Original Article

Nonunited humerus shaft fractures treated by external fixator augmented by intramedullary rod

Mahmoud A El-Rosasy

Abstract

Background: Nonunion of humeral shaft fractures after previously failed surgical treatment presents a challenging therapeutic problem especially in the presence of osteoporosis, bone defect, and joint stiffness. It would be beneficial to combine the use of external fixation technique and intramedullary rod in the treatment of such cases. The present study evaluates the results of using external fixator augmented by intramedullary rod and autogenous iliac crest bone grafting (ICBG) for the treatment of humerus shaft nonunion following previously failed surgical treatment.

Materials and Methods: Eighteen patients with atrophic nonunion of the humeral shaft following previous implant surgery with no active infection were included in the present study. The procedure included exploration of the nonunion, insertion of intramedullary rod (IM rod), autogenous ICBG and application of external fixator for compression. Ilizarov fixator was used in eight cases and monolateral fixator in ten cases. The monolateral fixator was preferred for females and obese patients to avoid abutment against the breast or chest wall following the use of Ilizarov fixator. The fixator was removed after clinical and radiological healing of the nonunion, but the IM rod was left indefinitely. The evaluation of results included both bone results (union rate, angular deformity and limb shortening) and functional outcome using the University of California, Los Angeles (UCLA) rating scale.

Results: The mean follow-up was 35 months (range 24 to 52 months). Bone union was obtained in all cases. The functional outcome was satisfactory in 15 cases (83%) and unsatisfactory in 3 cases (17%) due to joint stiffness. The time to bone healing averaged 4.2 months (range 3 to 7 months). The external fixator time averaged 4.5 months (range 3.2 to 8 months). Superficial pin tract infection occurred in 39% (28/72) of the pins. No cases of nerve palsy, refracture, or deep infection were encountered.

Conclusion: The proposed technique is effective in treating humeral nonunion especially in the presence of osteoporosis and short bone segments. The inclusion of intramedullary rod as internal splint improves stability of fixation and prevents refracture after fixator removal.

Key words: Humerus, nonunion, external fixation, intramedullary fixation

Introduction

Nonunion of a humerus shaft fracture after repeatedly failed surgical attempts at bone healing presents a difficult therapeutic problem especially in the presence of osteoporosis, bone defect, and joint stiffness. The incidence of nonunion of humeral shaft fractures is reported as 2-10% when managed conservatively and around 15% when managed by open reduction and internal fixation.[1-3]

The various methods of treating humeral shaft nonunion following primary operative management with success rates approaching 100% to achieve bone healing are reported.[2-8] Only few studies have focused specifically on nonunion after failure of one or more surgical interventions.[2] Treatment of nonunion of the humerus shaft using only external fixators has been fraught with the problems and complications of pin tract infection, iatrogenic radial nerve injury, refracture after fixator removal, and patient's inconvenience.[3,6,8-18]

The present study evaluates the results of external fixation augmented by intramedullary rod and autogenous iliac crest bone grafting (ICBG) for the treatment of humerus shaft nonunion following previously failed surgical treatment.

Materials and Methods

The study included 18 patients with established nonunion of the humerus diaphysis that were treated between the

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year 2000 and 2008. The patient of nonunion humerus diaphyseal fracture, previously treated surgically with either cortical or medullary fixation were included. The diagnosis of a nonunion was made if the fracture failed to unite at six months as evidenced by absence of a bridging callus on X-rays examination and/or mobility and pain at the fracture site. The patients with active infected nonunion were excluded.

The mean age was 36.9 years (range 22-60 years). There were 13 males (72%) and five female (28%) patients [Table 1]. Four (22%) patients had open fractures; one due to explosion of a truck tyre, one due to revolving machine injury, and two due to road traffic accidents. All patients had previous surgical treatment in the form of open reduction and internal fixation using plates and screws (n=20) and intramedullary nails (n=18) of different types. The average number of previous operations was 2.3 (range one to four operations). For all patients, autogenous ICBG was used previously at least one time together with internal fixation. The mean duration of nonunion was 20.8 months (range 10-65 months).

The history of previous infection was present in eight cases (44%) with no active infection at the time of presentation to us our treatment. No cases of active infection were included in the study. Associated injuries included one case of radial nerve injury which was treated by tendon transfers prior to our treatment and two cases of fracture both bone of the forearm in the same limb; they were treated surgically and united.

Preoperative evaluation included a complete history, especially symptoms of current or previous infection and

Table 1: Demographic data of the patients

No.	Age (years)	Gender	Affected side	Nonunion level	Original fracture	Previous Tx.	Previous ICBG	Nonunion duration	Retained hardware	Smoking
1	22	F	Rt.	U/3	Closed	2 Nail 1 Plate	*	11 mo.	KN	No
2	47	M	Rt.	L/3	Open G IIIB	1 Ex.Fix. 1 Nail 1 Plate	**	65 mo.	Plate and screws	+
3	46	M	Rt.	M/3	Closed	2 Nail 2 Plate	**	10 mo.	IN	+++
4	60	F	Lt.	L/3	Closed	2 Nail 1 Plate	*	24 mo.	RR	No
5	24	F	Lt.	M/3	Open G II	1 Nail 1 Plate	*	20 mo.	Plate and screws	No
6	32	M	Rt.	L/3	Closed	1 Nail 1 Plate	*	17 mo.	KN	+
7	35	F	Rt.	M/3	Closed	1 Plate	*	34 mo.	Plate and screws	No
8	52	M	Lt.	M/3	Closed	1 Nail 3 Plate	***	40 mo.	IN	+++
9	43	F	Rt.	U/3	Closed	2 Nail	**	14 mo.	IN	No
10	28	M	Rt.	L/3	Closed	2 Nail	*	12 mo.	KN	++
11	36	M	Lt.	M/3	Closed	1 Nail 1 Plate	*	11 mo.	KN	No
12	27	M	Rt.	L/3	Closed	2 Plate	*	10 mo.	Plate and screws	No
13	26	M	Lt.	L/3	Closed	2 Plate	*	13 mo.	Plate and screws	No
14	33	M	Lt.	L/3	Open G I	2 Plate	*	16 mo.	Plate and screws	No
15	50	M	Rt.	L/3	Open G II	1 Ex.Fix. 1 Plate	*	23 mo.	Non	+
16	37	M	Rt.	M/3	Closed	1 Nail 1 Plate	**	14 mo.	Plate and screws	++
17	44	M	Rt.	L/3	Closed	2 Plate	*	11 mo.	Plate and screws	++
18	23	M	Lt.	M/3	Closed	2 Nail	*	30 mo.	KN	+++
Average	36.9 year					2.3 operation per case		20.8 mo.		

F - Female, M - Male, Rt. - Right, Lt. - Left, U1/3 - Upper third, L1/3 - Lower third, M1/3 - Middle third, GIIIB - Grade three B open fracture, GII - Grade II open fracture, previous ICBG - *one time, **two times, ***three times, mo. - Month, KN - Kuntscher nail, IN - Interlocking nail, RR - Rush rod, Smoking - +one pack per day, ++two packs per day, +++three packs per day smoking. The involved limb was examined to detect a prior or actively draining sinus, erythema or induration of the skin; or tender, swollen axillary lymph nodes. Preoperative laboratory tests included complete blood count (CBC), C-reactive protein (CRP), and erythrocyte sedimentation rate (ESR).

All surgeries were performed by the same surgeon using different intramedullary nails based on the fracture level, type of the previously inserted nail, and size of the medullary canal combined with either unilateral fixator or a two-ring Ilizarov fixator (the main function of the fixator, regardless of its type, was to neutralize the shear strains and exert axial compression at the nonunion).

Operative procedure

The old operative scar was used to approach the nonunion in all cases. Debridement of the nonunion site entailed removal of all retained hardware and excision of nonviable tissues. The trimming of bone ends was done to get the maximum bone contact and an inherently stable fracture and decortication of the bone ends. Internal fixation using intramedullary rod was then performed. The choice of the rod depended on the level of nonunion and the type of previously inserted nail, if any. Middle third fractures were fixed using either Kuntscher conventional nail or interlocking nail. Lower third fractures were fixed using disto-proximal Rush rods inserted from the humeral condyles. The interlocking nails were locked on one side to allow axial compression at fracture site by external fixator.

After obtaining a stable fixation of the nonunion, autogenous ICBG was harvested and applied around the nonunion. The wound was closed with a suction drain inserted and opened intermittently to avoid hematoma collection.

After wound closure, the external fixator was applied under fluoroscopic control where two half pins were inserted proximally and distally. The proximal pins were inserted in the metaphyseal region taking care to keep a space of about four mm between the pin and the nail to avoid contamination of the IM rod if the pin site gets infected. For the distal half pin cluster, the most distal pin was inserted first through the humeral condyles from lateral to medial (trans-capitellar-trochlear). Under fluoroscopic control, a perfect lateral view of the distal humerus was obtained; then, a Kirschner wire was inserted through the condyles from lateral to medial. During wire insertion, an antero-posterior view was obtained so that the wire should be parallel to the joint line and stop short of the medial cortex to avoid ulnar nerve injury. On the lateral view, the humeral condyles will appear as a perfect circle and the wire as a dot in the middle (Bull's-eye appearance). Drilling over the wire was done by a cannulated drill bit and then a six mm half pin was inserted until its tip was only engaging the medial cortex to avoid ulnar nerve irritation. The second distal pin was then inserted in the distal humeral metaphysis proximal to the olecranon fossa in a manner similar to the proximal pins. The external fixator was then attached to the pins. Two types of external fixators were used; they were unilateral external fixator [limb reconstruction system and dynamic axial fixator (LRS and DAF)] and modified Ilizarov fixator. The unilateral fixator was preferred for obese and female patients to avoid abutment against the chest wall and breast [Figures 1–3]. The modified Ilizarov fixator was assembled from half rings divided into quarters and each two quarters were used as a block both proximally and distally [Figure 3]. Axial compression was exerted until no gap was left at

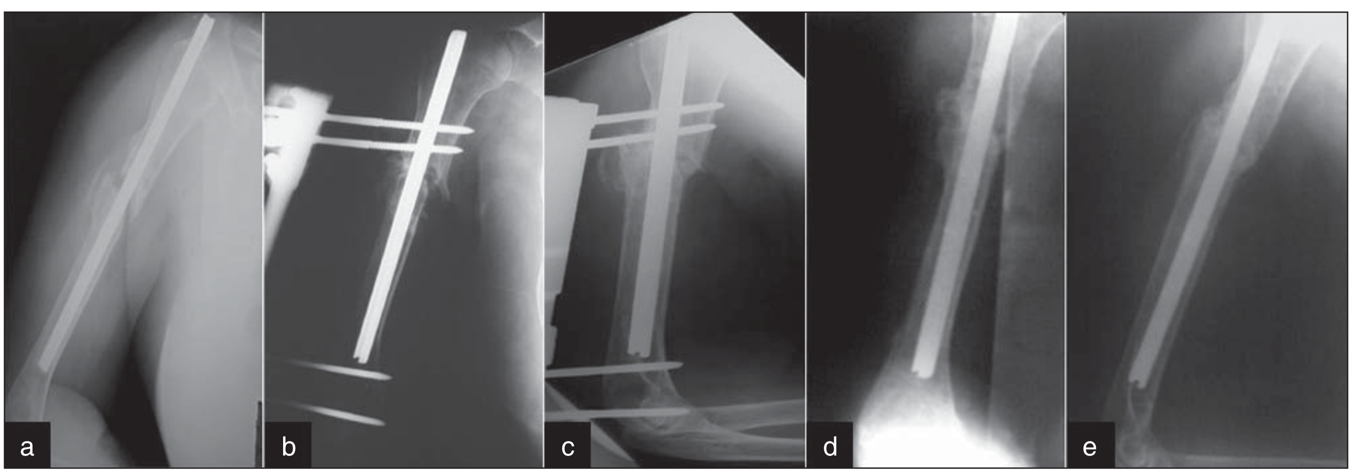

Figure 1: (a) Three years old nonunited fracture of upper third of the right humerus shaft in a 22–year-old female patient. The fracture was treated surgically by conventional Kuntscher nail fixation two times and one iliac crest bone graft (ICBG). Note the prominent nail causing limitation of shoulder abduction. (b, c) Postoperative radiographs show replacement of the Kuntscher nail with a shorter one, insertion of ICBG and application of orthofix limb reconstruction system (LRS). The nonunion was compressed to close the gap. (d, e) Follow-up radiographs show sound healing of the nonunion. The nail was left in place

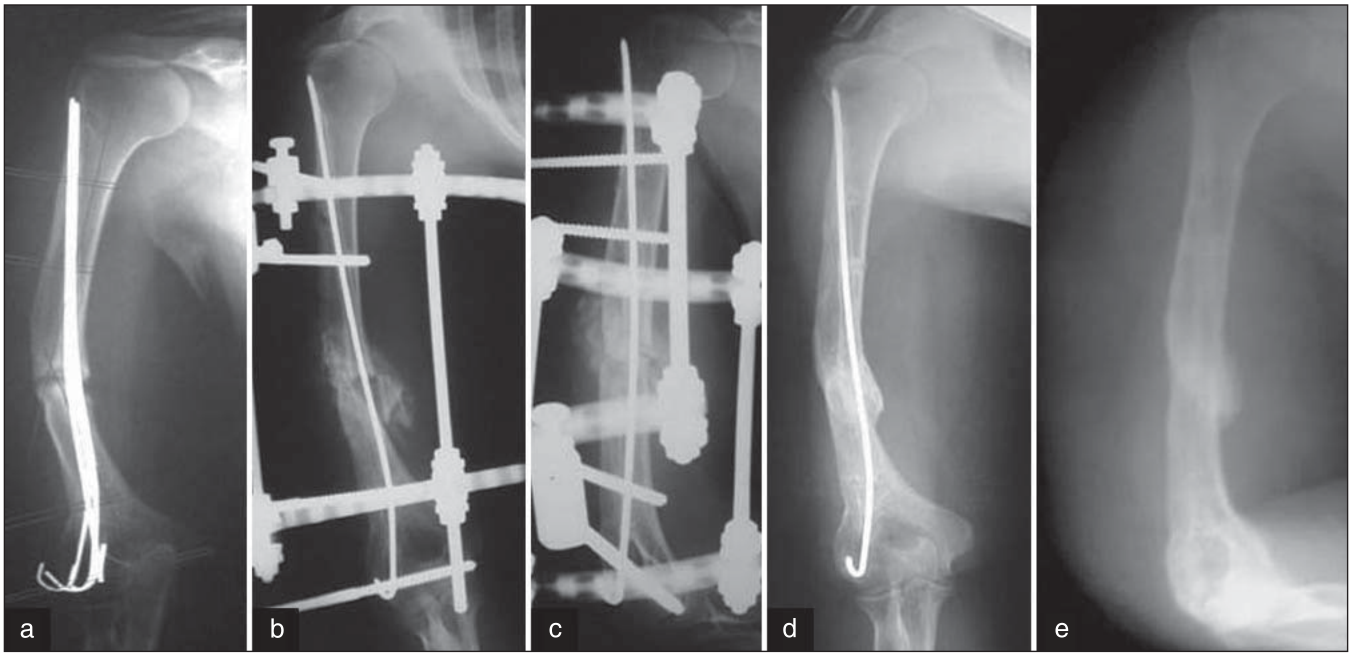

Figure 2: (a) Preoperative radiographs of a nonunited fracture of the middle third of the humerus in a 46–year-old female patient previously treated surgically with intramedullary fixation and bone graft. (b, c) Postoperative radiographs showing exchange of the intramedullary rod, with bone graft and application of a modified Ilizarov external fixator. (d, e) Follow-up radiographs showing sound union

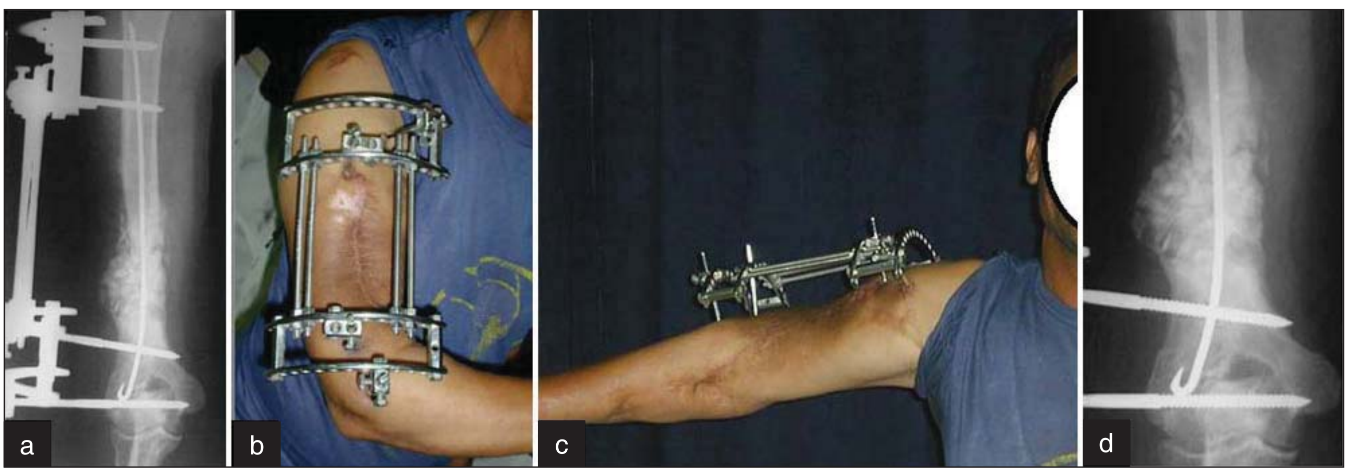

Figure 3: (a) A lower third humerus nonunion in a 47-year-old patient treated by Rush rod fixation combined with a modified Ilizarov fixator and autogenous bone graft (The nonunion developed after an open fracture sustained in a blast injury with radial nerve paralysis treated previously by tendon transfers). (b, c) Photographs of the same patient showing the functional use of the arm during treatment with the fixator in place. (d) A radiograph shortly before fixator removal shows incorporation of the graft

the nonunion site. Postoperative compression was started 3-5 days after surgery at a rate of 0.25 mm twice weekly until early signs of radiological healing were visible.

Postoperative management

The patient was allowed to use his arm and to do active exercises of all joints. Follow-up X-rays were obtained every two weeks during compression then every month until radiological bone healing and graft incorporation when dynamization was done by loosening the compression mechanism then tightening the device in the loosened position. After radiological healing of the fracture, the external fixator was removed without anesthesia as an outpatient procedure and a light splint was applied for one month. The IM rod was left *in situ* indefinitely.

Evaluation of results included both bone results and functional outcome. The bone results were evaluated by the union rate, angular deformity, and limb shortening. The functional outcome was evaluated using the UCLA rating scale which allocates points for pain, function, movement, muscle power, and patient satisfaction has a maximum score of 35 points. Patients with a score less than 27 were recorded as having a fair or poor function (unsatisfactory outcome). Those with 27 points or more were considered to have a good or excellent function (satisfactory outcome).[19,20]

Results

There were 18 cases with mean age of 36.9 years (range 22-60 years). There were 13 male (72%) and 5 female (28%) patients. All patients [Table 2] had atrophic nonunion of the humerus diaphysis of average 20.8 months (range 10 to 65 months). The right side was affected in 11 cases (61%) and left side in 7 cases (39%).

The nonunion was in the upper third of the humerus diaphysis in two cases (11%), middle third in seven cases (39%), and lower third in nine cases (50%). The original fracture was close in 14 cases (78%) and open in 4 cases (22%). In eight cases (44%), there was history of infection after the index surgery, however, active infection was not present at the time of presentation to us. Mean 2.3 surgeries per case (range one to four operations) were performed previously. These operations included ICBG and revisions of fixation. The intramedullary rods used were; conventional nails (Kuntscher nail) in seven cases (39%), Rush rods in nine cases (50%) and interlocking nails in two cases (11%). Autogenous Iliac crest bone graft (ICBG) was routinely performed in all cases. A second bone grafting was performed for one case of delayed healing (case no. 8). We used the Limb reconstruction system (LRS) and Dynamic axial fixator (DAF) in 10 cases (56%). The modified Ilizarov fixator was used in eight cases (44%). A total of 72 half pins were inserted (four pins per case). Superficial pin tract infection occurred in 28 pins (39%) more in the proximal side pins. A total of 19 surgeries were performed; this included 18 operations and one secondary ICBG.

Table 2: Summary of the results

No.	Ex. Fix. type	IM rod type	Fixator time (mo)	Time to bone healing	Follow-up length (mo)
1	LRS	KN	4.5	4	24
2	Mod. Ilizarov	RR	4.5	4	33
3	DAF	KN	4.3	4	36
4	DAF	RR	3.8	3.5	42
5	Mod. Ilizarov	KN	4.2	4	28
6	Mod. Ilizarov	RR	4.3	4	30
7	Mod. Ilizarov	RR	4.5	4	31
8	Mod. Ilizarov	KN	5.5	5	26
9	LRS	KN	3.2	3	27
10	LRS	RR	4	3.5	30
11	DAF	IN	4.3	4	40
12	Mod. Ilizarov	RR	4.2	4	52
13	LRS	RR	4.8	4.5	40
14	LRS	RR	5	4.5	35
15	DAF	IN	5.2	5	26
16	Mod. Ilizarov	RR	4.5	4	38
17	Mod. Ilizarov	KN	4.2	4	36
18	LRS	KN	8	7	50
Average			4.5	4.2	35

Ex. Fix. type - External fixator type, LRS - Limb reconstruction system, Mod. Ilizarov - Modified Ilizarov, DAF - Dynamic axial fixator, KN - Kuntscher nail, RR - Rush rod, IN - Interlocking nail

The mean fixator time (time to external fixator removal) was 4.5 months (range 3.2-8 months). The mean time of radiological bone healing was 4.2 months (range three to seven months). Sound bone healing was achieved in all cases (100%). No angular deformity of more than 10 degrees in any plane was detected. Bone shortening of less than three cm was present in three cases (17%). According to the UCLA score, the functional outcome was satisfactory (UCLA score > 27) in 15 cases (83%). In three cases (17%), the functional outcome was unsatisfactory (UCLA score < 27) due to shoulder and/or elbow joint stiffness. There were no cases of iatrogenic nerve or vascular injury due to pin insertion or surgery. The mean follow-up was 35 months (range 24-52 months).

Discussion

The incidence of nonunion of humeral shaft fractures is reported to be around 15% when managed by open reduction and internal fixation and 2-10% when managed conservatively.[1-3] The lack of mechanical stability due to a flail arm may interfere with personal hygiene, dressing, and simple activities of daily living. The goal of surgery is to achieve a stable fixation and institute early mobilization of stiff joints. A variety of techniques for fracture stabilization have been described, such as plating, locked intramedullary nails, external skeletal fixation (unilateral and circular).[2-6,8] Only few studies have focused specifically on nonunion after failure of one or more surgical interventions.[2] The treatment by open reduction and internal fixation with a 4.5 mm dynamic compression plate and autogenous bone graft has been considered the gold standard with a reported union rate ranging from 83% to 100% and a high rate of patient satisfaction.[1,2,8] The liberal use of autogenous ICBG is considered as a standard adjunct to surgical treatment.[1,2,5,13,14]

The use of a long compression plate requires extensive tissue stripping in the upper arm causing considerable impairment of blood supply and a significant risk of radial nerve injuries. Intramedullary nailing preserve the blood supply better and requires less soft tissue stripping, also allows homogeneous elastic stress distribution over the bone tissue and the nail and provides good fracture stabilization. However, problems of limited range of motion of the shoulder joint due to abutment of a protruding nail against the acromion, smooth IM rods not controlling rotational stresses and lack of axial compression are shortcomings of IM rods.[3]

Patel *et al*.[6] used an Ilizarov external fixation frame for treating humeral shaft nonunion without bone grafting after failure of treatment using humeral nails. The authors left the nail *in situ,* removed the locking screws (if present), applied Ilizarov frame for compression of the nonunion. They reported bone healing in 15 out of 16 cases in a mean time of 4 months. However, there were three cases of temporary nerve palsies and numerous pin tract infections and poor tolerance to the device. In contrast, Marsh *et al*.,[21] reported the results of using monolateral fixator for the treatment of open fractures of the humeral shaft, their patients tolerated the fixator well, when required in polytraumatized patients upper extremity weight-bearing was achieved with the fixator in place, the fixators were not removed early for pin tract infection and no iatrogenic nerve injury due to pin insertion.

Radial nerve injury is a major concern in the treatment of humeral shaft nonunion regardless of the type of surgical procedure performed.[3,6,8-16] The reported incidence of iatrogenic radial nerve injury is 12% with open reduction and plate fixation.[3,8] The radial nerve has a helical path from the proximal to middle third, it runs posteriorly and laterally to antero-laterally after piercing the lateral intermuscular septum 101 to 148 mm proximal to the lateral epicondyle.[3,15,16] The most common cause of radial nerve injury is damage by high location of pin in an attempt to insert pin closer to fracture during external fixation.[10,22-24] In our study and in the series of De Bastiani *et al*.,[23] there have been no cases of iatrogenic nerve injury where the distal pins were inserted in the safe zone distal to the radial nerve crossing point on the lateral humeral border. However, pin insertion far from the fracture site would jeopardize the stability of the construct, moreover, deflection of bone ends would ensue if axial compression was performed.

The hybrid fixation using half-pin external fixator augmented by intramedullary rod (IM rod) would decrease the number of half-pins needed in the fixator. Only two pins are needed in each bone segment, this allows a safer insertion of the pins in a good quality bones away from the fracture ends and from the radial nerve crossing point. The IM rod prevents angulation of the bone when axial compression is applied. Moreover, the IM rod can be left *in situ* as an internal splint after fixator removal thus allows early fixator removal once bone healing has established and prevents refracture at the original nonunion or at the pin sites.

The use of the modified Ilizarov fixator, only quarter rings proximally and distally, decreases the fixator size and renders it more convenient and comfortable to the patient. It also allows application of the half-pins at different angles, contrary to the monolateral fixator, and the surgeon can choose a safer location for pin insertion. Moreover, pins inserted at angles to each other would provide better fixation. However, the use of monolateral fixator was preferred for females and obese patients due to its convenience and better patient's tolerance. The main functions of the fixator were to control any rotational or shear strains on the fracture and to compress the fracture until bone healing. The type of the nail did not influence the fixator type or number of the Ilizarov rings. When a locked nail was used, it was locked only on one side to allow axial compression.

Preexisting shoulder or elbow stiffness can result in increased motion at the fracture site and thus predisposes patients to persistent nonunion.[1] This emphasizes the need for a stable fixation which allows early institution of postoperative physiotherapy to regain joint range of motion. The achievement of excellent bone results in terms of union, alignment, and length does not necessarily guarantee a good functional outcome which is predetermined by the soft tissue status before treatment.[14] The main cause of unsatisfactory outcome was shoulder and elbow stiffness regardless of bone results. However, this finding should not preclude attempts at bone healing and should be explained to the patient in the preoperative counseling.

Conclusion

The use of external fixation (unilateral or modified Ilizarov) augmented by IM rods together with the routine use of ICBG is a viable option to treat humeral shaft nonunion following failed implant surgery. The proposed technique improves stability of fixation, meanwhile minimizes the operative complications. The IM rod is left *in situ* after fixator removal to act as a permanent splint to prevent refracture after fixator removal.

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