Three and Four-Part Proximal Humeral Fractures

By Brian D. Solberg, MD, Charles N. Moon, MD, Dennis P. Franco, MD, and Guy D. Paiement, MD

Investigation performed at Cedars Sinai Medical Center, Los Angeles, California

Background: Optimal surgical management of three and four-part proximal humeral fractures in osteoporotic patients is controversial, with many advocating prosthetic replacement of the humeral head. Fixed-angle locked plates that maintain angular stability under load have been proposed as an alternative to hemiarthroplasty for the treatment of some osteoporotic fracture types.

Methods: The records of 122 consecutive patients who were fifty-five years of age or older and in whom a Neer three or four-part proximal humeral fracture had been treated surgically between January 2002 and November 2005 were studied retrospectively. After exclusions, thirty-eight patients treated with a locked-plate construct were compared with forty-eight patients who had undergone hemiarthroplasty. All patients had radiographic and clinical follow-up at a minimum of twenty-four months and an average of thirty-six months. Reduction and implant placement were evaluated radiographically. Clinical outcomes were measured with use of the Constant-Murley system.

Results: The mean Constant score (and standard deviation) at the time of final follow-up was significantly better in the locked-plate group (68.6 ± 9.5 points) than in the hemiarthroplasty group (60.6 ± 5.9 points) ($p < 0.001$). The Constant scores for the three-part fractures in the locked-plate and hemiarthroplasty groups were 71.6 and 60.4 points ($p < 0.001$), respectively, and the scores for the four-part fractures in those groups were 64.7 and 60.1 points ($p = 0.19$), respectively. Patients with an initial varus extension deformity in the locked-plate group had significantly worse outcomes than those with a valgus impacted pattern (Constant score, 63.8 compared with 74.6 points, respectively; $p < 0.001$). Complications in the group treated with locked-plate fixation included osteonecrosis in six patients, screw perforation of the humeral head in six patients, loss of fixation in four patients, and wound infection in three patients. Loss of fixation was seen only in patients with >20° of initial varus angulation of the humeral head. Complications in the hemiarthroplasty group included nonunion of the tuberosity in seven patients and wound infection in three patients.

Conclusions: In this series, open repair with use of a locked plate resulted in better outcome scores than did hemiarthroplasty in similar patients, especially in those with a three-part fracture, despite a higher overall complication rate. Open reduction and internal fixation of fractures with an initial varus extension pattern should be approached with caution.

Level of Evidence: Therapeutic Level III. See Instructions to Authors for a complete description of levels of evidence.

Proximal humeral fractures are common and have a bimodal age distribution[1,2]. Fracture-dislocations in younger patients result from high-energy injuries, and most surgeons attempt open reduction and internal fixation if at all possible[3-7]. Osteoporotic fractures in elderly patients are commonly associated with minor trauma such as ground-level falls, and most are minimally displaced impacted fractures that can be treated successfully with nonoperative means[2,8]. However, the optimal surgical management of three and four-part proximal humeral fractures in elderly osteoporotic patients remains controversial, with many advocating prosthetic replacement of the humeral head[9-15].

Recent advances in fracture fixation technology have led to the development of fixed-angle locked plates that maintain angular stability under load[16-18]. Biomechanical data suggest that these implants can resist physiologic loads in osteoporotic

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bone and may provide an alternative to hemiarthroplasty[19]. Clinical series have demonstrated some success with the use of these plates for two-part fractures, but their clinical utility for three and four-part fractures remains unclear[20-22]. Substantial rates of complications, including loss of fixation, humeral head perforation, and mechanical impingement, have been reported[20-23].

We retrospectively compared the outcomes of patients in whom a three or four-part proximal humeral fracture had been treated with either (1) open reduction and internal fixation with a locked plate or (2) hemiarthroplasty with cement.

Materials and Methods

The cases of 122 consecutive patients in whom a Neer three or four-part fracture had been treated surgically at our institution between January 2002 and November 2005 were retrospectively studied. Institutional review board approval was obtained for a retrospective review of patient records and radiographs, and informed consent was obtained from all patients in the final study group. Inclusion criteria included low-energy three or four-part proximal humeral fractures in patients fifty-five years of age or older treated with a locked plate or a hemiarthroplasty and followed clinically and radiographically for a minimum of twenty-four months. Three trauma-fellowship-trained surgeons were involved in the surgical management of all patients. Patients were excluded if they were younger than fifty-five years of age, had undergone surgical repair through a deltoid-splitting approach, had died during the review period, had a documented full-thickness rotator cuff tear at the time of the index procedure, or had sustained a traumatic refracture of the humerus or glenoid or a traumatic dislocation during the follow-up period. Fractures were classified according to the Neer[2] and the Orthopaedic Trauma Association (OTA)[24] fracture classification systems on the basis of the initial radiographs, which were available for all patients, or computed tomography scans, which were available for ninety-nine of the 122 patients. Displacement of a fracture part was defined, on the basis of Neer's criterion, as greater than either 1 cm of displacement or 45° of angulation.

Fifty-one patients in whom a three or four-part fracture had been treated with a locked plate were identified. Thirteen patients were excluded: eight had incomplete follow-up, two had died, two had undergone a deltoid-splitting surgical approach, and one had fallen and sustained a displaced glenoid fracture during the follow-up period. Thirty-eight patients (75%) had complete clinical and radiographic follow-up at a minimum of twenty-four months.

Seventy-one patients who had undergone a hemiarthroplasty for the treatment of a three or four-part fracture during the time period specified above were identified. Twenty-four were excluded: eleven had incomplete follow-up, five had a full-thickness rotator cuff tear documented at the time of the index procedure, four had undergone conversion to a hemiarthroplasty after open reduction and internal fixation, two had fallen and sustained a traumatic dislocation of the prosthesis, one had died, and one had sustained a periprosthetic humeral fracture requiring revision. Forty-eight patients (68%) had complete clinical and radiographic follow-up at a minimum of twenty-four months.

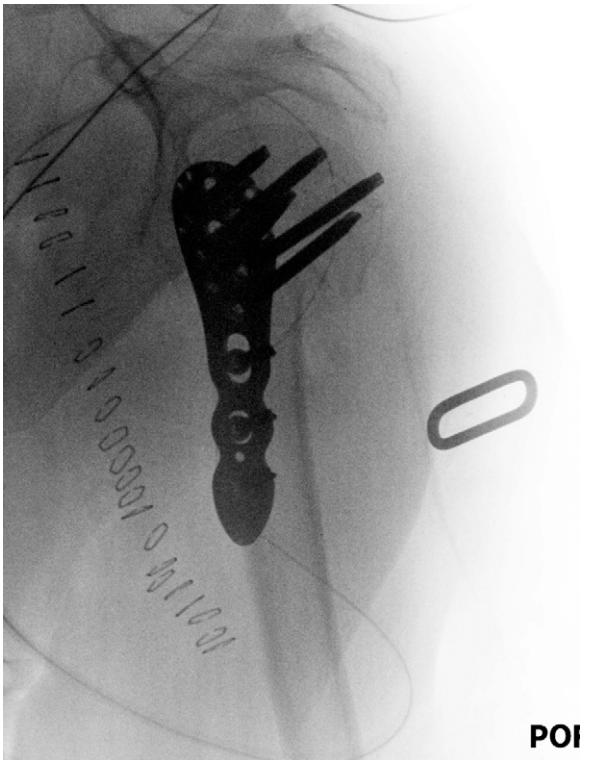

Fig. 1

Postoperative Y view showing superoposterior screw perforation of 3 mm.

The hemiarthroplasties were performed through a standard deltopectoral approach with the patient in the beach-chair position in all but four cases (later excluded from the study), in which the hemiarthroplasty was performed to convert a locked-plate construct and was done with the patient in a supine position. While a cemented humeral stem was used in all cases, the implants were produced by three different manufacturers: Zimmer (Warsaw, Indiana), DePuy (Warsaw, Indiana), and Stryker (Mahwah, New Jersey). Implant selection was not randomized and depended on surgeon preference. Tuberosity fractures were repaired with placement of number-2 FiberWire suture (Arthrex, Naples, Florida) through the implant fins and through bone tunnels in the humeral shaft and with direct tuberosity-to-tuberosity apposition. Bone-grafting of the tuberosities was not routinely performed. Intraoperative or immediate postoperative anteroposterior radiographs were made with the shoulder in 20° of external rotation to assess the implant position.

The locked-plate repairs were performed with one of three locked proximal humeral plate systems manufactured by Synthes (West Chester, Pennsylvania), Stryker, or Zimmer. Implant selection was not randomized and depended on surgeon preference. The surgical repair was performed, with the patient in the supine position on a radiolucent table, through a

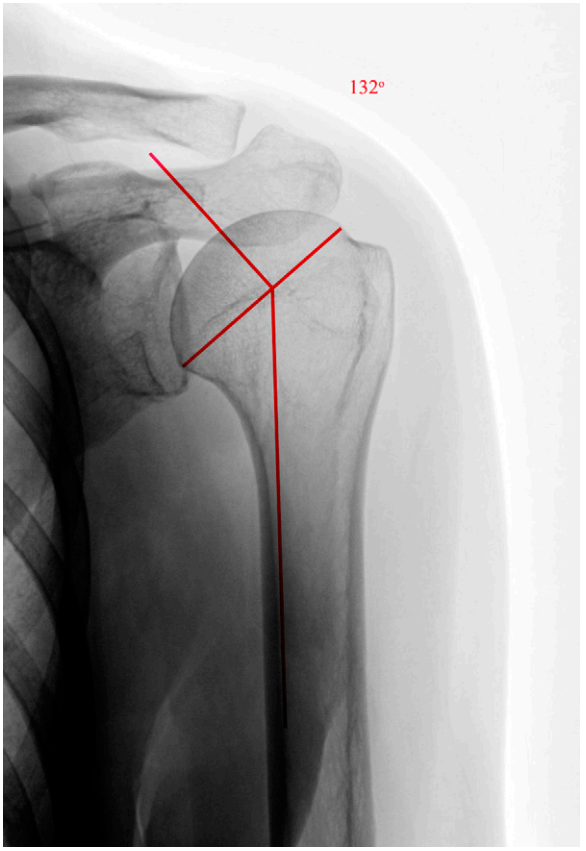

Fig. 2
Calculation of head-shaft angulation in an intact humerus.

standard deltopectoral surgical approach and with image intensification brought from the ipsilateral side. Surgical dissection was undertaken between the tuberosities, and articular surface reductions were carried out with use of a tamp on the lateral articular margin or a periosteal elevator placed under the medial calcar segment. Tuberosity fragments were manipulated with use of Kirschner wires, sutures through the intact rotator cuff attachment on the tuberosities, or tenaculum clamps. The fractures were reduced and were provisionally fixed with Kirschner wires before the locked plate was applied. Internal fixation was applied under image intensification in the anteroposterior and axillary projections to verify reduction, plate position, and screw lengths. Tuberosity repair was augmented by placement of nonabsorbable sutures through the rotator cuff tendons and the cephalad suture holes in the plate. Radiographs (20° external rotation anteroposterior, and axillary views) were made intraoperatively or immediately postoperatively to assess reduction and implant position. Three patients were taken back to the operating room within twenty-four hours because of ≥3 mm of screw perforation of the humeral head (Fig. 1). Patients presenting with late-onset screw perforation were examined with computed tomography scans to assess the magnitude and location of the hardware prominence.

All patients had anteroposterior radiographs made with the shoulder in 20° of external rotation and axillary radiographs of both the involved and uninvolved, contralateral shoulder (for comparison with the treatment side) to assess fracture reduction, implant position, the integrity of the metaphyseal hinge, and tuberosity displacement or migration. All radiographs were made at a standardized distance with use of a true-size digital format that was calibrated to within 1% of known values every 5000 images. There was no correction for magnification errors introduced by body habitus or patient positioning. In the locked-plate group, tuberosity displacement was assessed as the sum of the tuberosity displacements on the anteroposterior and axillary views by overlaying one of the two true-size images over the other and measuring the greatest extent of displacement. Head-shaft angulation was calculated on the 20° external rotation anteroposterior radiograph by comparing a tangent to the articular surface with a line parallel to the long axis of the humeral shaft as previously described by Hertel et al. (Fig. 2)[25]. The metaphyseal hinge distance was defined as the amount of intact metaphyseal bone (in millimeters) attached to the humeral head fragment seen on the initial radiographs.

In the hemiarthroplasty group, the humeral head height was recorded relative to the intact greater tuberosity on the uninvolved side, with a positive value recorded for a cephalad

TABLE I Patient Characteristics of Both Cohorts

	Locked Plate	Hemiarthroplasty	P Value
Patients *(no.)*	38	48	
Age* *(yr)*	66.5 ± 8.6	67.4 ± 6.3	0.49
Duration of follow-up* *(mo)*	36.1 ± 10.0	35.3 ± 8.9	0.68
Male/female *(no.)*	12/26	14/34	>0.90
Three-part fracture *(no.)*	23 (61%)	25 (52%)	0.52
Four-part fracture *(no.)*	15 (39%)	23 (48%)	0.44
Dislocation *(no.)*	8 (21%)	10 (21%)	>0.90

*The values are given as the mean and standard deviation.

TABLE II Comparison of Constant Scores Between Cohorts

	Constant Score* *(points)*		
	Locked Plate	Hemiarthroplasty	P Value
All patients			
Total	68.6 ± 9.5	60.6 ± 5.9	<0.001
Pain	13.2 ± 3.2	12.3 ± 2.5	0.05
Power	15.7 ± 1.8	15.4 ± 2.0	0.39
Range of motion	25.1 ± 9.8	19.9 ± 2.4	<0.001
Activities of daily living	15.0 ± 2.1	12.5 ± 2.1	<0.001
Three-part fractures	71.6 ± 7.5	60.4 ± 5.7	<0.001
Four-part fractures	64.7 ± 10.8	60.1 ± 6.1	0.19
Initial varus extension fracture patterns†	63.8 ± 7.8 (32%)	60.2 ± 6.1 (27%)	0.14
Initial valgus impaction fracture patterns†	74.6 ± 9.2 (68%)	60.3 ± 6.3 (73%)	<0.001
P value‡	<0.001	0.85	

*The values are given as the mean and standard deviation. †The percentage of patients in the subgroup is given in parentheses. ‡For the difference between subgroups based on the fracture pattern (varus extension or valgus impaction).

difference and a negative value recorded for a caudad difference. Tuberosity displacement was determined in the same fashion as described for the patients in the locked-plate group. Patients with a suspected nonunion or progressive migration of the tuberosity underwent a computed tomography scan.

All shoulders were immobilized in a sling for the first ten days postoperatively. Physical therapy was then started with gentle Codman and active-assisted range-of-motion exercises within the first two weeks postoperatively. Gentle resistive exercises with unrestricted passive motion were begun at six weeks postoperatively. Patients were followed clinically and radiographically at two and six weeks postoperatively and at three-month intervals thereafter. Shoulder outcomes were assessed with use of the Constant and Murley scoring system[26] at the last clinical shoulder examination. The active range of motion was measured with a goniometer. Power testing was performed with use of a digital dynamometer (Ametek, Largo, Florida) with the elbow extended and the arm abducted 60°.

The method of surgical treatment was chosen preoperatively on the basis of radiographs and computed tomography scans. Hemiarthroplasty was selected for patients with an articular surface fracture or a head-split pattern (thirty patients), displacement of the anatomic neck of >2 cm (seventeen), impaction of the articular surface (nine), dislocation of the humeral head for more than twenty-four hours (six), a documented previous rotator cuff tear (six), or an inability to perform open reduction and internal fixation with an open technique (three). All other patients underwent an attempt at open reduction and internal fixation with a locked plate. Four patients undergoing open reduction and internal fixation had immediate conversion to a hemiarthroplasty, two because of an inability to reduce the fracture and two because of iatrogenic intraoperative splitting of the head fragment; these patients were excluded from the study.

Statistical Analysis

The Fisher exact test or Student t test was used for comparison of demographic variables between the hemiarthroplasty and locked-plate groups. The Mann-Whitney U test (Wilcoxon rank sum test) was used to compare the outcomes data between the groups, and correlation was analyzed with a Spearman correlation coefficient. The level of significance was set at $p \leq 0.05$.

Source of Funding

No external funding was received in support of this study.

Results

With the numbers studied, there were no apparent differences between the two groups with regard to age, sex, humeral head dislocation rate, or fracture type (Table I). The patients in the locked-plate group underwent surgical treatment at an average of 4.8 days after the injury compared with an average of 6.9 days in the hemiarthroplasty group ($p = 0.24$).

The locked-plate cohort had an overall mean Constant score (and standard deviation) of 68.6 ± 9.5 points at a mean of thirty-six months (range, twenty-four to fifty-two months) postoperatively. The Constant scores in the three-part and four-part-fracture groups were 71.6 ± 7.5 and 64.7 ± 10.8 points, respectively, at the time of the last follow-up ($p = 0.11$). According to the OTA classification, two fractures were 11-B1, three were 11-B2, seven were 11-B3, twelve were 11-C1, thirteen were 11-C2, and one was 11-C3. Twenty-six (68%) of the thirty-eight patients presented with a valgus impacted humeral head deformity (OTA C type), and their overall mean Constant score was 74.6 ± 9.2 points; twelve patients (32%) had a varus extension humeral head deformity (OTA B type), and their mean Constant score was 63.8 ± 7.8 points ($p < 0.001$). The differences in the outcomes be-

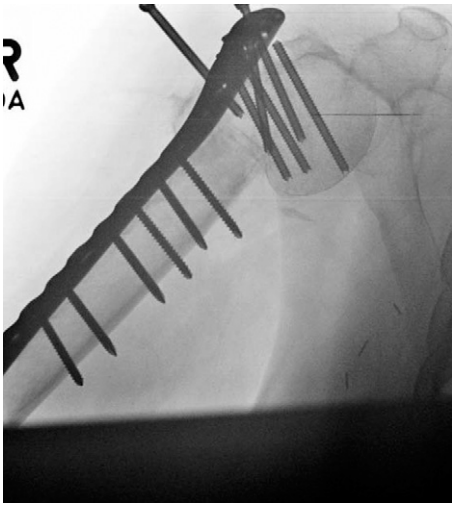

Fig. 3
Hardware failure with varus collapse at the site of an initially malreduced fracture.

tween the locked-plate and hemiarthroplasty groups are summarized in Table II.

Complications in the locked-plate group included three wound infections (8%), with one of them requiring surgical débridement with retention of the plate. Osteonecrosis of the humeral head developed in six patients (16%), who had a mean final Constant score of 62.5 ± 4.6 points, which was significantly worse than the mean score for the patients without osteonecrosis in the locked-plate group (68.7 points; $p = 0.05$) but was comparable with the score in the hemiarthroplasty group (59.7 points; $p = 0.25$). Six patients had screw perforation of the humeral head, and all underwent a second operation to reposition or remove the screw. Three of these patients underwent screw repositioning within twenty-four hours after the index operation, whereas three patients presented at an average of 4.5 months with varus subsidence of the fracture. All of the patients with late-onset screw perforation had extension of 1 to 3 mm of the screw through the superoposterior part of the humeral head, and all subsequently underwent screw removal at an average of 7.4 months. The mean Constant score for the patients with head perforation was 67.8 ± 9.6 points compared with 71.4 ± 8.5 points for those without perforation. The numbers of patients were not sufficient to allow us to determine if this difference was significant. Four patients had loss of fixation of the implant requiring conversion to a hemiarthroplasty. Three of these patients had the plate cut out through the humeral head, and one had varus loosening of the implant and collapse (Fig. 3). All four patients had an initial varus malreduction of >20°. The hardware failures occurred within eight weeks after the initial repair, and the hemiarthroplasties were performed within seventeen weeks after the index procedure. The patients with conversion of a failed open reduction and internal fixation to a hemiarthroplasty were considered to be part of the locked-plate group for the final comparison. The mean Constant score for these four patients was only 47.5 ± 3.5 points at the time of the latest follow-up (at a mean of twenty-nine months). There were no fractures of the locked plates.

The forty-eight patients in the hemiarthroplasty group had an overall mean Constant score of 60.6 ± 5.9 points at a mean of thirty-five months (range, twenty-four to fifty-two months) postoperatively. The mean Constant scores for the patients with a three-part fracture and those with a four-part fracture were 60.4 ± 5.7 and 60.1 ± 6.1 points, respectively, at the time of the last follow-up ($p > 0.90$). According to the OTA classification, three fractures were 11-B1, four were 11-B2, seven were 11-B3, fourteen were 11-C1, seventeen were 11-C2, and three were 11-C3. Thirty-five (73%) of the forty-eight patients presented with a valgus impacted humeral head fracture, and thirteen had a varus extension deformity. The patients with valgus impaction had a mean final Constant score of 60.3 ± 6.3 points compared with 60.2 ± 6.1 for those with varus deformity ($p > 0.85$).

Complications in the hemiarthroplasty group included a wound infection in three patients, with one of them requiring surgical irrigation and débridement with retention of the prosthesis. Computed tomography documented nonunion of the greater tuberosity in seven patients (15%), with an average of 8.8 ± 1.4 mm of tuberosity migration. All seven patients underwent a reoperation with autogenous bone-grafting and revision of the tuberosity fixation. The mean final Constant score in this group (52.9 ± 1.9 points) was significantly lower than that for the patients without a tuberosity nonunion (60.8 ± 6.0 points) ($p < 0.001$). The patients with a tuberosity nonunion were significantly older (74.4 years) than the patients who had primary tuberosity healing (66.5 years) ($p < 0.001$).

In the locked-plate group, the initial tuberosity displacement was variable, ranging from 0 to 8 mm, and was not progressive over time. Tuberosity displacement did not appear to have a significant effect on the final Constant score ($r = -0.23$, $p = 0.15$). The mean Constant score for the patients

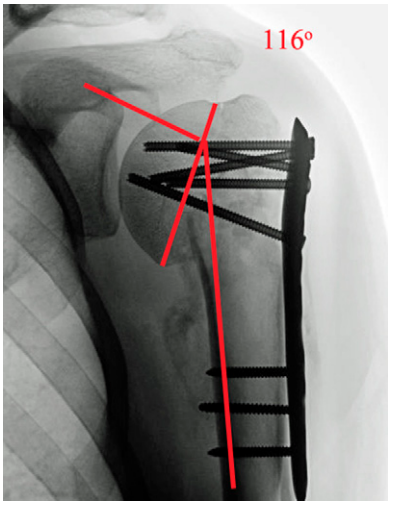

Fig. 4
Varus malreduction of approximately 15°.

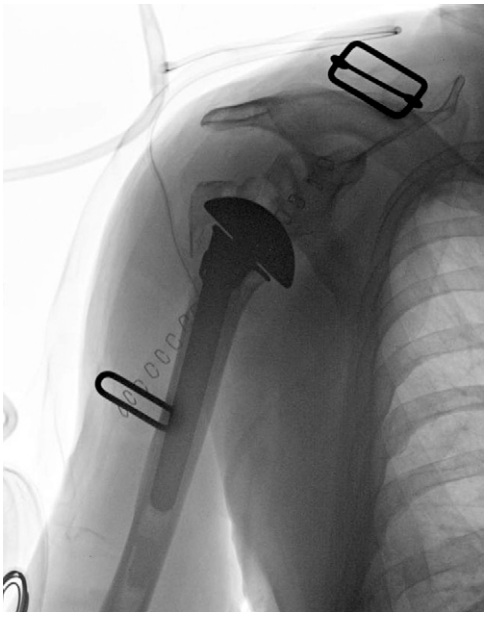

Fig. 5
Suboptimal placement of the hemiarthroplasty implant, with negative humeral head height and >5 mm of medial calcar offset.

with >5 mm of tuberosity displacement did not differ from that for the patients with ≤5 mm of displacement (66.8 compared with 70.2 points), but the data did not have sufficient power to prevent a type-II error. The metaphyseal hinge length was not correlated with the final outcome ($r = 0.136$, $p = 0.41$) but was strongly correlated with the development of osteonecrosis ($r = -0.94$, $p < 0.001$). Osteonecrosis developed in all patients in whom the metaphyseal hinge length was <2 mm. There was also a significant correlation between initial varus malreduction and the final Constant score ($r = -0.732$, $p < 0.001$). Of the twenty-four patients who had <5° of initial varus angulation of the humeral head, none had progressive varus subsidence over time, and these patients had a mean final Constant score of 76 points. Ten patients had an initial varus malreduction ranging from 5° to 20°, and all had progressive varus subsidence averaging 7.9° (Fig. 4); their mean Constant score was 66 points. The thirty-four patients with initial varus angulation of ≤20° had a better outcome than the patients in the hemiarthroplasty group (mean Constant scores, 71.4 compared with 59.8 points; $p < 0.001$). Four patients had an initial malreduction of >20°, and all four had rapid varus subsidence, loss of fixation, and conversion to a hemiarthroplasty; the mean Constant score was 47 points.

In the hemiarthroplasty group, the initial tuberosity displacement did not predict the subsequent development of nonunion and was not correlated with the final outcome ($r = -0.098$, $p = 0.49$). The humeral head height had a significant positive correlation with the outcome ($r = 0.54$, $p < 0.001$), and the best outcomes were seen in the patients with a positive variance of humeral head height. The medial calcar offset had a significant negative correlation with the final outcome ($r = -0.50$, $p < 0.001$), and the best outcomes were seen in the patients in whom the medial calcar offset approached zero (Fig. 5). The correlations between the radiographic measurements in the two groups are summarized in Table III.

The comparisons of the Constant scores between the locked-plate and hemiarthroplasty groups (Table II) showed the scores for power to be comparable (15.7 compared with 15.4 points; $p = 0.39$). The difference in the pain score reached significance (13.2 compared with 12.3 points; $p = 0.05$), but the clinical relevance of this finding is questionable. There was a pronounced difference, which was both statistically significant and clinically relevant, between the two groups with regard to the scores for activities of daily living (15.0 compared with 12.5 points; $p < 0.001$) and those for range of motion (25.1 compared with 19.9 points; $p < 0.001$). The Constant scoring scale is heavily weighted toward the range-of-motion and activity components, which explains the overall clinical and significant differences between the two groups.

TABLE III Influence of Radiographic Parameters on Final Outcome

Parameter	Correlation Coefficient (Spearman Rho)	P Value
Locked-plate group		
Tuberosity displacement	−0.23	0.15
Varus malreduction	−0.73	<0.001
Hemiarthroplasty group		
Humeral head height	0.54	<0.001
Medial calcar offset	−0.50	<0.001
Tuberosity displacement	−0.098	0.49

Discussion

Optimal treatment of three and four-part fractures of the proximal part of the humerus in patients with poor bone quality is controversial[13,14,20-22]. Open reduction and internal fixation of these fractures with standard implants has been discouraged[3,14,18]. Locked plates, which maintain angular stability in the face of axial load, have been found to provide substantial benefit in biomechanical studies, but their clinical utility has not been widely accepted[20,21,23]. Their clinical benefit in the treatment of two-part fractures has been established, but the overall complication rate is substantial, and when they have been used for more complex fracture patterns, loss of fixation and screw perforation of the humeral head have been challenging complications[20-22]. The authors of most studies have grouped fracture types together, and there is still debate over which three and four-part fracture types or patterns do better with open reduction and internal fixation or hemiarthroplasty and what constitutes good or adequate reduction with a locked plate[20,22]. This uncertainty is compounded by difficulty with classifying many of these fractures with use of the OTA or Neer system, both of which have had issues with interobserver variability[27].

In the present series, displacement of the greater tuberosity was variable in the locked-plate group but it did not appear to be progressive over time or to influence the final outcome in that group. Patients with initial tuberosity migration of >5 mm had some mechanical subacromial impingement with a concomitant loss of range of motion, but the Constant scores were not discernibly different from those with ≤5 mm of displacement. However, the numbers in this series were not sufficient for us to clearly distinguish differences in the results of these two groups. Defining the impairment from tuberosity-induced impingement alone was outside the scope of this study, and we are unable to comment on what constitutes a good reduction of the tuberosity.

The degree of humeral head angulation had a substantial effect on the final clinical outcome in the locked-plate group. Malreduction of the humeral head was the most common technical error, and there was a substantial learning curve in the first twelve months of the study. In this series, we observed three distinct groups that we deemed good, satisfactory, and poor reductions on the basis of the final outcome. Good reductions consisted of ≤5° of initial humeral head varus angulation and, overall, resulted in good clinical outcomes. Satisfactory reductions consisted of >5° but ≤20° of humeral head varus malreduction; all of these reductions were followed by some subsidence but resulted in healing and satisfactory outcomes. The patients with a good or satisfactory reduction had a better outcome than those treated with a hemiarthroplasty. Patients with a poor reduction had >20° of varus malreduction, and all had mechanical loss of fixation and a poor clinical outcome.

Hemiarthroplasty for the treatment of proximal humeral fractures has been reported to have discouraging clinical results, with significant functional deficits in the range of motion and activities of daily living and with Constant scores typically in the mid 50s to low 60s[9-12]. Pain relief, complication rates, and patient acceptance have been good despite the relatively poor functional outcomes[9-12]. These findings were reiterated in our series, in which the Constant scores were consistent regardless of the initial fracture pattern. Tuberosity nonunion was the most common complication and resulted in progressive tuberosity migration and the need for bone-grafting and revision in seven patients. The true number of tuberosity nonunions may have been higher, as computed tomography studies were performed only for patients with documented tuberosity migration over time. The rate of this complication might have been reduced with the use of autogenous bone-grafting, which we did not perform routinely and which has been described as a technique that may reduce the incidence of this complication[28]. Nonetheless, initial tuberosity displacement did not predict the development of tuberosity nonunion and did not significantly influence the final outcome in the hemiarthroplasty group.

Humeral head height had a significant positive correlation with the final outcome, whereas medial calcar offset was negatively correlated with the final outcome. Humeral head height was technically more difficult to assess than offset intraoperatively as most patients had comminution in the calcar region. The most common technical error in placing the prosthesis was negative humeral head variance. We believe that this problem can be reduced somewhat by having images of the normal shoulder available for templating. Medial calcar offset was less of a problem and led to the use of humeral head designs that were smaller than what we had templated from the radiographs. That effect may have been due to the slight eccentricity of the humeral head in the coronal plane, which has been described previously[25].

Osteonecrosis was the most common complication in the locked-plate group and was strongly correlated with the presence of a dislocation initially but seemed independent of the Neer fracture type. Osteonecrosis developed in six patients and was late-onset (after six months of follow-up) in four of them. Because we did not obtain magnetic resonance images routinely, the true prevalence of partial humeral head osteonecrosis may have been higher. There was a strong correlation between the development of osteonecrosis and the length of the initial metaphyseal hinge attached to the articular fragment. Osteonecrosis developed in all of the patients in whom the hinge was <2 mm in length, whereas the average hinge length was 6 mm in those without osteonecrosis. Five of the six patients with osteonecrosis also had had a dislocation at the time of injury; therefore, it is not possible to identify the specific cause of osteonecrosis in these patients. The patients in whom osteonecrosis developed had reasonable clinical outcomes, which were comparable with the results in the hemiarthroplasty group at the time of early follow-up. That suggests that this complication may be better tolerated by the elderly population and should not preclude attempts at open reduction and internal fixation.

Perforation of the humeral head has been described as one of the more devastating complications of open reduction and internal fixation[22]. In our series, the use of ipsilateral fluoroscopy and supine positioning at surgery aided in the accurate assessment of screw length and plate position. Despite this, three patients with >3 mm of screw protrusion through the humeral head had to return to the operating room for repositioning of the hardware. Three additional patients had 1 to 3 mm of screw protrusion through the articular surface that developed late as a result of varus subsidence, and these patients underwent elective screw removal. The patients with perforation did not have clinically worse outcomes than the seven patients without perforation and similar-quality reductions, but the numbers in the series were not sufficient for us to draw any conclusions regarding differences between these groups. All perforations were in the superoposterior quadrant of the head fragment, and given that the average range of motion in this group precluded abduction of >120° or external rotation of >60°, it is doubtful that the perforation of the articular surface in this area resulted in screw contact with the glenoid.

We had difficulty classifying the fracture patterns and correlating the fracture types with the clinical outcomes. Although in the locked-plate group there was a substantial difference between the mean Constant score for the patients with a three-part fracture (72 points) and that for the patients with a four-part fracture (65 points), we did not think that this

was clinically relevant. Moreover, the Neer classification did not have a particularly useful influence on treatment choice. There were a high number of fractures involving a portion of the articular surface (impaction or head-split pattern) that were not readily classified with either the OTA or the Neer system. Moreover, we found the OTA classification to be incomplete with regard to its ability to distinguish between the two basic fracture patterns that we observed (varus extension and valgus impaction). According to this classification, three and four-part varus extension patterns would be grouped as extra-articular (B1 or B2, depending on the amount of metaphyseal impaction), but there is no way to quantify the amounts of tuberosity or head displacement. In our series, the initial fracture deformity had the greatest influence on the final outcome, and this was independent of the Neer fracture type. The patients with a valgus impacted fracture had the best final outcomes (a mean Constant score of 75 points), whereas those with varus extension had a mean Constant score (64 points) that was comparable with that after hemiarthroplasty. The differences in outcomes may be related to the manner in which the plate functions in each group. In patients with a valgus impaction pattern, the plate acts as a mechanical strut under compressive forces resisting valgus subsidence. In those with a varus extension pattern, the plate functions as a tension band by "pulling" the humeral head out of varus. Therefore, with poor bone quality, varus fractures place the implant at a distinct mechanical disadvantage and failure is determined by the pull-out resistance of the screws rather than by the compressive strength of the bone. We believe that this is the most important distinction to help guide initial surgical decision-making regarding osteoporotic fracture patterns, and it should be more clearly defined in the classification systems.

The Constant scoring system has been demonstrated to have high rates of intraobserver and interobserver correlation and to correlate strongly with patient satisfaction[29,30]. Translating the numerical score into clinical recommendations, however, is less clear-cut. We perceived a 10-point difference in outcome scores to be clinically relevant, whereas even significant differences of ≤5 points were probably not clinically relevant. Using these criteria, we thought that there was a clinical benefit of open reduction and internal fixation over hemiarthroplasty for the treatment of three-part, but not four-part, fractures. When only the uncomplicated cases were considered, the scores for the pain and power components of the Constant score were very similar between the locked-plate and hemiarthroplasty groups. We excluded from the study patients in whom a rotator cuff tear had been previously documented or was present at the time of the surgery, as the inclusion of such patients would have confounded these components of the Constant score. The active range of motion was measured in the clinical assessment as we believed that this was the most clinically relevant approach. The main benefits seen in the locked-plate group were a better range of motion and a better ability to perform activities of daily living, which are closely linked. One possible reason for these better results in the locked-plate group was that there was less direct manipulation of the rotator cuff tendons during the open reduction and internal fixation; however, we could not quantify this variable.

Our study had several limitations. The difficulty in classifying many of the fractures confounded interpretation of the data and comparison of OTA and Neer subgroups. For example, head-splitting and articular impaction were fairly common and were largely diagnosed with the use of computed tomography scans as they were often difficult to visualize on plain radiographs. As previously described, the OTA classification of varus extension fracture patterns is incomplete. Many of these fractures had >1 cm of displacement of the head fragment and could have been characterized as C2 on the basis of the head displacement; however, they were classified as B1 because of the varus angulation and metaphyseal impaction.

An initial selection bias against the hemiarthroplasty group may have been introduced by the treatment algorithm. Articular head-splitting and impaction may represent a more severe fracture pattern, and these cases were all treated with hemiarthroplasty. Any patient with a documented history of a torn or repaired rotator cuff was treated with hemiarthroplasty, and this could have been a negative influence on the final outcome. Moreover, three patients in whom we could not perform open reduction and internal fixation for technical reasons had a hemiarthroplasty. Quantification and correction of this bias were beyond the scope of this retrospective study.

We used plain radiographs to quantify malreduction and implant position and attempted to standardize the views of the shoulder; however, the final resolution of the radiographs probably did not allow us to see differences of less than 2 to 3 mm of tuberosity displacement or 3° to 4° of humeral head angulation. In addition, we did not attempt to correct for magnification errors introduced by the body habitus or size of the patient, and we were unable to assess the magnitude of the error introduced by these variables. Finally, arm rotation was not strictly controlled while the radiographs were being made, and the magnitude of error in the measurement of tuberosity displacement and metaphyseal hinge length due to this variable was not quantified. The use of computed tomography would have provided more detailed information and an ability to quantify these variables. The routine use of a 20° external rotation view is based on the assumption that the humeral head or prosthesis is retroverted 20° in all cases; however, we knew that there was some variability in this parameter. Given these issues, the maximum magnitude of the deformity of the humeral head or tuberosities was probably underestimated.

In conclusion, in this series comparing similar groups of patients with a three or four-part proximal humeral fracture, the overall outcome after locked-plate fixation was better than that after hemiarthroplasty. The initial fracture deformity (varus versus valgus) was the preoperative variable that had the greatest influence on the outcome, regardless of the fracture type. The quality of the humeral head reduction was the intraoperative factor with the greatest influence on outcome. On the basis of our observations, we now classify a good reduction as ≤5° of varus angulation of the humeral head relative to the position of the normal, contralateral humeral head. Repair of

three or four-part proximal humeral fractures with an initial varus extension pattern with use of open reduction and internal fixation should be approached with caution, whereas valgus impacted patterns are better treated with open reduction and internal fixation than with hemiarthroplasty. Hemiarthroplasty provided more consistent, albeit worse, clinical outcomes than did open reduction and internal fixation, and this finding was independent of the Neer or OTA fracture type. Future fracture classification systems should include information on the initial fracture deformity to help guide the selection of optimal surgical management. ■

Brian D. Solberg, MD
1414 South Grand Avenue, Suite 123, Los Angeles, CA 90015.
E-mail address: brian@briansolbergmd.com

Charles N. Moon, MD
Dennis P. Franco, MD
Guy D. Paiement, MD
Cedars Sinai Medical Center, 444 South San Vicente Boulevard, Suite 603, Los Angeles, CA 90048.
E-mail address for C.N. Moon: charles.moon@cshs.org.
E-mail address for D.P. Franco: dennis.franco@cshs.org.
E-mail address for G.D. Paiement: guy.paiement@cshs.org

References

1. Baron JA, Barrett JA, Karagas MR. The epidemiology of peripheral fractures. Bone. 1996;18(3 Suppl):209S-213S.

2. Neer CS 2nd. Displaced proximal humeral fractures. I. Classification and evaluation. J Bone Joint Surg Am. 1970;52:1077-89.

3. Marti R, Lim TE, Jolles CW. On the treatment of comminuted fracture-dislocations of the proximal humerus: internal fixation or prosthetic replacement. In: Kolbel R, Helbig B, Blauth W, editors. Shoulder replacement. Berlin: Springer; 1987. p 135-48.

4. Olsson C, Nordquist A, Petersson CJ. Long-term outcome of a proximal humerus fracture predicted after 1 year: a 13-year prospective population-based follow-up study of 47 patients. Acta Orthop. 2005;76:397-402.

5. Schai P, Imhoff A, Preiss S. Comminuted humeral head fractures: a multicenter analysis. J Shoulder Elbow Surg. 1995;4:319-30.

6. Vallier HA. Treatment of proximal humerus fractures. J Orthop Trauma. 2007;21:469-76.

7. Wijgman AJ, Roolker W, Patt TW, Raaymakers E, Marti RK. Open reduction and internal fixation of three- and four-part fractures of the proximal part of the humerus. J Bone Joint Surg Am. 2002;84:1919-25.

8. Tejwani NC, Liporace F, Walsh M, France MA, Zuckerman JD, Egol KA. Functional outcome following one-part proximal humeral fractures: a prospective study. J Shoulder Elbow Surg. 2008;17:216-9.

9. Antuña SA, Sperling JW, Cofield RH. Shoulder hemiarthroplasty for acute fractures of the proximal humerus: a minimum five-year follow-up. J Shoulder Elbow Surg. 2008;17:202-9.

10. Bosch U, Skutek M, Fremery RW, Tscherne H. Outcome after primary and secondary hemiarthroplasty in elderly patients with fractures of the proximal humerus. J Shoulder Elbow Surg. 1998;7:479-84.

11. Goldman RT, Koval KJ, Cuomo F, Gallagher MA, Zuckerman JD. Functional outcome after humeral head replacement for acute three- and four-part proximal humeral fractures. J Shoulder Elbow Surg. 1995;4:81-6.

12. Green A, Barnard WL, Limbird RS. Humeral head replacement for acute four-part proximal humerus fractures. J Shoulder Elbow Surg. 1993;2:249-54.

13. Jakob RP, Miniaci A, Anson PS, Jaberg H, Osterwalder A, Ganz R. Four-part valgus impacted fractures of the proximal humerus. J Bone Joint Surg Br. 1991;73:295-8.

14. Neer CS 2nd. Displaced proximal humeral fractures. II. Treatment of three-part and four-part displacement. J Bone Joint Surg Am. 1970;52:1090-103.

15. Fankhauser F, Schippinger G, Weber K, Heinz S, Quehenberger F, Boldin C, Bratschitsch G, Szyszkowitz R, Georg L, Friedrich A. Cadaveric-biomechanical evaluation of bone-implant construct of proximal humerus fractures (Neer type 3). J Trauma. 2003;55:345-9.

16. Hessmann MH, Hansen WS, Krummenauer F, Pol TF, Rommens PM. Locked plate fixation and intramedullary nailing for proximal humerus fractures: a biomechanical evaluation. J Trauma. 2005;58:1194-201.

17. Siffri PC, Peindl RD, Coley ER, Norton J, Connor PM, Kellam JF. Biomechanical analysis of blade plate versus locking plate fixation for a proximal humerus fracture: comparison using cadaveric and synthetic humeri. J Orthop Trauma. 2006;20:547-54.

18. Walsh S, Reindl R, Harvey E, Berry G, Beckman L, Steffen T. Biomechanical comparison of a unique locking plate versus a standard plate for internal fixation of proximal humerus fractures in a cadaveric model. Clin Biomech (Bristol, Avon). 2006;21:1027-31.

19. Lever JP, Aksenov SA, Zdero R, Ahn H, McKee MD, Schemitsch EH. Biomechanical analysis of plate osteosynthesis systems for proximal humerus fractures. J Orthop Trauma. 2008;22:23-9.

20. Agudelo J, Schürmann M, Stahel P, Helwig P, Morgan SJ, Zechel W, Bahrs C, Parekh A, Ziran B, Williams A, Smith W. Analysis of efficacy and failure in proximal humerus fractures treated with locking plates. J Orthop Trauma. 2007;21:676-81.

21. Moonot P, Ashwood N, Hamlet M. Early results for treatment of three- and four-part fractures of the proximal humerus using the PHILOS plate system. J Bone Joint Surg Br. 2007;89:1206-9.

22. Owsley K, Gorczyca JT. Fracture displacement and screw cutout after open reduction and locked plate fixation of proximal humeral fractures. J Bone Joint Surg Am. 2008;90:233-40.

23. Strohm PC, Köstler W, Südkamp NP. Locking plate fixation of proximal humerus fractures. Tech Shoulder Elbow Surg. 2005;6:8-13.

24. Fracture and dislocation compendium. Orthopaedic Trauma Association Committee for Coding and Classification. J Orthop Trauma. 1996;10 Suppl 1;v-ix, 1-154.

25. Hertel R, Knothe U, Ballmer FT. Geometry of the proximal humerus and implications for prosthetic design. J Shoulder Elbow Surg. 2002;11:331-8.

26. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res. 1987;214:160-4.

27. Siebenrock KA, Gerber C. The reproducibility of classification of fractures of the proximal end of the humerus. J Bone Joint Surg Am. 1993;75:1751-5.

28. Krause FG, Huebschle L, Hertel R. Reattachment of the tuberosities with cable wires and bone graft in hemiarthroplasties done for proximal humeral fractures with cable wire and bone graft: 58 patients with a 22-month minimum follow-up. J Orthop Trauma. 2007;21:682-6. Erratum in: J Orthop Trauma. 2008;22:150.

29. Johansson KM, Adolfsson LE. Intraobserver and interobserver reliability for the strength test in the Constant-Murley shoulder assessment. J Shoulder Elbow Surg. 2005;14:273-8.

30. Rocourt MH, Radlinger L, Kalberer F, Sanavi S, Schmid NS, Jeuing M, Hertel R. Evaluation of intratester and intertester reliability of the Constant-Murley shoulder assessment. J Shoulder Elbow Surg. 2008;17:364-9.