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Locking plate fixation of three- and four-part proximal humeral fractures

Atilla Sancar PARMAKSIZOĞLU, Sami SÖKÜCÜ, Ufuk ÖZKAYA, Yavuz KABUKÇUOĞLU, Murat GÜL

Department of Orthopedics and Traumatology, Taksim Training and Research Hospital, İstanbul

Objectives: We evaluated the functional results of open reduction and internal fixation with a locking plate in patients with three- or four-part fractures of the proximal humerus.

Methods: We reviewed 32 consecutive patients (22 women, 10 men; mean age 63 years; range 29 to 82 years) who were treated with open reduction and internal fixation using the PHILOS locking plate for comminuted proximal humeral fractures. According to the Neer classification, 12 patients (mean age 56 years) had three-part fractures, 19 patients (mean age 67 years) had four-part fractures, and one patient had a four-part fracture dislocation. Ten patients were in the age group of <60 years, 22 patients were in the age group of 60≥years. All the patients were evaluated with plain radiographs preoperatively; in addition, computed tomography was used in 14 patients in whom articular surface and tuberculum displacement could not be assessed adequately. The operation was performed through a standard deltopectoral approach, and minimal soft tissue dissection was used aiming not to impair vascularization of the fracture fragments. A cerclage wire was used to help reduction in 12 patients. An oblique screw was inserted to stabilize the medial colon in cases in which medial cortical contact was insufficient. Bone grafting was not used in any of the patients. Active-assisted and passive exercises of the shoulder were initiated on the second postoperative day. Active abduction to 90 degrees was allowed two weeks after surgery. During follow-up, implant failure, loss of reduction, malunion, and bone healing were assessed on plain radiographs. Bone scintigraphy was performed after 12 postoperative months for the detection of avascular necrosis. The results were assessed using the Constant shoulder score. The mean follow-up period was 25 months (range 18 to 36 months).

Results: An anatomic or near-anatomic reduction was obtained in 29 patients (90.6%). In two patients, the fractures were fixed in a varus position, and in one patient, the greater tubercle was displaced proximally. All fractures united in a mean of three months (range 2 to 5 months). The mean Constant score of the patients was 79.5 (range 50 to 100). The results were excellent in 13 patients (40.6%), good in nine patients (28.1%), fair in eight patients (25%), and poor in two patients (6.3%). The mean Constant scores were 88.3 (range 69 to 100) and 74.2 (range 50 to 100) in three-part and four-part fractures, and 88.3 (range 71 to 100) and 75.5 (range 50 to 100) in the age groups of <60 years and ≥60 years, respectively. Constant scores showed significant differences with respect to the number of comminution and age groups (p=0.03). Avascular necrosis was observed in two patients. None of the patients had reduction loss, implant failure, deep infection, or neurovascular injury, and none required implant removal.

Conclusion: Preservation of humeral head vascularity through minimal soft tissue dissection, fixation with a locking plate, and early postoperative motion were effective in decreasing potential complications following surgical treatment of three- and four-part proximal humeral fractures. The degree of fracture comminution and age of the patients affect functional results significantly.

Key words: Bone plates; fracture fixation, internal/methods; humeral fractures/surgery; shoulder fractures.

Correspondence: Ufuk Özkaya, MD. Taksim Eğitim ve Araştırma Hastanesi, Ortopedi ve Travmatoloji Kliniği, 34433 Beyoğlu, İstanbul, Turkey.
Tel: +90 212 - 252 43 00 / 1409 e-mail: ufukozkaya2004@yahoo.com

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Three- and four-part fractures represent 13% to 16% of all proximal humeral fractures.[1] Although one or more fragments may be totally displaced in 15% of the patients, fragments may still keep their attachments through preserved soft-tissue composed of the intact rotator cuff, capsule, and uninjured periosteum.[2] Preservation of this intact soft tissue envelope during surgery is of utmost importance in all fractures, particularly high energy and/or comminuted fractures, to achieve reduction without endangering vascularity of the fragments and restore revascularization of the humeral head.[3,4]

Many different techniques have been described for the treatment of comminuted fractures of the proximal humerus, including closed reduction and percutaneous K-wire fixation, open reduction followed by fixation with bone sutures, tension band, cerclage wire, T-plate, intramedullary nails, or locking plate, and prosthetic replacement.[5-26] Complications have been reported including implant failure, avascular necrosis, nonunion, malunion, nail migration, rotator cuff impairment, and impingement syndrome.[2,10,11,14,15] The incidence of these complications has been reported to be higher in elderly patients compared to younger age groups.[10]

The purpose of this study was to evaluate the results of open reduction and internal fixation with a locking plate in patients with three- or four-part fractures of the proximal humerus.

Patients and methods

We reviewed 35 patients who were treated with open reduction and internal fixation using the PHILOS locking plate (Proximal Humeral Internal Locking System, Synthes, Stratec Medical, Mezzovico, Switzerland) for comminuted proximal humerus fractures during 2005 and 2007. Inclusion criteria were as follows: *(i)* three-part or four-part fractures according to the Neer classification system;[27] *(ii)* valgus impacted fractures described by Stableforth;[28] *(iii)* presentation within 10 days after fracture occurrence; and *(iv)* patients older than 18 years of age. Three patients were excluded; two due to presentation beyond 10 days of injury, and one due to a history of metastatic tumor. Of the remaining 32 patients (22 women, 10 men; mean age 63 years; range 29 to 82 years), 12 patients had three-part fractures, 19 patients had four-part fractures, and one patient had a four-part fracture dislocation. All the patients were evaluated with plain radiographs (anteroposterior, lateral, and axillary views); in addition, computed tomography was used in 14 patients in whom articular surface and tuberculum displacement could not be assessed on plain radiographs.

Ten patients were in the age group of <60 years, 22 patients were in the age group of 60≥years. The mean ages of the patients with three-part and four-part fractures were 56 years (range 29 to 75 years) and 67 years (range 57 to 82 years), respectively. The most common mechanism of injury was fall in 21 patients. None of the patients had neurologic impairment on admission. All patients received prophylactic 1 g of first-generation cephalosporin preoperatively.

Operative technique

The operation was performed in the beach-chair position through a standard deltopectoral approach. Meticulous care was taken during minimal soft tissue dissection in order not to impair vascularization of the fracture fragments. Bone fragments were not exposed. A Schanz screw was used as a joystick under fluoroscopic guidance for indirect reduction of the humeral head into the glenoid. A cerclage wire was placed around the tendinous insertions of the greater and lesser tuberosities and was used as a reduction clamp to reduce the fracture. Kirschner wires were used to temporarily fix the fracture fragments. Using the image intensifier, the height and position of the PHILOS locking plate were checked and the plate was placed 5-10 mm distal to the greater tubercle and 2-3 mm posterior to the bicipital groove, leaving adequate space between the plate and the long head of the biceps tendon. First, the proximal locking screws were inserted into the humerus head. Then, the distal screws were inserted into the humeral metaphysis or diaphysis. Tendinous insertions of both tubercles were fixed to the plate using 5/0 nonabsorbable sutures (polyethylene terephthalate). Care was taken to obtain sufficient cortical contact medially; in cases in which this was not possible, an oblique screw was inserted inferomedially to stabilize the medial colon, as described by Gardner et al. (Fig. 1).[29]

Bone grafting was not used in any of the patients. A broad arm sling was used postoperatively and the patients were discharged on the fourth postoperative day (range 2 to 7 days). Active-assisted and passive

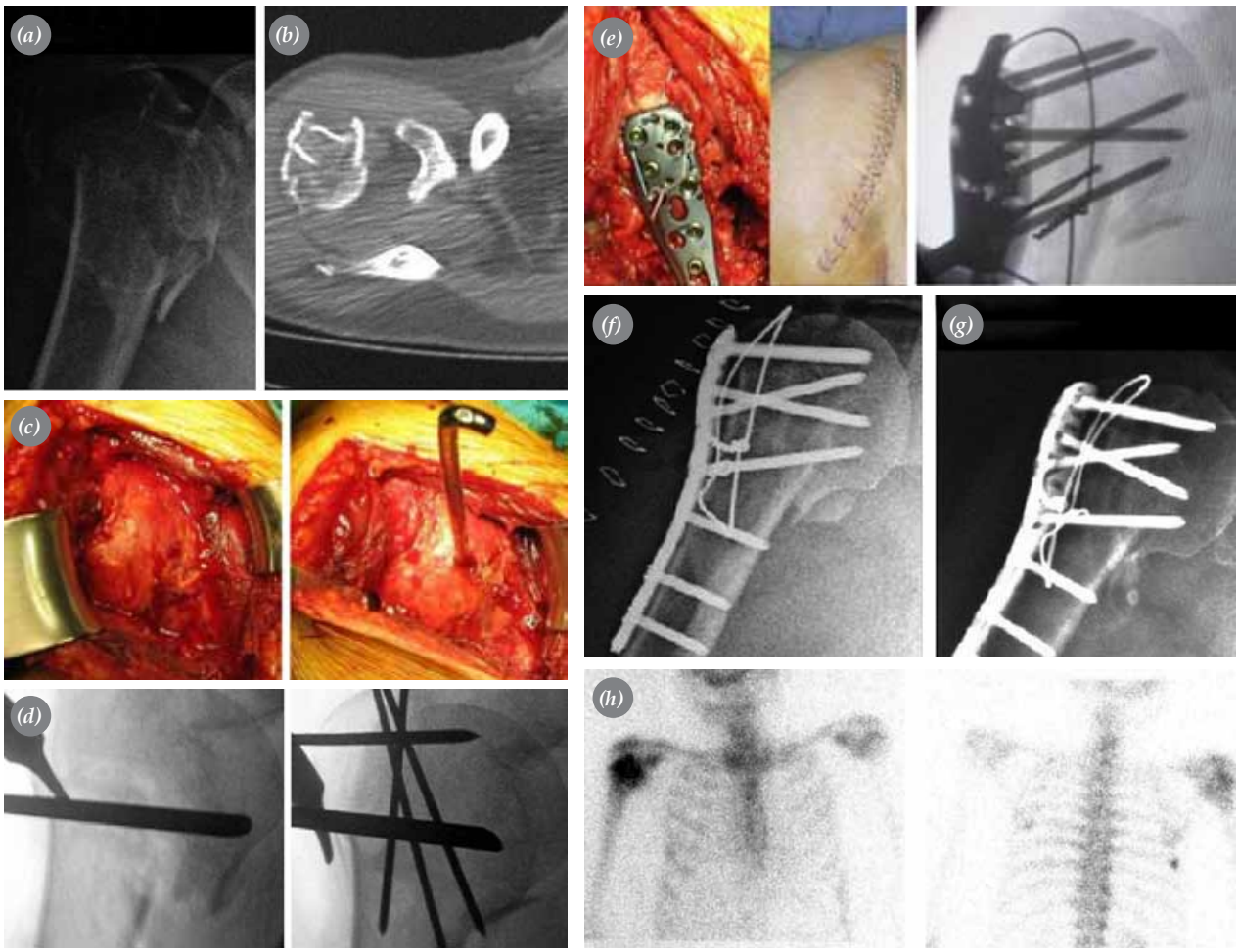

Fig. 1. **(a)** The anteroposterior radiograph of a 66-year-old woman sustaining a four-part fracture of the left humerus after a fall. **(b)** Computed tomography clearly demonstrates the comminution of the fracture. **(c)** Intraoperative views of the fracture showing preservation of soft-tissue attachments to avoid further devascularization of the bone. **(d)** Intraoperative fluoroscopic views of the fracture showing a Schanz screw used as a joystick to anatomically reduce the humeral head into the glenoid and Kirschner wires to temporarily keep the reduction of the fragments. **(e)** Intraoperative view showing fixation of the fracture using a locking plate. **(f)** Immediate postoperative radiograph shows reduction and internal fixation of the fracture using a locking plate and cerclage wire and an oblique screw inserted inferomedially to provide medial support. **(g)** Postoperative radiograph obtained at 12 months shows solid union of the fracture with no loss of reduction. **(h)** Bone scintigraphy performed at postoperative 12 months shows no sign of avascular necrosis.

exercises of the shoulder were initiated on the second postoperative day under the supervision of a physical therapist. Active abduction to 90 degrees was allowed two weeks after surgery.

Follow-up was designed at monthly intervals for the first six months, and yearly thereafter. Implant failure, loss of reduction, malunion, progress of bone healing were assessed on plain radiographs (anteroposterior, lateral, and axillary views). Bone scintigraphy was performed after 12 postoperative months for the detection of avascular necrosis. At final follow-ups, the results were assessed using the Constant shoulder score.[30] The mean follow-up period was 25 months (range 18 to 36 months).

For comparison of functional results with respect to age groups of patients (<60 years *vs*. ≥60 years) and the type of fractures (3-part *vs*. 4-part), the Mann-Whitney U-test was used. *P* values of less than 0.05 were considered significant.

Results

Of 32 patients, an anatomic or near-anatomic reduction was obtained in 29 patients (90.6%) (Fig. 2). Two patients whose fractures were fixed in a varus position

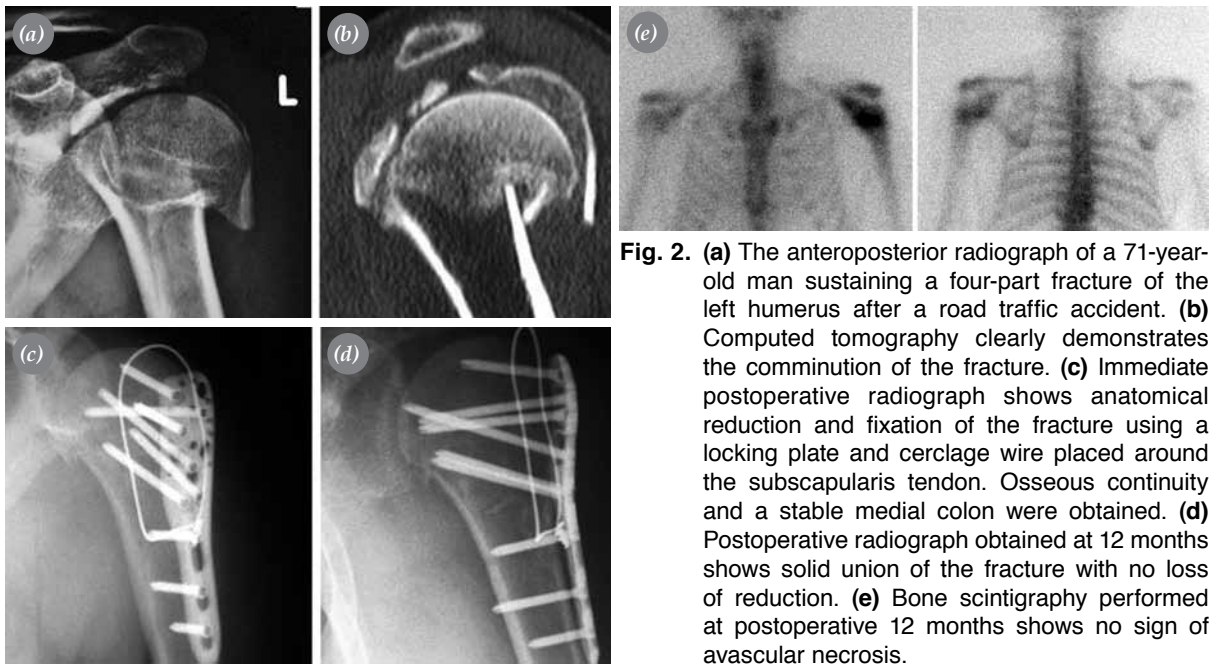

Fig. 2. **(a)** The anteroposterior radiograph of a 71-year-old man sustaining a four-part fracture of the left humerus after a road traffic accident. **(b)** Computed tomography clearly demonstrates the comminution of the fracture. **(c)** Immediate postoperative radiograph shows anatomical reduction and fixation of the fracture using a locking plate and cerclage wire placed around the subscapularis tendon. Osseous continuity and a stable medial colon were obtained. **(d)** Postoperative radiograph obtained at 12 months shows solid union of the fracture with no loss of reduction. **(e)** Bone scintigraphy performed at postoperative 12 months shows no sign of avascular necrosis.

had a fair functional result. In another patient, early postoperative examination showed that fixation of the greater tubercle had been made while proximally displaced. The patient refused revision surgery and later developed subacromial impingement and limitation in abduction, and finally was considered to have a poor functional outcome. No reduction loss was observed during the follow-up of these three patients. Despite the presence of radiographic and clinical bony union, the patient with a four-part fracture dislocation developed partial collapse of the humeral head, avascular necrosis, and penetration of the screw into the joint (Fig. 3). However, the patient whose Constant score was fair was satisfied with the functional outcome, so no further treatment was planned. Avascular necrosis was also observed in a patient with a four-part fracture, who ended up with a poor result.

All fractures united in a mean of three months (range 2 to 5 months). None of the patients had deep infection, implant failure, or neurovascular injury. None of the patients required implant removal.

At final assessments, the results were excellent in 13 patients (40.6%), good in nine patients (28.1%), fair in eight patients (25%), and poor in two patients (6.3%). The mean Constant score of the patients was 79.5 (range 50 to 100). The mean Constant scores showed significant differences between patients having three-part (88.3, range 69 to 100) and four-part (74.2, range 50 to 100) fractures (p=0.03), and between patients younger than 60 years of age (88.3, range 71 to 100) and ≥60 years of age (75.5, range 50 to 100) (p=0.03).

It was observed that computed tomography was helpful in patients in whom articular surface and tuberculum displacement could not be assessed satisfactorily on plain radiographs.

Discussion

There is controversy concerning both the surgical indications and treatment algorithms for proximal humeral fractures.[3,6,7,9-11,31] The management of three- and four-part fractures is even more complicated; open reduction and internal fixation using conventional or locking plates have been recommended.[4,14,17,19,20,32] Meticulous care must be taken to preserve the overlying soft tissues during open reduction and internal fixation since damage to these soft tissues may disturb the vascularity of fracture fragments.[4,29,32] Thus, the ideal incision to be chosen is also controversial; some authors favor the standard deltopectoral incision,[4,19,20,23-25] while some recommend the anterolateral acromial incision on the grounds that the former may cause injury to the anterior circumflex artery, which has an important role in vascularization of the humeral head.[17,21] In our study, we used the standard deltopectoral incision in all the patients.

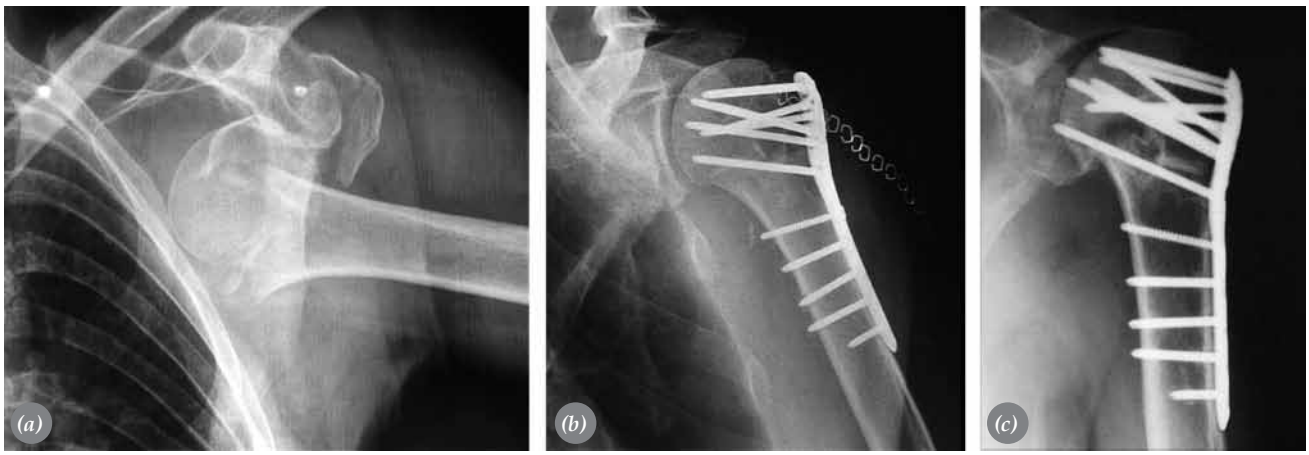

Fig. 3. **(a)** The anteroposterior radiograph of a 69-year-old man with a four-part fracture dislocation of the left humerus occurring after a fall. **(b)** Immediate postoperative radiograph shows anatomical reduction, internal fixation of the fracture, and a stable medial colon. **(c)** Radiograph of the fracture at postoperative 12 months shows partial collapse of the humeral head and penetration of the screws into the joint.

Conventional radiographs are usually adequate to evaluate the comminution of the fracture, displacement of the fragments, and congruity of the articular surface in proximal humeral fractures. However, computed tomography has been recommended in fractures where plain radiographs fail to provide adequate information to assess articular surfaces and tuberculum displacement.[17,19] Computed tomography was used in 14 patients in whom the articular surface was not clearly seen on plain radiographs.

Complications may have an adverse effect on functional results. The most important complications encountered in the treatment of three- or four-part fractures are nonunion and avascular necrosis.[32-35] The incidence of avascular necrosis has been reported in a wide range of 4% to 75%.[7,32-36] Wijgman et al.[32] pointed out the importance of obtaining a stable osteosynthesis and preservation of vascularity of the fragments through meticulous surgical handling of soft tissues. The main advantage of the locking plate system is that early and stable fixation can be obtained even in elderly osteoporotic patients.[4,22] However, avascular necrosis may occur even with the use of locking plates in the management of proximal humeral fractures.[4,15,20] Gerber et al.[35] found a direct relationship between avascular necrosis and poor functional results. In our study, avascular necrosis developed in only two patients (6.3%), one with a four-part fracture, and the other with a four-part fracture dislocation. Minimal soft tissue dissection without disturbing the vascularity of the humeral head was thought to be effective in decreasing the risk for avascular necrosis.

Nonunion is another potential complication of three- or four-part fractures of the proximal humerus. Wijgman et al.[32] reported union in all their patients treated with open reduction and internal fixation using either cerclage wires or butress plates. Jaberg et al.[7] encountered nonunion in 4% of patients following closed reduction and percutaneous K-wire fixation of unstable proximal humeral fractures. The incidence of nonunion following open reduction and internal fixation using locking plates has been reported as 2.7% to 8%.[19,20,23-25] Nonunion was not observed in our study, being mainly attributable to our attentive surgical approach to handle soft tissues.

The incidence of infection is low following open reduction and internal fixation using locking plates. Egol et al.[20] observed only one case of acute infection in their series of 51 patients who mainly had three- or four-part fractures. Gardner et al.[29] reported superficial wound dehiscence in one patient, and Moonot et al.[24] reported one superficial infection that healed with oral antibiotic treatment. No superficial or deep wound infection was observed in our study. This may be related to appropriate antibiotic prophylaxis as well as to good preservation of soft tissues during surgery.

Implant failure and loss of primary fixation of the implants occur in 2.7% to 13.7% following open reduction and fixation with a locking plate in proximal humeral fractures.[15,20,24,25] During radiographic follow-up, Owsley and Gorczyca[19] observed pen-

etration of the screws to the joint in 23% of their patients and a tendency to varus displacement. In a series of 29 patients treated with a locking plate, Fankhauser et al.[16] reported implant failure in one patient and loss of reduction in four patients. Agudelo et al.[25] found a statistically significant correlation between a primary varus malreduction defined as the head-shaft angle of <120 degrees and loss of reduction. Gardner et al.[29] noted that the presence or absence of medial support had a significant effect on the degree of postoperative reduction loss. In our study, excluding the two patients whose fractures were initially fixed in a varus position of 90 degrees, no reduction loss or implant failure were seen following fixation of the fractures. Partial collapse of the humeral head due to avascular necrosis and screw penetration into the joint were observed in the patient with a four-part fracture dislocation.

Malunion is another potential complication in the treatment of proximal humeral fractures. Moonot et al.[24] reported the incidence of malunion as 6% following open reduction and internal fixation with a locking plate of three- and four-part fractures of the proximal humerus. Björkenheim et al.[15] reported that 26.3% of the fractures having two, three, or four parts united in a slightly varus position after open reduction and internal fixation with a locking plate. Agudelo et al.[25] considered primary varus reduction to be an important risk factor for poor results. Gerber et al.[35] who achieved an anatomic reduction in 88.2% of the patients concluded that this was the major factor to obtain a good functional outcome. In our study, anatomic reduction was observed in 90.6% of the patients and good functional results were attributed to both anatomic reduction and rigid fracture fixation.

Atalar et al.[8] used tricortical bone graft to support the impacted humeral head in patients with valgus impacted fractures. We did not use bone graft in our patients and none developed loss of reduction.

Many authors assessed the effect of early postoperative exercise on functional results following surgical treatment of comminuted proximal humeral fractures. Björkenheim et al.[15] initiated passive shoulder range of motion exercises on the first postoperative day, and active exercises at four weeks, and found the mean Constant score as 78 in three-part fractures, 60 in four-part fractures, and the overall score as 77 at the end of 12 months. The authors emphasized the role of increased stability provided by the PHILOS plate in starting early motion and obtaining good functional results. Using a similar postoperative rehabilitation program, Egol et al.[20] and Papadopoulos et al.[4] achieved good functional results. Moonot et al.[24] allowed active exercises after three postoperative weeks in three- and four-part fractures. In our study, the mean Constant scores were 88.3 and 74.2 in patients having three-part and four-part fractures, respectively, showing a significant difference in favor of three-part fractures. Despite some studies reporting no significant differences between functional results of patients in the age groups of <60 years and ≥60 years,[20,24] functional results in our study were significantly better in patients younger than 60 years of age.

This study has some limitations. First, there was no other treatment or control group to compare our results. Second, as in most series on proximal humeral fractures, the number of patients was relatively small. Finally, its retrospective design is another limitation of this study. On the other hand, two main strengths of this study merit mention. First, the data pertain to a specific type of injury, three-part or four-part fractures of the proximal humerus which are quite challenging even for experienced shoulder surgeons. Second, despite different surgeons performing the operations, the results were found similar indicating the feasibility of the technique.

In conclusion, preservation of the vascularity of the humeral head through minimal soft tissue dissection and fixation with a locking plate were effective in decreasing potential complications following surgical treatment of three- and four-part proximal humeral fractures. The degree of fracture comminution, age of the patients, and the role of early postoperative motion must be considered to obtain good functional results.

References

1. Rose SH, Melton LJ 3rd, Morrey BF, Ilstrup DM, Riggs BL. Epidemiologic features of humeral fractures. Clin Orthop Relat Res 1982;(168):24-30.
2. Bigliani LU, Craig EV, Butters KP. Fractures of the shoulder. In: Rockwood CA, Green DP, Bucholz RW, editors. Rockwood and Green's fractures in adults. Vol. 1, 3rd ed. Philadelphia: Lippincott; 1991. p. 871-927.
3. DeFranco MJ, Brems JJ, Williams GR Jr, Iannotti JP.

Evaluation and management of valgus impacted four-part proximal humerus fractures. Clin Orthop Relat Res 2006;(442):109-14.

4. Papadopoulos P, Karataglis D, Stavridis SI, Petsatodis G, Christodoulou A. Mid-term results of internal fixation of proximal humeral fractures with the PHILOS plate. Injury 2009;40:1292-6.
5. Kayalar M, Toros T, Bal E, Özaksar K, Gürbüz Y, Ademoğlu Y. The importance of patient selection for the treatment of proximal humerus fractures with percutaneous technique. [Article in Turkish] Acta Orthop Traumatol Turc 2009; 43:35-41.
6. Herscovici D Jr, Saunders DT, Johnson MP, Sanders R, DiPasquale T. Percutaneous fixation of proximal humeral fractures. Clin Orthop Relat Res 2000;(375):97-104.
7. Jaberg H, Warner JJ, Jakob RP. Percutaneous stabilization of unstable fractures of the humerus. J Bone Joint Surg [Am] 1992;74:508-15.
8. Atalar AC, Demirhan M, Uysal M, Seyahi A. Treatment of Neer type 4 impacted valgus fractures of the proximal humerus with open reduction, elevation, and grafting. [Article in Turkish] Acta Orthop Traumatol Turc 2007; 41:113-9.
9. Park MC, Murthi AM, Roth NS, Blaine TA, Levine WN, Bigliani LU. Two-part and three-part fractures of the proximal humerus treated with suture fixation. J Orthop Trauma 2003;17:319-25.
10. Rajasekhar C, Ray PS, Bhamra MS. Fixation of proximal humeral fractures with the Polarus nail. J Shoulder Elbow Surg 2001;10:7-10.
11. Sadowski C, Riand N, Stern R, Hoffmeyer P. Fixation of fractures of the proximal humerus with the PlantTan Humerus Fixator Plate: early experience with a new implant. J Shoulder Elbow Surg 2003;12:148-51.
12. Sehr JR, Szabo RM. Semitubular blade plate for fixation in the proximal humerus. J Orthop Trauma 1988;2:327-32.
13. Seidel H. Humeral locking nail: a preliminary report. Orthopedics 1989;12:219-26.
14. Wanner GA, Wanner-Schmid E, Romero J, Hersche O, von Smekal A, Trentz O, et al. Internal fixation of displaced proximal humeral fractures with two one-third tubular plates. J Trauma 2003;54:536-44.
15. Björkenheim JM, Pajarinen J, Savolainen V. Internal fixation of proximal humeral fractures with a locking compression plate: a retrospective evaluation of 72 patients followed for a minimum of 1 year. Acta Orthop Scand 2004; 75:741-5.
16. Fankhauser F, Boldin C, Schippinger G, Haunschmid C, Szyszkowitz R. A new locking plate for unstable fractures of the proximal humerus. Clin Orthop Relat Res 2005;(430):176-81.
17. Korkmaz MF, Aksu N, Göğüş A, Debre M, Kara AN, Işıklar ZU. The results of internal fixation of proximal humeral fractures with the PHILOS locking plate. [Article in Turkish] Acta Orthop Traumatol Turc 2008;42:97-105.
18. Koukakis A, Apostolou CD, Taneja T, Korres DS, Amini A. Fixation of proximal humerus fractures using the PHILOS plate: early experience. Clin Orthop Relat Res 2006; (442):115-20.
19. Owsley KC, 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.
20. Egol KA, Ong CC, Walsh M, Jazrawi LM, Tejwani NC, Zuckerman JD. Early complications in proximal humerus fractures (OTA Types 11) treated with locked plates. J Orthop Trauma 2008;22:159-64.
21. Gardner MJ, Voos JE, Wanich T, Helfet DL, Lorich DG. Vascular implications of minimally invasive plating of proximal humerus fractures. J Orthop Trauma 2006;20: 602-7.
22. Ring D, Jupiter JB. Internal fixation of the humerus with locking compression plates. Tech Shoulder Elbow Surg 2003;4:169-74.
23. Rose PS, Adams CR, Torchia ME, Jacofsky DJ, Haidukewych GG, Steinmann SP. Locking plate fixation for proximal humeral fractures: initial results with a new implant. J Shoulder Elbow Surg 2007;16:202-7.
24. 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.
25. Agudelo J, Schürmann M, Stahel P, Helwig P, Morgan SJ, Zechel W, et al. Analysis of efficacy and failure in proximal humerus fractures treated with locking plates. J Orthop Trauma 2007;21:676-81.
26. Demirhan M, Kılıçoğlu O, Altınel L, Eralp L, Akalın Y. Prognostic factors in prosthetic replacement for acute proximal humerus fractures. J Orthop Trauma 2003;17:181-8.
27. Neer CS 2nd. Displaced proximal humeral fractures. I. Classification and evaluation. J Bone Joint Surg [Am] 1970;52:1077-89.
28. Stableforth PG. Four-part fractures of the neck of the humerus. J Bone Joint Surg [Br] 1984;66:104-8.
29. Gardner MJ, Weil Y, Barker JU, Kelly BT, Helfet DL, Lorich DG. The importance of medial support in locked plating of proximal humerus fractures. J Orthop Trauma 2007;21:185-91.
30. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res 1987;(214):160-4.
31. Robinson CM, Page RS. Severely impacted valgus proximal humeral fractures. Results of operative treatment. J Bone Joint Surg [Am] 2003;85:1647-55.
32. Wijgman AJ, Roolker W, Patt TW, Raaymakers EL, 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.

33. Esser RD. Treatment of three- and four-part fractures of the proximal humerus with a modified cloverleaf plate. J Orthop Trauma 1994;8:15-22.
34. Lee CK, Hansen HR. Post-traumatic avascular necrosis of the humeral head in displaced proximal humeral fractures. J Trauma 1981;21:788-91.
35. Gerber C, Werner CM, Vienne P. Internal fixation of complex fractures of the proximal humerus. J Bone Joint Surg [Br] 2004;86:848-55.
36. Hawkins RJ, Bell RH, Gurr K. The three-part fracture of the proximal part of the humerus. Operative treatment. J Bone Joint Surg [Am] 1986;68:1410-4.