ORIGINAL ARTICLE

Mid- to long-term outcomes of proximal humerus fractures treated with open reduction, plate fixation, and iliac bone autograft augmentation

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ABSTRACT

BACKGROUND: Open reduction and internal fixation (ORIF) using locking plates is a widely adopted treatment for displaced proximal humerus fractures. Various augmentation techniques have been developed to enhance the stability of plate fixation. Among these, iliac bone autograft is notable for its advantages over allografts, such as ready availability and the elimination of costs and risks associated with disease transmission. Despite its potential benefits, data on the outcomes of iliac bone autograft augmentation (IBAA) are still limited. This study aims to present the mid- to long-term results of treating proximal humerus fractures with ORIF using locking plates and IBAA.

METHODS: The study included 15 patients treated with ORIF and IBAA. We classified fracture patterns using the Neer classification and estimated local bone density via the deltoid tuberosity index. We measured the neck shaft angle (NSA) and humeral head height (HHH) on both immediate postoperative and most recent X-ray images to assess the maintenance of reduction. Clinical outcomes were evaluated using the DASH (Disabilities of the Arm, Shoulder, and Hand) and Constant scores.

RESULTS: The average follow-up duration was 59.56 months, ranging from 24 to 93 months. A majority of fractures were classified as four-part (53%). The average immediate and late postoperative NSAs were 132.6±8.19 and 131.6±7.32 degrees, respectively. The average HHH on the immediate postoperative and latest follow-up images were 16.46±6.07 and 15.10±5.34, respectively. None of the patients exhibited any radiological signs of avascular necrosis or loss of reduction at the latest follow-up. The mean postoperative Constant and DASH scores at the latest follow-up were 79.6 and 11.5, respectively.

CONCLUSION: Our findings suggest that ORIF with IBAA is an effective method for managing three- or four-part proximal humerus fractures, yielding excellent outcomes.

Keywords: Autografts; fracture fixation; shoulder fractures.

INTRODUCTION

Open reduction and internal fixation (ORIF) of proximal humerus fractures is a technically demanding procedure, with reported surgical failure rates varying widely across studies, reaching as high as 34%.[1,2] However, compared to joint replacement, ORIF preserves both the patient's bone stock and native anatomy, which is especially important for younger patients. Furthermore, although high complication rates for fixation have been reported, achieving anatomic reduction of

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these fractures is linked to significantly lower complication rates and favorable clinical outcomes.[3]

Several risk factors have been identified that predict failure after surgical fixation of proximal humerus fractures. The most critical factors include failure to achieve anatomic restoration of medial support, decreased local bone density, and advanced age.[4] Various augmentation methods have been developed to reduce surgical failure rates and enhance the outcomes of surgical fixation of proximal humerus fractures. This study aims to report the mid- and long-term outcomes of open reduction, plate and screw fixation with iliac bone graft augmentation for proximal humerus fractures. We hypothesize that excellent outcomes can be achieved through anatomic reduction, iliac bone autograft augmentation, and appropriate surgical technique.

MATERIALS AND METHODS

Patients

This retrospective study included patients who underwent open reduction, plate fixation, and iliac bone autograft augmentation with a minimum follow-up period of 2 years. Between April 2012 and November 2020, a total of 488 patients with traumatic proximal humerus fractures were admitted to our emergency department. Out of these patients, 117 underwent operative treatment, with 48 receiving open reduction and plate fixation. Among these 48, 17 were augmented with iliac bone autograft. Patients identified as potential candidates for augmentation with iliac bone autograft included those with fractures classified as three- or four-part according to the Neer classification, fractures accompanied by valgus impaction, loss of medial calcar, or a reduction in volume due to crushing of bone fragments. Anatomical reduction was not attempted in comminuted metaphyseal fractures where the neck-shaft angle was undisturbed and there was no shortening greater than 2 cm after reduction. Two patients were excluded from the study due to loss of follow-up, resulting in 15 patients included in the research.

Radiological Evaluation

Preoperative evaluation included computed tomography and anteroposterior (AP), true AP, and scapula Y view radiographs for all patients. Fractures were classified using the Neer classification.[5] During the final postoperative follow-up, a four-view shoulder series, including AP, true AP, scapula Y, and axillary views, was obtained (Figures 1 and 2). The risk of developing avascular necrosis was assessed using preoperative X-rays based on criteria defined by Hertel et al., which include the loss of the integrity of the medial hinge and anatomic neck, as well as the length of the medial calcar.[6] Additionally, the deltoid tuberosity index was used as a surrogate measure of the local bone mineral density of the proximal humerus.[7] Radiographs obtained immediately after surgery and at the last follow-up were evaluated. The neck-shaft angle (NSA) was measured on the true AP view. To determine if subsidence of the humeral head had occurred, we measured the distance between the superior tip of the plate and the most superior point of the humeral head (humeral head height).[8] Avascular necrosis was considered to have developed if there were sclerotic changes in the humeral head, disruption of head architecture, and decreased local bone density.[9]

Surgical Technique and Postoperative Rehabilitation

All operations were performed by a single surgeon in the same hospital. Arthroplasty instruments were readily available during all procedures to accommodate any potential need to convert from fixation to joint replacement. All pro-

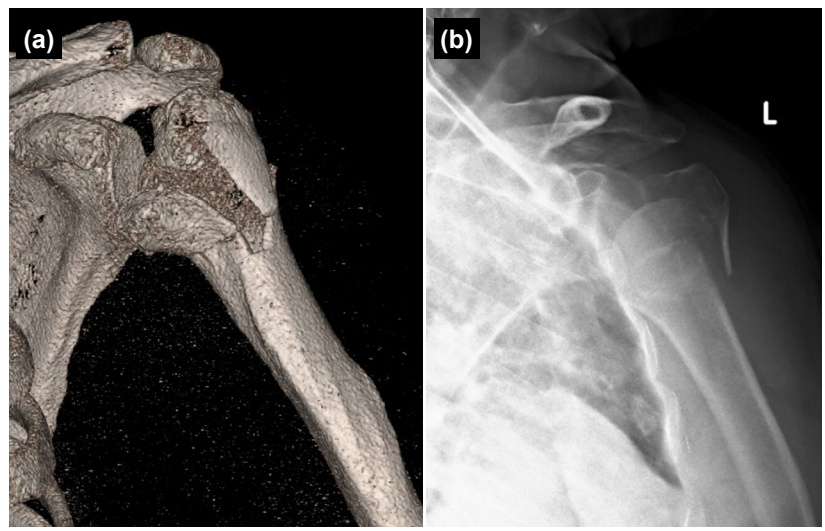

Figure 1. Preoperative imaging of a patient with a proximal humerus fracture treated with open reduction internal fixation and iliac bone autograft augmentation (patient no. 3): **(a)** 3-D reconstruction image from the preoperative computed tomography scan. **(b)** Preoperative shoulder AP view radiograph.

Table 1. Fracture patterns according to Neer classification and Hertel's criteria for each patient enrolled in the study. The most common pattern is the four-part fracture (53%).

Patient	Age	Sex	Neer Classification	Disruption of Medial Hinge	Fracture Involving Anatomical Neck	Medial Calcar Length <8 mm	Constant Score (Postop)	DASH* Score (Postop)	Flexion (Degrees) (Postop)	Abduction (Degrees) (Postop)	Internal Rotation (Level) (Postop)	External Rotation (Degrees) (Postop)
1	77	Male	4	Yes	Yes	No	70	3.4	150	130	T12	45
2	71	Male	4	Yes	Yes	Yes	77	6	140	140	T12	40
3	48	Male	4	No	Yes	Yes	82	8.3	145	150	Hip	40
4	83	Female	3	Yes	Yes	Yes	68	0.8	125	120	L4	40
5	56	Male	4	Yes	Yes	No	100	0	160	160	T12	65
6	59	Female	3	Yes	Yes	Yes	69	13.8	150	120	L4	60
7	75	Male	3	Yes	Yes	No	96	4.3	160	140	T12	60
8	56	Female	4	Yes	Yes	No	7	137	140	140	L4	25
9	75	Female	3	Yes	Yes	Yes	78	12.9	140	90	T12	65
10	61	Male	3	Yes	No	No	86	3.6	140	135	T12	45
11	79	Male	3	Yes	No	Yes	77	0.9	120	120	L4	20
12	59	Female	4	Yes	Yes	Yes	66	27.6	140	130	T12	40
13	61	Female	4	Yes	Yes	Yes	98	0	160	160	T12	45
14	64	Female	4	Yes	Yes	Yes	78	13	140	130	L4	30
15	70	Female	3	Yes	Yes	Yes	78	13	150	140	L4	40

Postoperative Constant and DASH scores of each patient and postoperative active range of motion (AROM) of each patient are also presented. Postop: Postoperative

cedures were conducted with patients in the beach chair position. The deltopectoral approach was consistently favored in all cases. Non-absorbable stay sutures were placed on the anterior, posterior, and superior edges of the humeral head where the cuff attached to the minor and major tubercles to facilitate control of the tubercles during reduction. With the arm in neutral rotation, the shoulder was abducted to 30 degrees and elevated forward to 10 degrees to relax the deltoid muscle and aid in the reduction process. Traction was applied to the stay sutures, and the reduction of the humeral head was performed using a blunt elevator under fluoroscopic guidance. Once reduction was achieved, a tricortical iliac bone graft was harvested and used to establish inferomedial support. The graft was interposed between the fragments to avoid excessive motion of the tubercles. On average, six screws were inserted into the proximal locking section of the plate. Inferomedial support was established by placing one or two screws within the inferior quarter of the humeral head height. The central screw was positioned in the subcortical bone. During the postoperative period, all patients wore an arm sling with an abduction pillow to avoid shoulder rotation, except for obese patients. Passive range of motion exercises were initiated after the first week once swelling and pain had subsided. Active assisted exercises commenced after the fourth week, and strengthening exercises began as soon as bony union was observed on the X-ray.

Clinical Outcomes

Clinical outcomes were assessed using the Constant and Disabilities of the Arm, Shoulder, and Hand (DASH) scores.[10] Patient satisfaction following surgery was evaluated by asking them to rate their experience as poor, fair, good, or excellent.

Statistical Analysis

The data presented below are expressed as mean±standard deviation. All means and standard deviations were calculated using IBM SPSS Statistics Software 25 (IBM Corp., Armonk, NY, USA).

RESULTS

Patients

The study included 15 patients, eight female and seven male (Table 1). The mean age was 66.26 years (range 48-83 years) (Table 1). Only patients with a minimum follow-up period of two years were included, and the average follow-up duration was 59.56 months (range 24-93 months). Six patients were diagnosed with diabetes mellitus, and one patient had rheumatoid arthritis and was using corticosteroids.

Radiologic Outcomes

The type of fracture for each patient, according to the Neer classification, is detailed in Table 1. All patients sustained a comminuted fracture, classified as either three- or four-part. Hertel's criteria for assessing the risk of avascular necrosis for each patient are also listed in Table 1. The mean deltoid

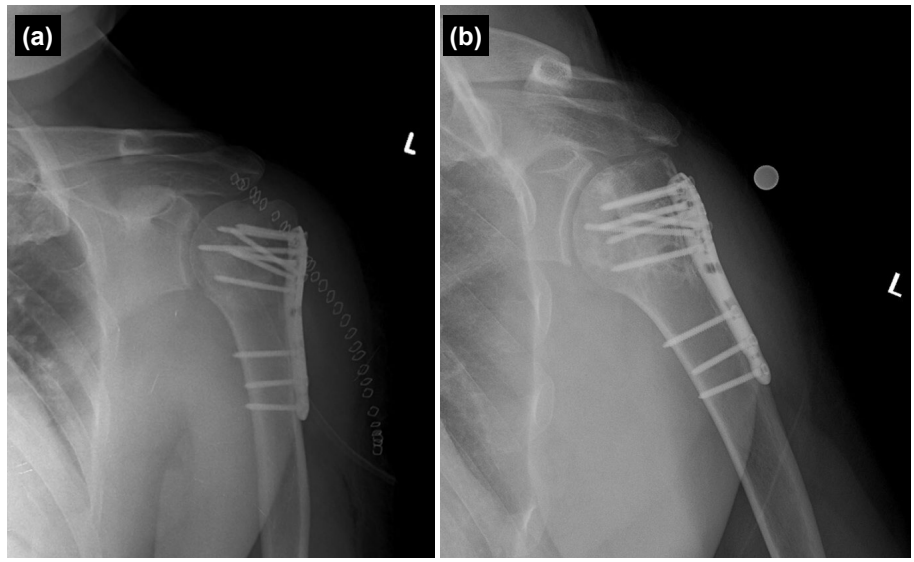

Figure 2. Postoperative true AP view radiographs of the patient no. 3 **(a)** immediately after surgery **(b)** at the latest follow-up, 6 years after the surgery.

tuberosity index for all patients was 1.51±0.21. Five patients had a value below 1.4, indicating a low local bone density of the humeral head.[7] The early postoperative (obtained immediately after surgery) and late (at the latest follow-up) mean NSA values were 132.6±8.19 and 131.6±7.32 degrees, respectively. None of the patients showed any radiologic signs of avascular necrosis or loss of reduction at the latest follow-up. The humeral head height measured on the X-rays obtained on the postoperative first day and the latest follow-up was 16.46±6.07 and 15.10±5.34, respectively. Anatomical reduction was achieved in all cases. In four cases, eight screws were inserted into the head, while in the remaining cases, seven screws were used (Fig. 2).

Clinical Outcomes

The mean postoperative Constant and DASH scores at the latest follow-up were 79.6 (range 66-100) and 11.5 (range 0-27.6), respectively (Table 1). The mean shoulder forward elevation was 144±11.28 degrees, abduction was 133.67±16.98 degrees, and external rotation was 45.33±15.54 degrees. The internal rotation level reached T12 in 8 patients, L4 in 6 patients, and the hip in 1 patient (Table 1). Twelve patients rated their satisfaction with the treatment as excellent, and three as good. No surgical wound complications occurred at either the shoulder or the donor site of any patient. In one case, an iliac bone fracture occurred at the donor site during the early postoperative period, leading to the subsequent use of an oscillating saw instead of an osteotome for harvesting the tricortical graft from the iliac bone.

DISCUSSION

The findings of this study support the use of anatomical reduction and plate fixation with iliac bone autograft as a viable treatment for comminuted proximal humerus fractures, demonstrating satisfactory clinical outcomes with an acceptable rate of complications.

Controversy still exists regarding the optimal treatment of proximal humerus fractures. While conservative treatment may be the preferred first-line approach for elderly patients with limited activity, surgical treatment is often necessary for complex fracture types, such as comminuted or Neer type 3 and 4 fractures, and those accompanied by additional injuries or instability in relatively active patients.[11] Surgical options for managing these fractures include reverse shoulder arthroplasty (RSA), hemiarthroplasty (HA), and ORIF.[12] Preferences for treating complex fractures among surgeons vary significantly and may be influenced by factors related to the fracture, patient, and surgeon. These include the surgeon's experience, skill, fracture morphology (such as involvement of the surgical neck, displacement, and impaction), as well as the patient's age, gender, level of activity, and physical status.[13]

Several factors have been shown to affect the success of ORIF of proximal humerus fractures, including local bone quality, fracture morphology, surgical technique, and implant choice. Key elements of surgical technique include achieving anatomical reduction, restoring medial support, and placing an adequate number of screws of appropriate length in strategic locations, all crucial in preventing surgical failure.[14] The quality of reduction significantly impacts both clinical outcomes and complication rates. A 2016 study demonstrated that cases with anatomical or acceptable reduction experienced lower complication rates (such as osteonecrosis, head-shaft displacement, and greater tubercle cranialization) and revision rates, and achieved higher outcome scores compared to cases with malreduction.[3] Screw placement is important because the anterosuperior part of the head has low local bone density, leading to a reduced pull-out force and higher likelihood of screw failure in this region. In contrast, the central, posterior, and inferior regions exhibit higher local bone

density and greater pull-out force, enhancing screw stability and reducing the risk of failure.[15] The placement of an inferomedial calcar screw is also vital for maintaining reduction, and incorrect placement can lead to early mechanical failure.[16] Additionally, the number of screws in the head plays a significant role in maintaining reduction. While a cadaveric study by Erhardt et al. reported that at least five screws are necessary for adequate fixation, a more recent biomechanical study indicated that at least seven screws are required to prevent fixation failure.[14,17]

According to a meta-analysis published in 2018, the most common complication is intra-articular screw penetration, occurring at a rate of 9.6%.[18] However, in our study, we found that none of the patients experienced screw penetration during early or late follow-ups, despite 53% having Neer type 4 fractures and approximately 93% showing impaired medial hinge integrity. A 2012 study examining the outcomes of locking plate and fibular allograft application in 17 patients with three- or four-part proximal humerus fractures reported no occurrences of screw penetration during an average follow-up period of 13 months.[19] Results from both this study and ours suggest that bone graft augmentation reduces the risk of screw penetration in cases with plate screw fixation, possibly due to the graft's effectiveness in restoring medial hinge integrity or stabilizing the fixation.

Varus collapse is another complication that can lead to treatment failure, with several identified risk factors including advanced age, low local bone density, disruption of the medial hinge, improper reduction, and failure to use properly placed calcar screws.[20] The use of bone grafts may play a preventive role in the development of this complication. In a study involving 38 cases that used intramedullary fibular allograft, varus collapse was reported in only one patient, who did not require reoperation.[21] Our study found that none of the patients, including those with the aforementioned risk factors, experienced varus collapse. These results suggest that anatomical reduction and bone graft augmentation are effective in preventing varus collapse.

Avascular necrosis of the humeral head is a potential complication following ORIF treatment for proximal humeral fractures, which may require reoperation.[22] Hertel et al. identified specific criteria that predict the risk of vascular disruption and avascular necrosis in these fractures, including a medial metaphyseal head extension of less than 8 mm, displacement of the shaft relative to the head by more than 2 mm, and a fracture pattern involving the anatomic neck. The presence of multiple criteria increases the risk cumulatively.[6] In our study, the majority of patients met multiple criteria, placing them at high risk for developing avascular necrosis (AVN). However, none of our study's patients developed AVN, which aligns with findings from a similar study reporting outcomes for 21 patients treated with locking plate fixation and an autologous morselized iliac bone impaction graft;[23] that study also reported no cases of AVN. The authors suggested that autografting may help prevent AVN by promoting angiogenesis at the fracture site.[23]

Patients with osteoporosis, associated with higher failure rates after ORIF for proximal humerus fractures, tend to experience greater complication rates and revisions. For example, a study of 27 osteoporotic patients reported complications in 16 patients, with 8 requiring revision surgery.[24] Augmentation with allograft, alongside locking plate fixation, has been shown to improve clinical and radiologic outcomes and reduce complication rates in elderly and osteoporotic patients with proximal humeral fractures.[25,26]

Despite the benefits of fibular allografts, they also present significant drawbacks including limited availability, high costs, and the large size of the grafts, which can complicate reduction efforts. For instance, obtaining these grafts may be difficult in certain regions or hospitals, including ours, and the associated high costs can inhibit their use. Furthermore, the relatively large size of these grafts compared to iliac grafts can cause excessive motion of the tubercles, potentially complicating the maintenance of reduction during application.

Iliac bone autografts can serve as an alternative to fibula allografts for augmentation, although studies demonstrating the results of iliac bone augmentation are limited. In a study by Zhu et al., the outcomes of ORIF with iliac autograft were compared to ORIF alone in 40 patients with comminuted proximal humerus fractures. Among the 18 patients treated with tricortical iliac autograft, no complications were observed. They also reported significantly shorter radiographic union times and better range of motion compared to the control group.[27] Similarly, a 2012 study involving 21 patients with four-part proximal humerus fractures treated with iliac bone graft augmentation and ORIF reported no complications or failures, and found NSA values of 129±9°, comparable to our results.[23]

Although iliac bone autografting may be associated with donor site complications such as infections, seroma/hematoma formation, iliac bone injuries, and neurovascular or abdominal wall injuries,[28] these can be avoided with proper surgical technique and meticulous postoperative wound care. However, in our study, one patient experienced an iliac bone fracture associated with the harvesting of the iliac bone graft, likely due to too frequent ambulation during the early postoperative period. Additionally, an osteotome was used to harvest the iliac bone graft in this case. By limiting frequent ambulation postoperatively and using an oscillating saw instead of an osteotome for iliac bone harvesting, potential iliac bone fractures can be prevented.[29] Besides donor site complications, the harvesting of the iliac bone graft may also prolong the duration of surgery. However, we observed that the re-establishment and securing of medial support using the graft may facilitate reduction, potentially compensating for the time spent on graft harvesting, although no data regarding surgical duration were recorded.

In elderly patients, higher complication and revision rates of ORIF have led to an increase in the use of RSA for managing proximal humerus fractures.[30] It is important to note, however, that the complication rate after RSA is not negligible, and these complications can be more devastating and challenging to manage.[31] A 2017 study reported a complication rate of 29% and a revision rate of 12% following RSA.[32] Post-revision complication rates in RSA ranged from 5-45%, with re-revision rates at 19.8%.[33] These complications include infection, instability, periprosthetic fractures, aseptic loosening, component disassembly, neurologic injuries, scapular notching, heterotopic ossification, and restricted range of motion, especially in external rotation, if tuberosity repair is not performed.[34]

According to the authors of this article, the choice of surgical treatment should be based on appropriate patient selection and the ability to achieve proper reduction during surgery, rather than solely on the fracture classification from preoperative imaging or patient factors such as age or bone quality. Therefore, it is crucial for the surgeon to be prepared to perform either RSA or ORIF in all cases. The exceptions to ORIF are cases involving elderly patients with inadequate bone stock and intra-articular fracture involvement, where achieving and maintaining reduction may be highly unlikely, and performing RSA may be more appropriate than attempting reduction and fixation.

The present study has several limitations that should be acknowledged. Firstly, the number of cases is limited, and our study lacks a control group. Future studies including more cases and a control group may provide further insight into the contribution of iliac bone graft augmentation to the good clinical outcomes reported in our study.

CONCLUSION

The ORIF of comminuted proximal humerus fractures is technically challenging and may be associated with a high risk of failure. However, several augmentation methods may be used to decrease the rate of failure and improve outcomes. In our study, we demonstrate excellent clinical and radiologic outcomes following anatomical reduction, plate fixation, and iliac bone augmentation.

Ethics Committee Approval: This study was approved by the Istanbul University-Cerrahpasa, Cerrahpasa Medical Faculty Ethics Committee (Date: 20.12.2022, Decision No: 402).

Peer-review: Externally peer-reviewed.

Authorship Contributions: Concept: M.F.G.; Design: M.F.G.; Supervision: M.F.G.; Resource: M.F.G.; Materials: M.F.G.; Data collection and/or processing: S.U., U.Y., M.Ö.; Analysis and/or interpretation: M.F.G., U.Y.; Literature search: M.F.G., U.Y., C.D.D.; Writing: M.F.G., U.Y., C.D.D.; Critical review: M.F.G., G.U.D., M.Ö.

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ORİJİNAL ÇALIŞMA - *ÖZ*

Açık redüksiyon, plak fiksasyonu ve iliak kemik otogreft augmentasyonu ile tedavi edilen proksimal humerus kırıklarının orta-uzun dönem sonuçları

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AMAÇ: Kilitli plaklar kullanılarak yapılan açık redüksiyon ve internal tespit (ARİF), deplase proksimal humerus kırıklarında yaygın olarak kullanılan bir tedavi yöntemidir. Plak fiksasyonunun stabilitesini arttırmak için çeşitli augmentasyon yöntemleri geliştirilmiştir. İliak kemik otogrefti, allogreftlere göre temin etmede herhangi bir güçlük olmaması, maliyetsiz olması ve hastalık bulaşı riski olmaması gibi avantajlar sunan potansiyel bir greft seçeneğidir. Potansiyel avantajlarına rağmen iliak kemik otogreft augmentasyonnun (İKOA) sonuçlarına ilişkin mevcut veriler sınırlıdır. Çalışmamızın amacı, kilitli plak ve İKOA kullanılarak açık redüksiyon ve internal fiksasyon (ARİF) ile tedavi edilen proksimal humerus kırıklarının orta-uzun dönem sonuçlarını bildirmektir.

GEREÇ VE YÖNTEM: ARİF ve İKOA ile tedavi edilen 15 hasta dahil edildi. Kırıklar Neer sınıflandırması kullanılarak sınıflandırıldı. Lokal kemik yoğunluğu deltoid tüberkül indeksi kullanılarak değerlendirildi. Redüksiyonun korunduğunu değerlendirmek için hem erken postoperatif, hem de son takip röntgen görüntülerinde boyun şaft açısı (BŞA) ve humerus başı yüksekliği (HBY) ölçüldü. Klinik sonuçlar DASH ve Constant skorları kullanılarak değerlendirildi.

BULGULAR: Ortalama takip süresi 59,56 ay (aralık 24-93 ay) idi. Kırıkların çoğu 4 parçalı (%53) olarak sınıflandırıldı. Ortalama erken ve geç postoperatif BŞA'lar sırasıyla 132.6±8.19 ve 131.6±7.32 derece idi. Erken postoperatif görüntülerdeki ve son takip görüntülerindeki ortalama HBY sırasıyla 16.46±6.07 ve 15.10±5.34 idi. Son takipte hiçbir hastada avasküler nekroz veya redüksiyon kaybının herhangi bir radyolojik belirtisi görülmedi. Ameliyat sonrası ortalama Constant ve DASH skorları son takipte sırasıyla 79.6 ve 11.5 idi.

SONUÇ: Çalışmamız, ARİF ve İKOA'nın üç veya dört parçalı proksimal humerus kırıklarının tedavisinde oldukça iyi sonuçlarla güvenilir bir teknik olduğunu göstermektedir.

Anahtar sözcükler: Kırık tespiti; omuz kırıkları; otogreft.

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