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Results of surgical management of valgus-impacted proximal humerus fractures with structural allografts

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Objective: The aim of this study was to clinically and radiologically evaluate patients treated with plate osteosynthesis with structural allografts for severely valgus-impacted fractures of the proximal humerus.

Methods: The study included 10 patients (average age: 57 years; range: 34 to 77 years) with valgus-impacted Neer Type 4 proximal humerus fractures. Fractures were classified according to the Robinson classification. Patients were called for an up-to-date examination and evaluated radiologically and clinically with Constant and DASH scores.

Results: Average follow-up period was 22.5±12.2 (range: 12 to 50) months. Average DASH score at the final follow-up was 7.6±4.5 (range: 2.5 to 16.7) and average Constant score was 87.7±4.4 (range: 83 to 94). None of the cases had early or late head collapse. There was no avascular necrosis. One early screw penetration was observed.

Conclusion: Surgical treatment of valgus-impacted proximal humerus fractures achieved successful results. However, the cavity under the humeral head may lead to failure due to mechanical insufficiency. Plate osteosynthesis with structural allografts warrants initial mechanical support until union, thus avoiding complications related to head collapse.

Key words: Proximal humerus fracture; structural allograft; valgus impaction.

Fractures of the shoulder region present a difficult challenge for orthopedic surgeons due to high functional expectations. Valgus impaction patterns represent one fifth of all proximal humerus fractures.[1] Among all described fracture patterns, valgus-impacted fractures are particularly prevalent in older osteoporotic patients, with up to 90% occurring in low-energy indoor incidents.[2]

First described by Neer among other three and four-part fractures,[3] valgus-impacted fractures were first distinguished by Jakob et al. as a distinct entity and suggested to be associated with better prognosis.[4] Robinson et al. described the injury in terms of anatomical features and suggested a grading system.[5]

Although conservative treatment methods may produce good results in minimally displaced fracture patterns, surgical treatment methods are more judicious in severely displaced types.[4,6] Various surgical treatment methods have been described for valgus-impacted fractures, including percutaneous fixation,[7-9] locked plating,[10] minimal invasive plating[11] and arthroplasty.[12,13]

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As the humeral head consists largely of metaphyseal bone, most fracture patterns include bone loss and require grafting.[14-17] Many complications occur due to lack of head support with all osteosynthesis techniques.[18,19] Structural grafts are used to support the humeral head, both as allografts and autografts from iliac crests.[20]

We hypothesized that utilization of structural allografts provides adequate support in patients treated with locked plates for severely valgus-impacted fractures of the proximal humerus. The aim of this study was to clinically and radiographically evaluate patients who received the identical surgical treatment.

Patients and methods

Fifty-nine patients with proximal humerus fractures treated with plate osteosynthesis between 2008 and 2011 were retrospectively evaluated. This study included 10 patients (7 female, 3 male; mean age: 57 years, range: 34 to 77 years) of 26 valgus-impacted Neer Type 4 humerus fractures treated with open reduction and structural allograft support. Patients were called for an up-to-date clinical and radiological evaluation. Fractures with humeral head fragments tilted in the valgus direction and displaced tuberosity fragments as described by Jakob et al.[4] in which the angle between the humeral diaphysis and the line perpendicular to the articular surface (humeral head inclination angle) was more than 170 degrees were named as 'valgus-impacted'.[21]

According to the grading described by Robinson et al.,[5] five patients had Grade 1B, four Grade 2 and one Grade 3B fractures in the study. The four patients with Robinson Grade 2 and 1 patient with Robinson Grade 3B valgus-impacted fractures had an average translation of 6.8 (range: 5 to 9) mm.

One patient (Pat. No. 8) was admitted with an anterior dislocation of the shoulder accompanying a valgus-impacted humerus fracture. Physical examination and computed tomography (CT) angiography revealed a possible vascular injury at the surgical neck level or a perfusion problem due to compression. After reduction, perfusion of the extremity improved greatly and axillary artery exploration revealed no direct or intimal injury (Fig. 1).

After the initial workup (thorough physical examination and trauma series radiographs), CT scans with 3-dimensional reconstruction were acquired for surgical planning. Surgery was performed 1 to 3 days after trauma, depending on the patient's preoperative preparation. The senior surgeon operated all patients using a similar approach.

Patients were positioned in the beach chair position and the deltopectoral approach was used on a radiolucent table. After the usual dissection, separated tuberosities were identified and tagged with heavy sutures, then spread carefully for evaluation of the head fragment, preserving soft tissue attachments. A rotator interval was used for the evaluation of the glenohumeral joint; loose intra-articular fragments were removed and larger fragments were fixed through. Unnecessary dissection of the fragments from soft tissue attachments was avoided. Elevation of the head fragment was performed with a blunt elevator (Fig. 2). Dissection, reduction and fixation were performed with great care, preserving the medial hinge of the head fragment. Reduction was radiologically verified with a fluoroscopic image intensifier and fixed with

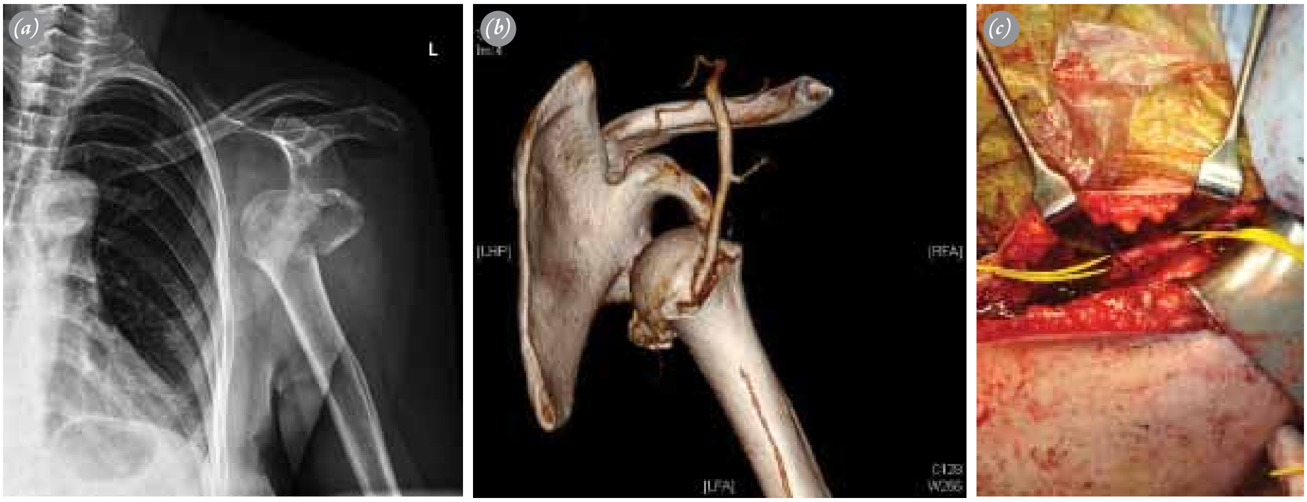

Fig. 1. **(a)** Valgus-impacted humerus fracture with anterior dislocation of the shoulder; **(b)** Arterial occlusion due to compression or direct injury at the CT angiography. **(c)** Exploration of the axillary artery. [Color figures can be viewed in the online issue, which is available at www.aott.org.tr]

temporary Kirschner wires when necessary. A prosthetic replacement implant was prepared in the operation room in the event that fixation was not possible.

After reducing the head fragment, the metaphyseal bone defect was assessed. A metaphyseal cavity volume of 5 ml or greater was accepted as a suitable candidate for structural grafting (Fig. 2). Lyophilized tricortical iliac allografts were used.

Grafts were washed with isotonic 0.9% NaCl solution with 1 g of cefazolin sodium and shaped according to the cavity. While preparing the graft, three cortices were preserved for maximum strength. Grafts were placed in the cavity with their cristae positioned just under the humeral head. It was assured that grafts were placed tightly and reduction of the head was preserved with this support (Fig. 2). Further tuberosity fragmentation on the graft was reduced and a plate (PHILOS proximal humerus anatomical locking plate; Synthes, West Chester, PA, USA) was placed on this fragment.

The remainder of the surgical procedure continued in a standard manner. No. 5 non-absorbable polyester sutures (Ethibond; Ethicon Inc., Auneau, France) were passed through the rotator cuff posteriorly, superiorly and anteriorly; they were also passed through the plate suture holes afterwards, to adapt the plate and facilitate reduction. The plate was positioned 5 to 8 mm below the tip of the greater tubercle and 2 to 4 mm lateral to the bicipital groove. Reduction and position of the plate was verified with an image intensifier. The plate was initially fixed with a 3.5 mm cortical screw just below the surgical neck. A minimum of six locking screws were directed to pass the graft and reach the subchondral bone of the head fragment. Screws were placed below the subchondral bone as close as 5 mm to achieve maximum purchase. Finally, two more locking screws were inserted to the diaphyseal part of the plate. The wound was closed over with a Hemovac drain left in place, which was removed two days following the surgery.

All patients were hospitalized up to 4 days postoperatively and discharged. Shoulder slings were used for the first month then discontinued. Isometric deltoid and passive range of motion exercises were started after the operation and continued for three weeks, followed by Phase 2 active-assisted range of motion exercises. Resisted strengthening exercises were started following radiological signs of bone union. Postoperative radiological assessments were performed at the 1st and 6th weeks and at the 3rd and 6th months (Fig. 3).

During follow-ups, patients were evaluated radiologically with true anterior-posterior axillary X-rays and clinically, using the DASH and Constant scores.[22] The paired t-test using MedCalc v10.1.6 (MedCalc Software, Mariakerke, Belgium) software was used for statistical analysis. P values of less than 0.05 were considered significant.

Results

Average follow-up period was 22.5±12.2 (range: 12 to 50) months. None of the patients had neurologic injuries. No intraoperative complications occurred.

Preoperative average humeral head inclination angle was 187±19.4° (range: 171 to 228°). Inclination angle improved in early postoperative radiographs to an average value of 141.9±8.9° (range: 127 to 150°). Inclination angles observed at the final follow-up had an average value of 144±8.5° (range: 134 to 150°). This loss of inclination was statistically insignificant (p=0.6). Fracture healing was observed 8 to 12 weeks after the operation.

Screw penetration was evaluated by observing the

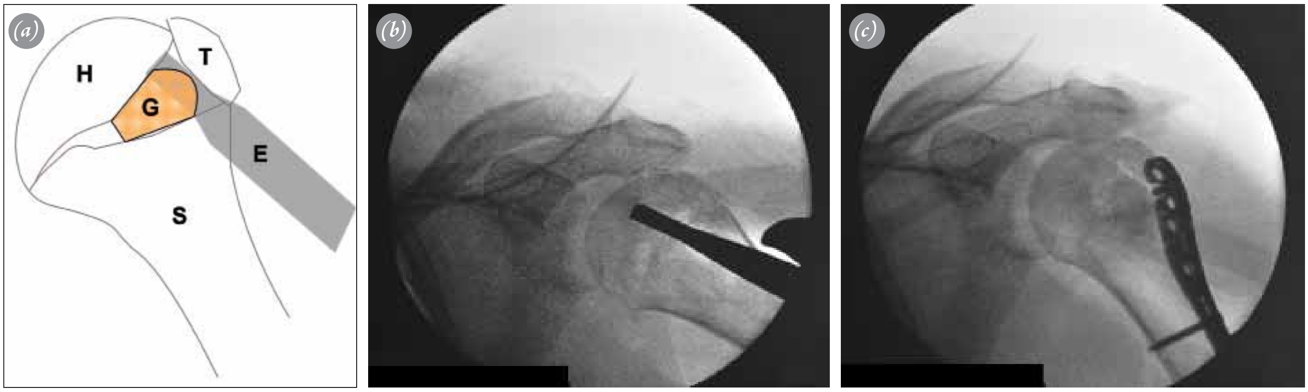

Fig. 2. **(a)** Schematic drawing of the elevation of the head fragment, assessment of the cavity, and position of the graft (E: elevator, G: graft, H: head, S: humeral shaft, T: tuberosity). **(b)** Before reduction, blunt device put in place. **(c)** Head reduced, graft in place. Reduction creates a gap under the head, and allograft usage is indicated for gaps of 5 ml and above. Note the reduction is preserved without any support beyond the graft itself. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

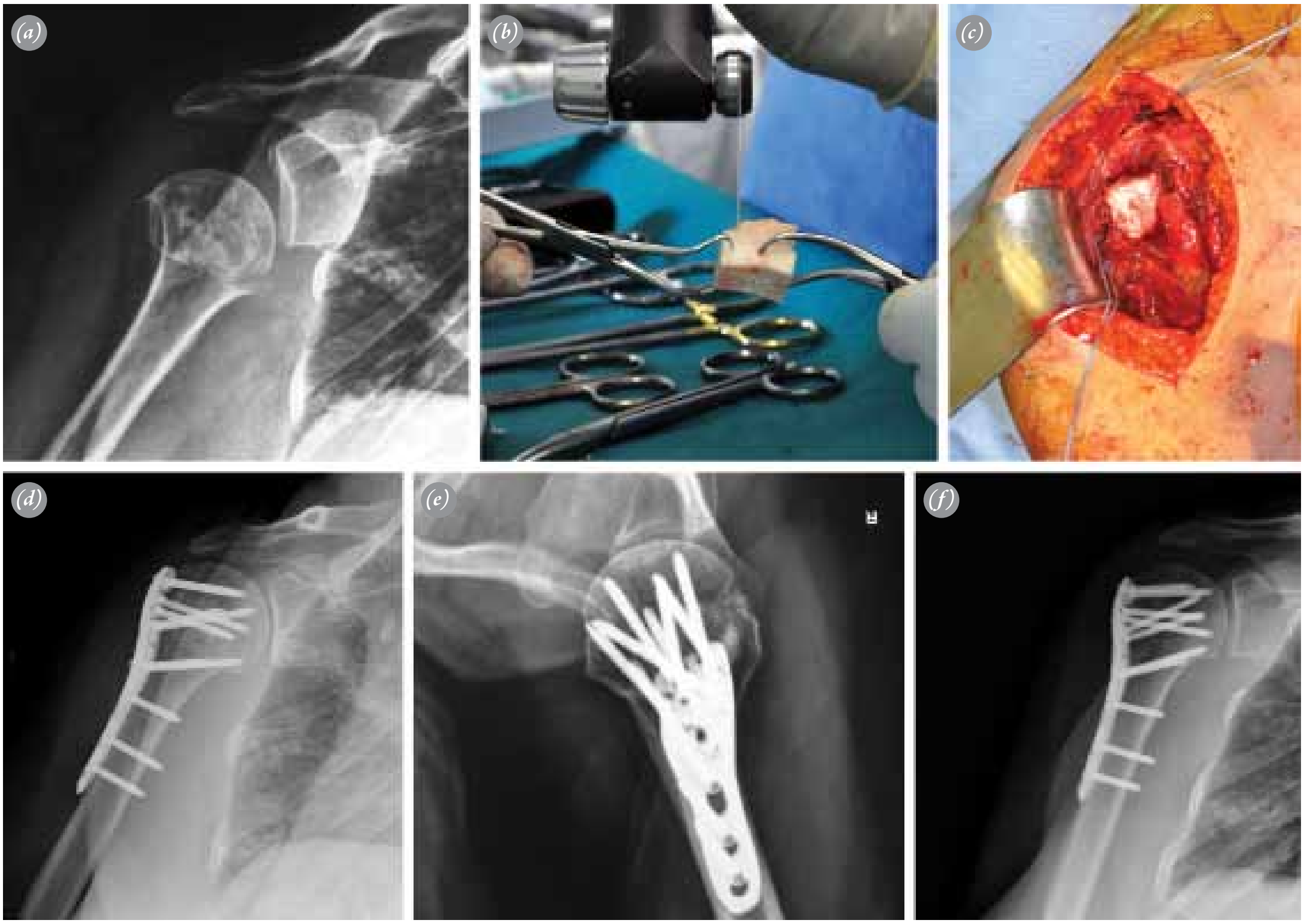

Fig. 3. **(a)** 70-year-old patient (Pat. No. 7), referred with a valgus-impacted proximal humerus fracture. **(b)** Allograft being prepared to fit the cavity under the head. **(c)** Graft placed before instrumentation. **(d, e)** Early postoperative X-rays; graft is visible below head. **(f)** Follow-up at 1 year postoperatively, graft united successfully without any collapse. [Color figures can be viewed in the online issue, which is available at www.aott.org.tr]

screw tip's protrusion from the subchondral bone. Early postoperative (1 month) screw penetration was observed in only one patient who refused reoperation for implant removal as she was asymptomatic. None of the patients had signs of osteonecrosis in the humeral head. Implants were removed in one patient due to local discomfort.

Mean DASH score at the last follow-up visit was 7.6±4.5 (range: 2.5 to 16.7) and mean Constant score was 87.7±4.4 (range: 83 to 94). All clinical and radiological assessments are summarized in Table 1.

Table 1. Clinical and radiological assessment of the patients.

Patient No.	Age	Robinson Grade	Translation (mm)	Preop inclination (degrees)	Postop inclination (degrees)	Last inclination (degrees)	DASH score	Constant score	Follow-up (months)
1	34	1B	0	187	149	150	16.7	83	50
2	74	1B	0	205	132	134	4.2	92	18
3	43	1B	0	174	139	148	7.5	92	38
4	76	2	6.25	205	150	150	5	94	17
5	77	2	9	228	150	150	6.7	88	14
6	49	1B	0	176	146	148	13.3	84	12
7	70	2	8.25	171	131	134	7.2	83	24.5
8	62	3B	5.5	173	147	150	2.5	92	12
9	47	2	5	171	148	148	9.2	83	21
10	39	1B	0	180	127	128	3.3	86	23.8

Discussion

Treatment strategies for proximal humerus fractures have changed greatly in the last two decades, with an increase in functional expectations and greater understanding of the role of vascularity. In this study, the utilization of structural allografts to support the head fragment is presented as a viable method against head collapse. This argument was supported radiologically with comparison of early and late postoperative humeral head inclination angles and clinically with Constant and DASH scores.

Previously, valgus-impacted humerus fractures were managed conservatively with high union rates and moderate to good functional results.[2,23] Court-Brown et al.[2] evaluated 125 non-operatively managed valgus-impacted fractures. Thirty-one of their patients had surgical neck and greater tubercle fractures. The average Constant score for this group was 65.6, lower than our average score of 87.7. Today, the tendency is to prefer surgical management in order to achieve bone union with anatomic reduction and normal shoulder range of motion and strength.

The anterior humeral circumflex artery (ACA) is the major blood supply for the humeral head, along with the anterolateral ascending branch and intra-osseous branch (arcuate artery).[24] While avascular necrosis of the humeral head is encountered more commonly in Neer Type 3 and 4 fractures, valgus impaction patterns in contrast are more resistant to avascular necrosis due to the well-preserved integrity of the medial side.[4]

Osteosynthesis of any kind should be performed in cases in which head/shaft continuity is preserved. For valgus-impacted fractures, medial periosteal hinges preserve vascular supply and are particularly good candidates for osteosynthesis. Medial periosteal continuity preserves ACA and vascular supply to the head. It is widely accepted that disruption of the medial hinge leads to avascular necrosis. However, the degree of translation required remains contested. Cadaver studies suggest that complete disruption occurs from 6 to 11 mm of translation.[25-28] However, it has also been reported that translations as low as 5 mm can lead to avascular necrosis.[29] Our translation range varied from 5 to 9 mm. No avascular necrosis was observed in our patients.

According to Robinson et al.'s grading,[5] Grade 1B fractures supply blood to the intact periosteal hinge at the medial side. This is the most common pattern and has a low avascular necrosis rate. A key feature of the Grade 2 pattern is the lateral translation of the humeral head. This translation breaks the medial hinge and puts the blood supply at risk. The amount of translation required to disrupt the medial periosteal hinge, and therefore the vascular supply, is uncertain. Various reports, including cadaver studies, mention translations as low as 5 mm and up to 11 mm that disrupt the medial hinge.[25-29] Grade 3 fracture patterns require dislocation of the shoulder, either leaving the head in place or dislocating the head while preserving its attachment to the shaft. Robinson et al.[5] point out a high risk of necrosis as the head denudes from all its soft tissue attachments.

As displacement of the head creates a cavity after reduction, surgical options require some sort of structural or cancellous grafting. As has been shown in many studies, while autografts provide both structural and cancellous grafting options, some donor site morbidity occurs, particularly with structural autografts.[30] Gerber et al.[31] published results of proximal humerus fractures treated with various methods. Patients with cancellous grafting had no malunions, while 4 of 21 patients without grafting had malunion. The authors suggested that cancellous grafts provide adequate support. However, lack of structural support with both cancellous allografts and autografts is a widely accepted fact. Only cortical grafts provide structural support. Currently, there are no studies available that compare the outcomes of cancellous grafts and structural grafts. Egol et al.[32] reported that augmentation with calcium phosphate cement is a more reliable option for filling metaphyseal defects than cancellous grafting alone or no grafting, with less head collapse. Structural allografts, in contrast to their non-osteogenic and non- or less-osteoinductive properties, provided enough mechanical and biological support for the reduced head and achieved union rates equally successful as those achieved with autografts. Fibula and iliac crest structural autografts are reliable options, although donor site morbidity is a concern.[33] Matassi et al. published a study on successful utilization of fibular allograft in unstable proximal humerus fractures.[34]

In our study, all patients achieved full union in the expected period, without any delay or nonunion. Equal inclination measurements immediately after operation and at the final follow-up suggest no head or graft collapse. It is clear that a vital humeral head is the key factor to success. Prosthetic replacement was not necessary in any of the cases.

Osteoporosis is an important risk factor for proximal humerus fractures, particularly for valgus-impacted fractures. In patients with low bone quality, conventional plates have higher failure rates. Locked plates provide more stable fixation with better anchorage.[35-37] Lee and Shin[38] evaluated 7 independent variables in a series of

45 unstable proximal humerus fractures treated with locked plates. Age and degree of bone quality did not have a significant influence on clinical outcomes. Due to the small number of patients in our series, it was not possible to draw conclusions about the effect of age or the impaction pattern on outcome. A larger study comparing impaction amount and failure patterns would be necessary to clarify this point.

Screw penetration is the most common early complication of locked plating of proximal humeral fractures, occurring in up to 23% of cases.[19,39,40] Aside from unrecognized intraoperative screw length miscalculation, collapse of the humeral head is the major reason for screw penetration. Our early postoperative and final follow-up inclination comparison suggested no head collapse (Table 1). As there was no inclination change in subsequent follow-ups, we believe unrecognized intraoperative penetration was responsible for the one case with early penetration. Utilizing structural allografts for valgus-impacted fractures might be a valuable method for eliminating penetration as an early complication.

Another failure mode for proximal humerus fractures is the backing-out of the plate-screw construct with varus displacement. This is uncommon for valgus-impacted fractures as the head fragment tends to collapse instead of backing out. With valgus collapse of the head, the greater tubercle displaces laterally and superiorly. Inadequate fixation of this fragment or postoperative failure of the fixation leads to inferior functional results. Two of our patients required additional fixation of the rotator cuff, with metal suture anchors (Corkscrew®; Arthrex, Naples, FL, USA). None of the patients experienced complications involving non-union of the fragment or loss of abduction.

The absence of a control group, the retrospective design and the small number of patients can be considered limitations of this study and render its implications unclear. Additional prospective studies with a control group are necessary to further clarify our conclusions.

In conclusion, surgical management of valgus-impacted humerus fractures has recently gained popularity due to the superior functional results that can be achieved. These fractures tend to create a cavity after reduction, risking the stability of reduction. It is vital to recognize fracture patterns where graft support is required. Structural allografts may provide excellent support, with adequate union potential.

Conflicts of Interest: No conflicts declared.

References

1. Court-Brown CM, Garg A, McQueen MM. The epidemiology of proximal humeral fractures. Acta Orthop Scand 2001;72:365-71. CrossRef
2. Court-Brown CM, Cattermole H, McQueen MM. Impacted valgus fractures (B1.1) of the proximal humerus. The results of non-operative treatment. J Bone Joint Surg Br 2002;84:504-8. CrossRef
3. Neer CS 2nd. Displaced proximal humeral fractures. I. Classification and evaluation. J Bone Joint Surg Am 1970;52:1077-89.
4. 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.
5. Robinson CM, Longino D, Murray IR, Duckworth AD. Proximal humerus fractures with valgus deformity of the humeral head: the spectrum of injury, clinical assessment and treatment. J Shoulder Elbow Surg 2010;19:1105-14.
6. Mills HJ, Horne G. Fractures of the proximal humerus in adults. J Trauma 1985;25:801-5. CrossRef
7. Resch H, Povacz P, Fröhlich R, Wambacher M. Percutaneous fixation of three- and four-part fractures of the proximal humerus. J Bone Joint Surg Br 1997;79:295-300. CrossRef
8. Magovern B, Ramsey ML. Percutaneous fixation of proximal humerus fractures. Orthop Clin North Am 2008;39:405-16. CrossRef
9. 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. Acta Orthop Traumatol Turc 2007;41:113-9.
10. Sanders RJ, Thissen LG, Teepen JC, van Kampen A, Jaarsma RL. Locking plate versus nonsurgical treatment for proximal humeral fractures: better midterm outcome with nonsurgical treatment. J Shoulder Elbow Surg 2011;20:1118-24. CrossRef
11. Röderer G, Erhardt J, Graf M, Kinzl L, Gebhard F. Clinical results for minimally invasive locked plating of proximal humerus fractures. J Orthop Trauma 2010;24:400-6.
12. Demirhan M. Factors affecting the results of hemiarthroplasty for proximal humerus fractures. [Article in Turkish] Acta Orthop Traumatol Turc 2000;34:463-74.
13. Kralinger F, Schwaiger R, Wambacher M, Farrell E, Menth-Chiari W, Lajtai G, et al. Outcome after primary hemiarthroplasty for fracture of the head of the humerus. A retrospective multicentre study of 167 patients. J Bone Joint Surg Br 2004;86:217-9. CrossRef
14. Robinson CM, Page RS. Severely impacted valgus proximal humeral fractures. J Bone Joint Surg Am 2004;86-A Suppl 1(Pt 2):143-55.
15. Robinson CM, Page RS. Severely impacted valgus proximal humeral fractures. Results of operative treatment. J Bone Joint Surg Am 2003;85-A:1647-55.
16. Resch H, Beck E, Bayley I. Reconstruction of the valgus-impacted humeral head fracture. J Shoulder Elbow Surg

1995;4:73-80. CrossRef
17. Yu KS, Chan PT, Lau SC, Cheng SK, Faan YS, Ngai WK. Internal fixation of valgus-impacted humeral head fractures using the screw-wiring technique. Int Orthop 2002;26:13-6. CrossRef
18. Aksu N, Göğüş A, Kara AN, Işiklar ZU. Complications encountered in proximal humerus fractures treated with locking plate fixation. Acta Orthop Traumatol Turc 2010;44:89-96. CrossRef
19. 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. CrossRef
20. Vandenbussche E, Peraldi P, Naouri JF, Rougereau G, Augereau B. Four part valgus impacted fractures of the upper extremity of humerus: ilium graft reconstruction. Apropos of 8 cases. [Article in French] Rev Chir Orthop Reparatrice Appar Mot 1996;82:658-62. [Abstract]
21. Boileau P, Walch G. The three-dimensional geometry of the proximal humerus. Implications for surgical technique and prosthetic design. J Bone Joint Surg Br 1997;79:857-65. CrossRef
22. Constant CR, Murley AH. A clinical method of functional assessment of the shoulder. Clin Orthop Relat Res 1987;214:160-4.
23. Iyengar JJ, Devcic Z, Sproul RC, Feeley BT. Nonoperative treatment of proximal humerus fractures: a systematic review. J Orthop Trauma 2011;25:612-7. CrossRef
24. Gerber C, Schneeberger AG, Vinh TS. The arterial vascularization of the humeral head. An anatomical study. J Bone Joint Surg Am 1990;72:1486-94.
25. Warner JJP, Iannotti JP, Flatow EL, editors. Complex and Revision Problems in Shoulder Surgery, 2nd ed. Philadelphia: Lippincott, Williams & Wilkins; 2005.
26. Hausberger KH. Blood supply of intraarticular fractures of the humeral head: an anatomical and biomechanical study. In: Proceedings of the 14th Congress of the European Society for Shoulder and Elbow Surgery, Lisbon, 2000.
27. Levine WN, Marra. G, Bigliani LU, editors. Fractures of the shoulder girdle. New York, NY: Marcel Dekker; 2003.
28. Resch H, Aschauer E, Povacz P, Ritter E. Closed reduction and fixation of articular fractures of the humeral head. Tech Shoulder Elbow Surg 2000;1:154-62. CrossRef
29. Wiss DA, editor. Master techniques in orthopaedic surgery: fractures. 2nd ed. Philadelphia: Lippincott, Williams & Wilkins; 2006.
30. Kim DH, Rhim R, Li L, Martha J, Swaim BH, Banco RJ, et al. Prospective study of iliac crest bone graft harvest site pain and morbidity. Spine J 2009;9:886-92. CrossRef
31. Gerber C, Werner CM, Vienne P. Internal fixation of complex fractures of the proximal humerus. J Bone Joint Surg Br 2004;86:848-55. CrossRef
32. Egol KA, Sugi MT, Ong CC, Montero N, Davidovitch R, Zuckerman JD. Fracture site augmentation with calcium phosphate cement reduces screw penetration after open reduction-internal fixation of proximal humeral fractures. J Shoulder Elbow Surg 2012;21:741-8. CrossRef
33. Zhu L, Liu Y, Yang Z, Li H, Wang J, Zhao C, et al. Locking plate fixation combined with iliac crest bone autologous graft for proximal humerus comminuted fracture. Chin Med J (Engl) 2014;127:1672-6.
34. Matassi F, Angeloni R, Carulli C, Civinini R, Di Bella L, Redl B, et al. Locking plate and fibular allograft augmentation in unstable fractures of proximal humerus. Injury 2012;43:1939-42. CrossRef
35. 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. CrossRef
36. Brunner F, Sommer C, Bahrs C, Heuwinkel R, Hafner C, Rillmann P, et al. Open reduction and internal fixation of proximal humerus fractures using a proximal humeral locked plate: a prospective multicenter analysis. J Orthop Trauma 2009;23:163-72. CrossRef
37. 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. CrossRef
38. Lee CW, Shin SJ. Prognostic factors for unstable proximal humeral fractures treated with locking-plate fixation. J Shoulder Elbow Surg 2009;18:83-8. CrossRef
39. Erhardt JB, Roderer G, Grob K, Forster TN, Stoffel K, Kuster MS. Early results in the treatment of proximal humeral fractures with a polyaxial locking plate. Arch Orthop Trauma Surg 2009;129:1367-74. CrossRef
40. Owsley KC, Gorczyca JT. Fracture displacement and screw cutout after open reduction and locked plate fixation of proximal humeral fractures [corrected]. J Bone Joint Surg Am 2008;90:233-40. CrossRef