Comparison of Three Different Treatment Modalities in the Management of Humeral Shaft Nonunions (Plates, Unilateral, and Circular External Fixators)

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Objectives: To compare 3 different fixation methods for the treatment of humeral shaft nonunions in terms of union time, functional outcome, and complications.

Design: Retrospective case series.

Setting: University hospital.

Patients: Between 1996 and 2004, 80 patients (mean age, 49; range, 15 to 86; 30 women and 50 men) with nonunions of the humeral shaft were treated surgically in our institution. Circular external fixators (CEF) were used in 35 patients, unilateral limb reconstruction system (LRS) fixators in 24 patients and fixation with plates in 21 patients.

Intervention: Surgical procedure included hardware removal in previously operated patients, autogenous grafting in all patients in the plate group and in those patients with atrophic nonunions in the external fixator groups, compression of the nonunion site in all patients.

Main Outcome Measurements: Radiological union time, complications, shortening, and disabilities of the arm, shoulder, and hand (DASH) score.

Results: Mean follow-up period was 48.1 months (range, 12 to 121). Mean radiological union time was 5.5 months (range, 1.5 to 12) in the CEF group, 5.2 months (range, 3 to 10) in the LRS group, and 5.7 months (range, 3 to 12) in the plate group. Mean DASH score was 23.7 in the CEF group, 18.6 in the LRS group, and 26 in the plate group. There were no statistical differences in terms of union time and the DASH score among the 3 groups. Successful union was achieved in 77 (96.3%) patients.

Conclusion: Both external fixation and plate fixation produce excellent results in humeral shaft nonunions if applied properly. The procedure can be tailored to the surgeon's experience, keeping in mind that plate fixation demonstrates a longer healing time in those cases that had previous surgeries.

Key Words: humeral shaft nonunion, circular external fixator, unilateral external fixator, plate fixation

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INTRODUCTION

Humeral shaft nonunion is defined as a fracture displaying no boney consolidation on radiographs 6 to 8 months after treatment.[1] Nonunion rates vary from 2% to 33%.[2–5]

Primary stability of the reconstruction during nonunion surgery should be sufficient to allow early rehabilitation to avoid stiff elbow and/or shoulder problems. Moreover, in distal humeral shaft nonunions stable fixation can be difficult to achieve, especially if there is bone loss due to previous surgery.[6]

External fixation has been used for the management of open humeral fractures and fractures of the humerus associated with gunshot wounds and vascular injury. There are limited data on its role in the management of humeral shaft nonunions.[7] Plate fixation for humeral shaft nonunions is a well accepted method with successful results.[8–10]

In this study, we report the results of 80 patients with humeral shaft nonunions treated with either unilateral external fixators [Limb Reconstruction System (LRS)], circular external fixators (CEF), or plate fixation. We aimed to compare 2 different external fixation methods with the gold-standard plate technique in terms of union time, functional outcome, and complications.

PATIENTS AND METHODS

Between the years 1996 and 2004, 80 patients with clinically and radiologically established nonunions of the humeral shaft were referred to our institution.

Of the 80 patients, 30 were women and 50 were men, and the mean age was 49 years (range, 15 to 86 years). Only 2 patients were younger than 18 years. Both were at the end of skeletal maturation and were treated as adults. Patients with bone defects exceeding 5 cm, patients who required dead bone segment resections of more than 5 cm, and patients with infected nonunions were not included in the study.

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The primary causes of the nonunited fractures were motor vehicle accidents in 44 patients, falls in 30 patients, and gunshot wounds in 5 patients. Nonunion occurred in 1 patient due to tumoral resection. The fractures were located in the proximal third of the humeral shaft in 14 patients, the middle third in 36 patients, and the distal third in 30 patients. Twenty-two of the nonunions were evaluated as hypertrophic, and 58 were evaluated as atrophic. Fifty-two patients had been previously treated by operative means, and the remaining 28 had been treated by nonoperative methods. There was a total of 69 previous surgical interventions in these patients: 36 fixations with plates, 9 intramedullary nail fixations, 18 external fixator applications, 6 minimal osteosynthesis (K-wire, screw only, etc.). The average time between the last treatment and our intervention was 11.8 months (range, 2 to 110 months). Detailed demographic data are included in Tables 1, 2, and 3.

In the external fixation group, 35 patients were treated with CEF between 1996 and 2001. After that period, considering patient comfort, we changed our strategy and applied LRS fixators in 24 humeral shaft nonunions; however, circular devices were preferred for proximal metaphyseal nonunions, stiff nonunions with deformity, and nonunions with fixed elbow contracture. In the same time period, 21 patients were treated by open reduction and plate fixation with grafting by another surgeon at the same institution.

Surgical Intervention With Orthofix LRS

Implanted hardware was removed in previously operated patients. All fibrous and soft tissues at the nonunion sites were excised. In atrophic nonunions, the sclerotic bone ends were removed until vital bone was observed, the medullary canal was reamed, and the fracture line became perpendicular to the shaft. Average bone resection was 2.2 cm (range, 1 to 5 cm).

The radial nerve was explored in the distal third of the humerus to insert distal Schanz screws. Three conically shaped, 6-mm diameter, hydroxyapatite-coated Schanz screws were inserted into the proximal segment, and 3 similar screws were inserted into the frontal plane of the distal fragment.

In 8 patients with distal nonunions, the third Schanz screw was inserted through the *trochlea humeri* to obtain additional stability (Figure 1).

Autogenous iliac crest bone grafting was added to the procedure for patients with atrophic nonunions after the external fixator was applied.

After Treatment in the LRS Group

Physical therapy was encouraged on the first postoperative day. This consisted of passive shoulder and elbow range of motion exercises. Active range of motion and isometric exercises were initiated and increased according to the patient's tolerance.

To obtain an increased stability of the construct, monofocal compression divided into 4 equal 0.25-mm increments each day was applied in patients with atrophic nonunions beginning on the third postoperative day and continuing until the device did not allow further compression mechanically, which usually occurred within 4 days.

Surgical Intervention With CEF

After implant removal and debridement of dead tissue as described above, an average of 2.4 cm (range, 1 to 5 cm) bone resection was performed. Each bone segment was fixed with 1.8-mm K-wires and 6-mm conical, hydroxyappatite-coated Schanz screws. We used a hybrid Ilizarov technique with K-wires and Schanz pins, combining circular rings, half rings, and a proximal arch with a preassembled frame (Figure 2). The diaphyseal and distal rings were connected by threaded rods, and the proximal arch was connected by 2 oblique supports.

After anatomical reduction, bone segments were compressed with the external fixator until sufficient stability was observed. Autogenous corticocancellous graft was used in all atrophic cases to augment consolidation. After treatment was the same as described for the LRS group.

Surgical Intervention (Plates)

Anterolateral or lateral approaches were used as standard while deltopectoral extension was added in proximal fractures. Implants were removed; fracture ends were debrided of dead tissue as described above and shaped appropriately for compression plating. Bone resection was never more than 1cm. The radial nerve was dissected carefully in patients with middle and distal third fractures. In ten patients a dynamic compression plate (DCP, Synthes, Switzerland) was applied with at least three, preferably four screws on either side of the fracture. (Figure 3) After 2004, locking compression plates (LCP, Synthes, Switzerland) were used in the remaining eleven patients. Compression at the fracture site was obtained with lag screws in oblique fractures and, with eccentric drilling of the screw holes of the plates. After fixation, the fracture site was grafted with autogenous corticocancellous graft from the iliac crest.

After Treatment in Plate Group

The arm was immobilized in a sling for 3 weeks postoperatively. Active assistive shoulder and elbow motion was begun after swelling subsided, namely 5 to 7 days postoperatively.

Follow-up Visits

Clinical and radiological follow-up examinations were performed in all 3 groups every 3 to 4 weeks. Complications, patient complaints, and radiological union time were recorded. We evaluated the functional results using the disabilities of the arm, shoulder, and hand (DASH) score at their last follow-up visit.[11] Satisfactory consolidation (radiographic union) in the external fixator groups (LRS, CEF) was defined as detection of 3 to 4 areas of cortical consolidation in anteroposterior and lateral radiographs. The external fixator was removed by local anesthesia at the pin sites. A polyethylene Sarmiento-type brace was prescribed to protect the union site against refractures for an additional 4 weeks. In the plate group, osseous healing was defined radiologically as the presence of at least 3 healed cortices with bridging callus and crossing bone trabeculae on anteroposterior and lateral radiographs.

Statistical Analyses

Statistical analyses was performed by ANOVA and unpaired t tests, statistical significance being $P < 0.05$ with

TABLE 1. Demographic Data of the CEF (Circular External Fixator) Group

Patient No.	Age	Sex	Time Between Last Treatment and İndex Operation (Months)	Etiology	Initial Treatment	Number of Previous Operations	Location
1	39	M	3	TA	Cast+ Circular external fixator	1	Mid
2	28	F	4	TA	Cast	0	Distal
3	77	M	6	Fall	Cast	0	Proximal
4	15	M	4	GSW	Cast	0	Distal
5	26	F	12	TA	Plate fix	1	Proximal
6	24	M	14	TA	Plate fix+ Monolat fix	2	Distal
7	36	M	15	TA	Plate fix+IMN	2	Distal
8	38	M	15	Fall	Plate fix	2	Mid
9	59	M	12	TA	Cast	0	Mid
10	15	M	7	TA	Plate fix	1	Distal
11	22	M	7	Fall	Monolat fix	1	Mid
12	26	M	24	GSW	Monolat fix	1	Mid
13	31	M	20	TA	Plate fix	1	Distal
14	43	M	6	Fall	IMN nail	1	Distal
15	59	M	6	TA	Cast	0	Proximal
16	25	M	8	TA	Plate fix+IM nail+graft	3	Mid
17	37	M	60	TA	Monolat fix	1	Proximal
18	49	M	15	TA	Plate fix	1	Mid
19	23	M	7	TA	Cast	0	Distal
20	48	M	8	Fall	Cast	0	Mid
21	35	F	6	Fall	Plate fix	1	Distal
22	50	M	48	Fall	IMN nail+Monolat fix	2	Distal
23	34	M	6	GSW	Cast + Monolat fix	1	Distal
24	60	F	7	Fall	Cast	0	Mid
25	77	F	12	Fall	Cast	0	Distal
26	44	M	18	ABC	Intercalary prosthesıs+Fibula graft	2	Mid
27	25	M	4	Fall	Plate fix	1	Proximal
28	36	M	10	Fall	Screw fix	1	Distal
29	47	M	8	GSW	Cast	0	Distal
30	43	M	7	Fall	Cast	0	Mid
31	70	F	6	Fall	Cast	0	Mid
32	69	F	18	Fall	Plate fix	1	Distal
33	65	F	12	TA	Plate fix	2	Distal
34	44	M	24	TA	Circular external fixator	1	Distal
35	57	M	7	Fall	Cast	0	Mid

Patient No.	AO Type	Type of Nonunion	Radiological Union Time (Months)	Follow-up (Months)	Complication	DASH Score	Shortening (Centimeters)
1	A1	Atrophic	4	96	Radial nerve p.	1	2
2	B1	Atrophic	4	121	None	14	1
3	A3	Atrophic	2	100	None	8	2
4	C2	Hypertrophic	2	96	None	6	3
5	B1	Atrophic	10	110	None	24	4
6	A2	Atrophic	3.5	97	None	1	3
7	A3	Atrophic	6	86	G3 Pin tract inf	85	3
8	C1	Hypertrophic	6	46	None	17	3
10	B3	Hypertrophic	5	82	None	38	1
11	A1	Atrophic	12	79	None	14	2
12	B1	Atrophic	8	75	None	1	3
13	A2	Atrophic	3	73	None	2	2
14	A3	Atrophic	6	69	Ulnar nerve p.	6	2
15	A2	Hypertrophic	5	60	Radial nerve p.	14	1
16	B3	Atrophic	NA	64	Nonunion	17	4

TABLE 1. (*continued*) Demographic Data of the CEF (Circular External Fixator) Group

Patient No.	AO Type	Type of Nonunion	Radiological Union Time (Months)	Follow-up (Months)	Complication	DASH Score	Shortening (Centimeters)
17	B1	Atrophic	8	32	None	95	3
18	A2	Atrophic	8	54	Refracture	1	2
19	A1	Atrophic	4	70	G 3 Pin tract inf	0	1
20	A1	Atrophic	6	68	None	28	2
21	B2	Atrophic	6	72	None	0	3
22	B1	Atrophic	6	12	None	2	4
23	C1	Atrophic	6	12	None	34	2
24	C3	Atrophic	6	12	None	16	2
25	A1	Atrophic	8	63	None	80	1
26	A2	Atrophic	7	12	Malunion	48	3
27	NA	Atrophic	5.5	51	None	76	4
28	A3	Atrophic	4	52	None	49	3
29	A1	Hypertrophic	6	50	G 3 Pin tract inf	1	1
30	C3	Atrophic	6	47	None	18	2
31	B2	Atrophic	6	46	None	0	1
32	A3	Atrophic	5	38	Refracture	34	3
33	B2	Atrophic	4	37	None	16	2
34	B1	Hypertrophic	6	26	Ulnar nerve p	52	2
35	A2	Hypertrophic	6	26	Radıal nerve p.	32	3
36	A3	Atrophic	8	44	None	1	1

F, female; M, male; TA, traffic accident; GSW, gun shut wound; ABC, aneursymal bone cyst; Mid, middle; Plate fix, plate and screw fixation; IM nail, intramedullary nail; Monolat fix, monolateral fixator; NA, not available; nerve p, nerve palsy.

a confidence interval of 95%. SPSS version 12.0 was used to perform analyses.

RESULTS

The mean follow-up period of all groups was 48.1 months (range, 12 to 121 months). Follow-up periods for the LRS, CEF, and plate groups were 34 months (range, 12 to 60 months), 57.5 months (range, 12 to 121 months), and 48.5 months (range, 12 to 108 months), respectively.

Solid bony union was obtained in all but 1 patient (98.3%) in the CEF group. This patient (patient 15 in Table 1) was revised successfully by intramedullary nailing and autogenous bone grafting after the removal of the external fixator.

Radiological union was observed in 23 patients (95.8%) in the LRS group. One patient (patient 2 in Table 2) had a nonunion after 3 months of external fixation. The fixator was removed relatively early because the patient could not tolerate the device and had a painful and stiff nonunion. She was then treated with locked intramedullary nail and bone grafting. After an additional 3 months, her fracture healed without any complications.

Solid union was observed in 20 patients (95.2%) in the plate group. The fixation of 1 patient (patient 9 in Table 3) failed, but he refused revision surgery due to age (85 years) and cardiac problems.

The radiological union time was 5.5 months (range, 1.5 to 12 months) in the CEF group, 5.2 months (range, 3 to 10 months) in the LRS group, and 5.7 months (range, 3 to 12 months) in the plate group.

Shortening in the external fixator groups averaged 2.2 cm (range, 1 to 5 cm). The mean shortening was 2.4 cm (range, 1 to 5 cm) in the CEF group and 2.1 cm (range, 1 to 4 cm) in the LRS group. As mentioned in the surgical intervention section, bone resection never exceeded 1 cm in the plate group.

Mean DASH scores were 23.7 in the CEF group, 18.6 in the LRS group, and 26 in the plate group (Tables 1, 2, and 3). All younger patients returned to their work (mostly office jobs), and older retired patients were able to do their daily activities.

Patients with graft harvesting had minimal or mild pain at their donor site. Their complaints regarding the bone graft donor site resolved within 6 to 8 weeks after surgery.

Statistical Analyses

We evaluated union time and DASH score among 3 groups with 1-way ANOVA. No statistical significant difference could be detected ($P > 0.05$)

The effects of nonunion type, localization, gender and number of previous operations on radiological union time, DASH score and shortening (in external fixator) were analyzed with the unpaired t-test. Nonunion type, localization and gender had no significant effect on any result ($P > 0.05$).

Patients with 0 or 1 previous operation had significantly better DASH score results than patients with 2 or more operations ($P = 0.03$). This parameter did not affect other results significantly ($P > 0.05$).

All 3 groups were also analyzed individually for detecting the effect of previous number of operation number. In the CEF

TABLE 2. Demographic Data of the LRS Group

Patient No.	Age	Sex	Time Between Last Treatment and İndex Operation (Months)	Etiology	Initial Treatment	Number of Previous Operations	Location
1	44	M	8.5	TA	Plate fix- Circular external fixator	2	Distal
2	66	F	10	TA	Cast and Circular external fixator	1	Proximal
3	69	M	9	TA	Plate fix	1	Mid
4	60	M	17	TA	Monolat fix	1	Proximal
5	44	F	12	TA	Plate fix - AB spacer and Monolat fix	2	Mid
6	28	F	24	TA	Plate fix	1	Distal
7	54	M	18	TA	Cast and Ilizarov	1	Mid
8	70	M	7	TA	Cast		Mid
9	41	F	14	TA	Plate fix	1	Distal
10	63	M	7	TA	Cast		Mid
11	35	F	4	GSW	Cast		Distal
12	55	F	5	TA	IM Nail	1	Distal
13	52	F	6	Fall	Plate fix	1	Distal
14	33	F	4	TA	Plate fix	1	Mid
15	64	M	5	Fall	Cast		Mid
16	51	F	8	TA	Circlage	1	Distal
17	23	F	12	TA	Plate fix	1	Distal
18	45	M	4	TA	Cast		Mid
19	29	M	16	Fall	Plate fix	1	Mid
20	55	F	24	Fall	Cast –Monolat fix	1	Proximal
21	42	M	8	TA	IM Nail	1	Mid
22	56	F	110	TA	Plate fix- IM Nail	2	Mid
23	37	M	15	TA	Plate fix	2	Mid
24	32	F	24	TA	IM Nail	1	Mid

Patient No.	AO Type	Type of Nonunion	Radiological Union Time (Months)	Follow-up (Months)	Complications	DASH Score	Shortening (cm)
1	B2	Atrophic	6.5	70	Radial nerve palsy	36	4
2	A2	Hypertrophic	NA	72	Non-union + Radial nerve palsy	61	2
3	A3	Hypertrophic	5	69	None	42	1
4	A1	Artrophic	4	66	None	16	2
5	A1	Hypertrophic	4	54	None	12	2
6	B1	Atrophic	5	52	None	17	4
7	A3	Hypertrophic	10.5	42	None	26	1
8	A1	Hypertrophic	5.5	47	None	12	3
9	A2	Atrophic	4.5	36	None	9	1
10	B2	Hypertrophic	6.5	28	Radial nerve palsy	14	2
11	C3	Atrophic	5	26	None	24	2
12	A1	Atrophic	5	30	None	16	1
13	A2	Atrophic	5.5	33	None	25	2
14	A3	Atrophic	5.5	28	None	8	1
15	B2	Hypertrophic	4	26	None	18	2
16	A1	Hypertrophic	5	24	None	17	2
17	A3	Hypertrophic	4.5	23	Radial nerve palsy	16	1
18	A2	Atrophic	3	20	None	14	1
19	B3	Atrophic	5	14	None	12	4
20	A1	Atrophic	5	13	None	12	3
21	A1	Atrophic	4.5	12	Pin tract inf	14	2
22	B1	Atrophic	8	12	Pin tract inf	2	4
23	A2	Hypertrophic	7	12	None	12	3
24	A1	Atrophic	7	12	None	12	2

F, female; M, male; TA, traffic accident; GSW, gunshot wound; AB, antibiotic; Mid, middle; Plate fix, plate and screw fixation; IM Nail, intramedullary nail; Monolat fix, monolateral fixator; NA, not available.

TABLE 3. Demographic Data of the Plate Group

Patient No.	Age	Sex	Time Between Last Treatment and Index Operation (Months)	Etiology	Initial Treatment	Number of Previous Operations	Location
1	59	F	12	TA	IMN	1	Mid
2	52	M	7	TA	Monolat fix+int.fix	3	Proximal
3	32	M	9	Fall	Cast	0	Mid
4	66	M	3	TA	Cast	0	Proximal
5	86	F	3	Fall	Cast	0	Distal
6	61	M	5	TA	Plate fix	1	Mid
7	73	F	5	Fall	Plate fix	2	Mid
8	74	F	4	Fall	Cast	0	Mid
9	85	M	3	Fall	Cast	0	Proximal
10	78	F	11	Fall	Min fix	1	Distal
11	38	M	5	TA	Cast	0	Mid
12	71	F	5	Fall	Cast	0	Mid
13	46	M	8	TA	Cast	0	Distal
14	79	F	7	Fall	IMN nail	2	Distal
15	34	M	4	TA	Min fix	1	Proximal
16	63	M	8	Fall	Plate fix	2	Mid
17	47	M	6	TA	Min fix	1	Proximal
18	71	F	2	Fall	Cast	0	Mid
19	52	F	3	Fall	Cast	0	Mid
20	58	M	9	TA	Plate fix	1	Proximal
21	65	M	12	TA	Plate fix	1	Distal

Patient No.	AO Type	Type of Nonunion	Union Time (Months)	Follow-up (Months)	Complications	DASH Score
1	A1	Hypertrophic	4	10	None	23
2	B1	Atrophic	10	18	None	22
3	A2	Atrophic	3	106	None	1
4	B1	Atrophic	5	92	None	25
5	A3	Atrophic	6	108	Radial nerve palsy	57
6	A2	Atrophic	4	10	Radial nerve palsy	35
7	B1	Hypertrophic	10	12	Donor site pain	27
8	B1	Atrophic	6	96	None	25
9	A3	Atrophic	NA	96	Nonunion (hardware failure)	85
10	A1	Atrophic	12	78	Radial nerve palsy	45
11	B2	Atrophic	3	21	None	10
12	B1	Atrophic	3	36	None	14
13	A1	Atrophic	6	30	None	1
14	A3	Hypertrophic	6	16	None	72
15	A2	Atrophic	3	27	None	1
16	B2	Atrophic	8	74	None	25
17	A2	Atrophic	4	98	None	6
18	A1	Atrophic	4	12	None	4
19	B1	Atrophic	5	26	None	12
20	A3	Hypertrophic	6	24	None	7
21	A1	Hypertrophic	6	28	None	50

F, female; M, male; TA, traffic accident; Mid,: middle; Plate fix, plate and screw fixation; IM nail, intramedullary nail; Min fix, Minimal fixation, NA, not available.

group, patients with 0 or 1 previous operation had significantly better DASH scores than patients with 2 or more operations ($P = 0.02$). In the plate group, patients without previous operations demonstrated a significantly shorter union time than patients with previous operations ($P = 0.01$). In the LRS group, the number of previous operations did not affect the results ($P > 0.05$).

Complications

CEF Group Complications

Transient, early postoperative radial nerve palsy was observed in 3 patients and ulnar nerve palsy in 2 patients, which completely resolved within 3 months in all but 1 patient. The patient with a permanent radial nerve palsy was treated by

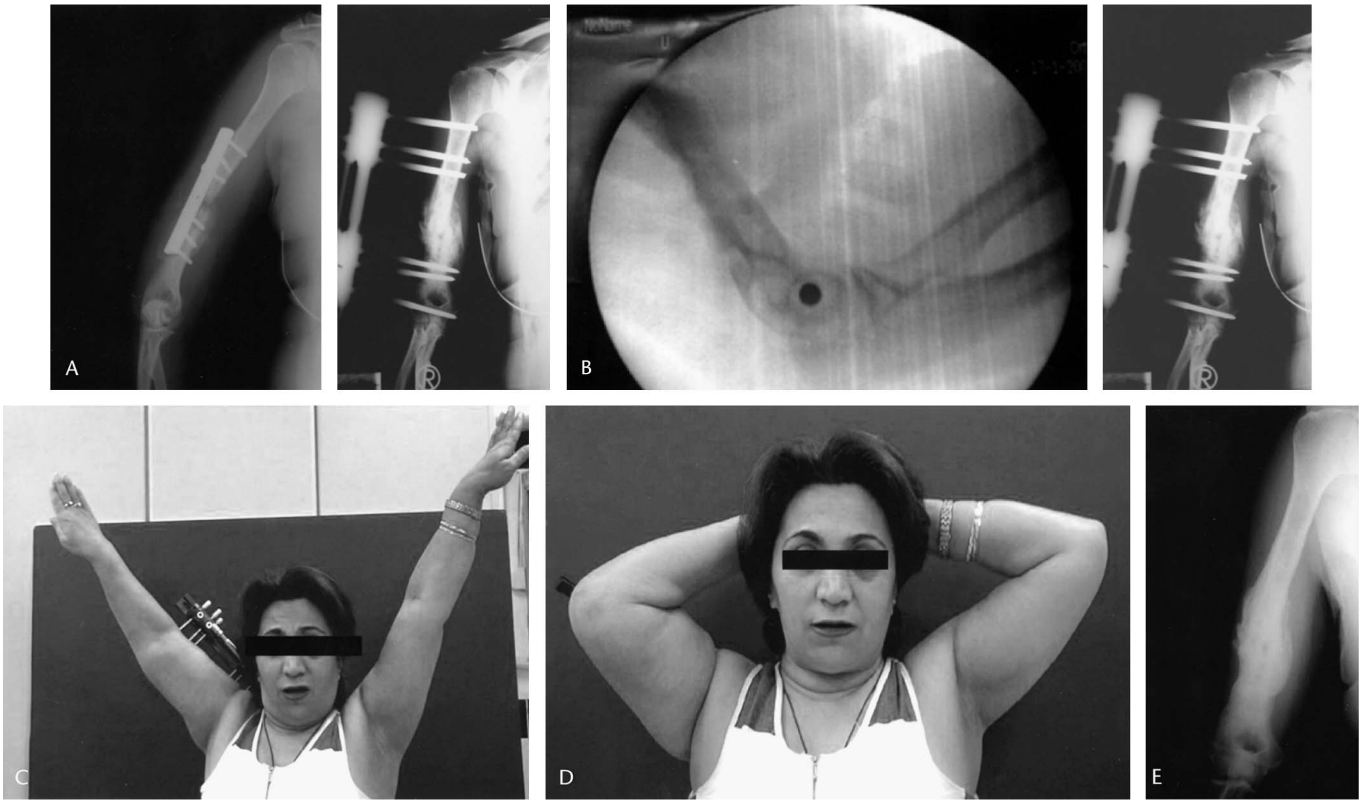

FIGURE 1. A, After plate removal and grafting, this atrophic humeral midshaft nonunion in a 33-year-old female patient with 1 previous operation (ORIF with plate) was fixed with a unilateral LRS fixator (patient 14 in Table 2). B, The most distal Schanz pin was inserted at the transcondylar level. C and D, Shoulder and elbow functions of the patient during the treatment. E. Radiograph after external fixator removal, when solid union was achieved 5.5 months after the operation.

Green's triple tendon transfer during fixator removal. Three grade 3 infected pins were removed. One patient had malalignment (15 degrees varus deformity) at the end of the treatment, but she was satisfied with the result and did not require revision surgery.

Two refractures in the circular external fixator group were managed by an LRS fixator in one patient and a Sarmiento brace in the other and both healed successfully within 3 months.

Total complication rate in this group was 31% (11 of 35). Nine of eleven complications were classified as problems. Two of them required operative intervention and were classified as obstacles according to Paley's complication description.[12]

LRS Group Complications

Four postoperative radial nerve palsies healed in 6 months. Grade 1 pin tract infection was observed in 20 pins and grade 2 in 2 pins. There were no refractures in the LRS group. No angulation greater than 10 degrees was observed in any patient in either frontal or sagittal planes in the LRS group.

Five problems and one obstacle were observed in the group. Total complication rate in this group was 25% (6 of 24).

Plate Group Complications

Transient radial nerve palsy was observed in 3 patients, all of whom recovered their function within 3 months. One patient had moderate graft donor site pain that impaired her gait for 6 weeks. One patient's plate fixation resulted in nonunion and hardware failure, but he refused revision surgery due to age (85 years) and cardiac problems.

Total complication rate in this group was 24% (5 of 21). Four of these complications were classified as problems and one as a true complication.

DISCUSSION

The quality of the soft tissue envelope and the blood supply around the fracture site are the factors determining the outcome of fracture treatment.[13] In case of nonunion, mechanical stability at the fracture site and biologic revitalization are keys for the management.[3,13,14]

As a rule, humeral shaft fractures are treated effectively with classical methods. However, when complicated by nonunion, they are incapacitating for the patient. Poor bone quality or bone stock, scar tissue near neurovascular structures, and anatomic boundaries are challenges for surgeons. A high incidence (8%) of synovial pseudarthrosis in humeral shaft nonunions has been reported; if present, the pseudoarthrosis tissue or soft tissues interposed between fragments need to be excised before fixation.[6,15] However, our patient population consisted of 80 patients, and no synovial pseudoarthrosis was observed in this population. The fact that there were none in

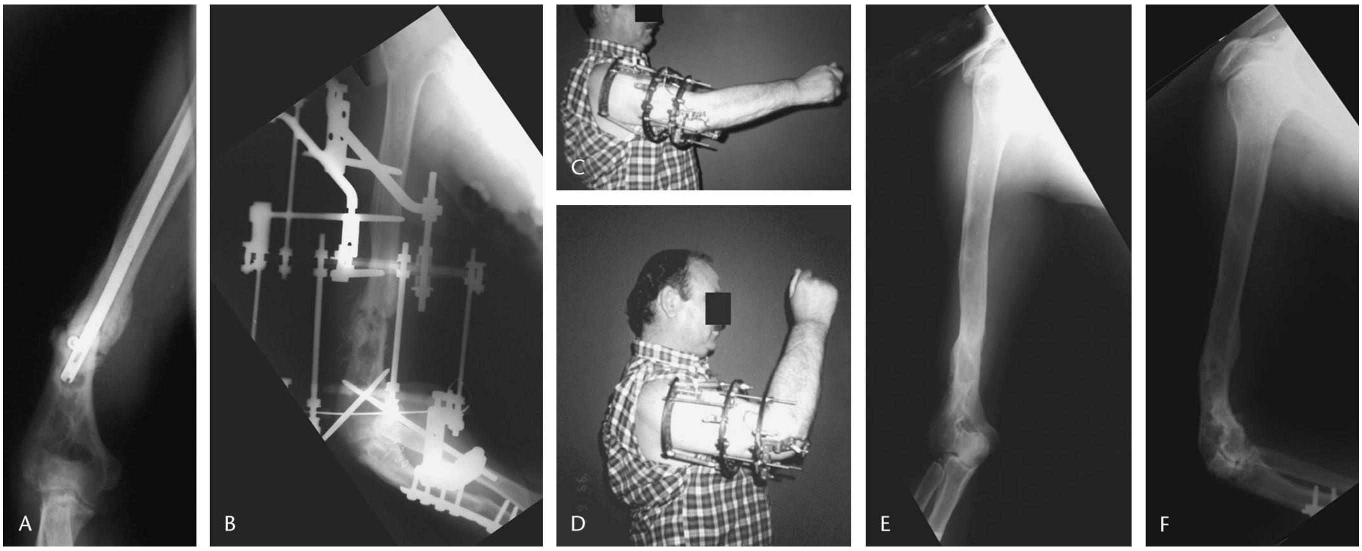

FIGURE 2. A, 43-year-old male patient (patient 14 in Table 1) admitted with painful hypertrophic nonunion and radial nerve paralysis to our hospital 6 months after his initial treatment with retrograde intramedullary nailing elsewhere. B, Nail was removed, circular external fixator was applied, and fracture site was grafted with autogenous bone. The patient underwent a tendon transfer procedure at his wrist in the same session, because of unresolved radial nerve paralysis 6 months after initial injury. C and D, Functional status of the patient during the treatment. E and F. External fixator was removed 5 months after nonunion surgery. Radiographs 4 months after removal are showing complete union without any deformity.

this series does not rule out the possibility that we might have synovial pseudoarthroses in future cases.

Numerous surgical methods have been described for the treatment of humeral shaft nonunions. Compression plating with autogenous grafting has yielded satisfactory results with 92 to 100% healing rates.[8,9,14–17] The main disadvantage of compression plating is extensive soft tissue dissection, causing devitalization of the bony fragments. Plate fixation also poses a high risk of radial nerve injury (3 to 29%).[15,16] Engaging at least 6 cortices on either side of the nonunion with screws is advised in these patients.[9] Such a large-scale dissection is sometimes morbid for the patient. Moreover, sometimes in distal nonunions, there is not enough space to engage 6 cortices. Additionally, this technique is not advised for infected cases, osteoporotic patients, long spiral and large segmented fracture lines, and especially distal metaphyseal nonunions.[6,15,16]

Radical debridement of the nonunion tissue, reliable fixation with sound cortex-cortex stability, and augmentation with autogenous graft or demineralized bone matrix augmentation are suggested to increase the rate of union.[8] To increase stability, reconstruction with 2 plates at right angles has been suggested, but clinical results have revealed no significant difference between single-plate and double-plate constructions.[14] Plate fixation is accepted as the gold standard method, so we have compared our external fixation results with this method.

Intramedullary locking nails are controversial for treating humeral nonunions.[4,9,11,18] Successful results with retrograde nailing have been reported.[19,20] In contrast to their success in the lower extremity nonunions, lack of weight-bearing and inadequate compression diminish their success rates in humeral shaft nonunions.[15,21] Complaints related to the entry site can be a problem.

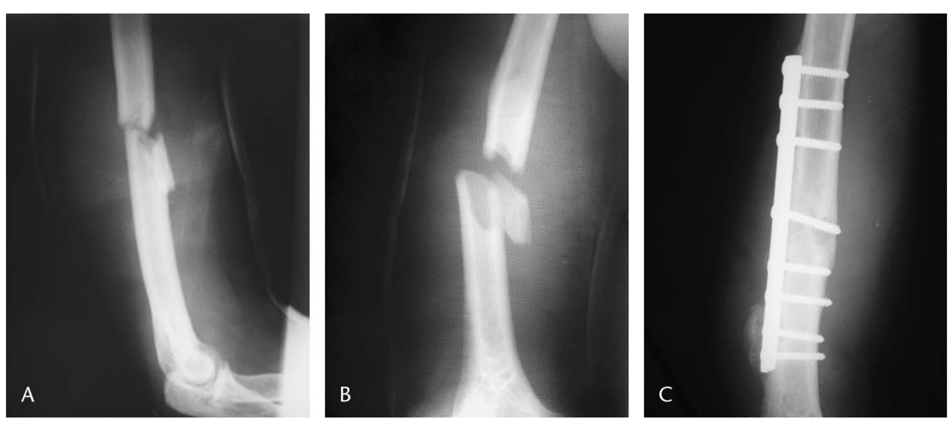

FIGURE 3. A and B, Atrophic nonunion after nonoperative treatment for 5 months in a 38–year-old male patient (patient 11 in Table 3). C. Solid union was observed in the radiograph 3 months after DCP fixation and grafting in the same patient.

External fixation respects the soft tissue envelope and conserves the vitality of the remaining bone. The technique can also be applied in osteoporotic patients and in infected cases.[15,18]

The devices allow gradual compression of the nonunion site, which mimics the weight-bearing status of the lower extremity.[21,22]

Circular external fixators were used and proved to be very successful in the treatment of all types of nonunions including the humerus.[23] Additionally, this method has the advantage of gradually correcting displaced, angulated, shortened, and malunited fragments during the treatment. Another major advantage of circular fixators is their application in bone defects using monofocal or bifocal compression methods. With controlled compression and distraction periods, healing is stimulated and the quality of regenerated bone is increased. Gradual realignment and compression of the nonunion site are possible during the treatment,[24,25] whereas reduction and static compression are achieved at the end of operation in plate fixation.

Circular external fixators can be superior to internal fixation methods when the nonunion is complicated by deformity, infection, bone loss, and length discrepancy. However, the bulkiness of the frame and numerous wires are the main sources of discomfort to the patient.[21,26]

Unilateral external fixators are widely used in trauma cases, in open fractures, but rarely in nonunion treatment.[27] Although they have little potential for deformity correction, if good alignment is obtained during operation, they can perfectly compress the nonunion site. Unilateral fixators allow compression and distraction, thus are able to enhance healing similar to circular external fixators.

Martinez et al[28] reported 5 solid unions in 6 patients with humeral shaft nonunions treated by a unilateral external fixator. In their series, the average time to union was 4 months, which is 1.5 months shorter than reported in the current series. This difference can be attributed to the relatively high mean age of our patient group compared to other studies in the literature.[28,29] Moreover, 4 of 6 patients in Martinez's group had been treated by nonoperative methods previously, thus providing a healthier biologic environment. Lammens et al[14] reported 4 refractures out of 30 humeral nonunion cases due to early removal of the CEF, and their average union time was 4.5 months. Lavini et al[29] treated 31 patients with a mean age of 39 years with monolateral dynamic external fixator and achieved union in a mean time of 4.9 months. Five of their patients required additional surgery during treatment, mostly because of preexisting infection. They used autogenous grafts in 26 patients. In our series, we applied autogenous bone grafts to all patients with previous implants and atrophic nonunions and to all patients treated with fixation with plates, which may have contributed to the higher union rate compared to other series.

A major advantage of our method is the stability obtained by the insertion of a transcondylar Schanz screw, allowing a secure fixation even in distal third humeral shaft nonunions. An alternative method for secure fixation of distal humeral fragment has been described by Odathurai et al.[30] This technique necessitates violation of the olecranon fossa by an intramedullary nail, advanced into the distal humerus, which causes destruction of a normal anatomic structure. When compared to this technique, our percutaneous Schanz screw fixation through the trochlea is completely safe.

Comfort during treatment, preserved range of motion, and laterally placed pins respecting soft tissues seem to be the advantages of LRS over CEF. The authors advise the use of LRS for the treatment of humeral nonunions. The superior stabilization capacity of CEF in distal locations may be overcome by a transcondylar Schanz screw insertion in the LRS.

In this study, we could not detect any significant difference among plates, CEF, and LRS external fixators in terms of union time and DASH score. In patients treated by external fixators, the number of previous surgeries did not affect the healing time. If plate fixation is to be the method of choice for the treatment of nonunion, consideration should be given to the fact that patients with history of previous operations will have a longer time to bony union.

If applied properly, plates and external fixators lead to excellent results overall in humeral shaft nonunions. The procedure can be tailored to the surgeon's experience, keeping in mind that plate fixation demonstrates a trend towards longer healing time in cases with several previous surgeries.

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