Compression distraction for the management of complex femoral nonunion

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Background
Complex nonunion is defined as established nonunion of at least 6 months' duration with one of the following criteria: infection, bone defect or shortening of more than 4 cm, deformity, and an attempt to achieve union that failed to heal after at least one supplementary surgical intervention such as bone graft. Internal fixation methods are limited in their ability to deal with infection, bone defect, or shortening, and they involve extensive dissection around the fracture site for realignment of severe deformity. The Ilizarov method of compression distraction is particularly valuable in these complex cases.
Patients and methods
Between January 2004 and December 2010, 52 patients were treated for complex femoral nonunion using Ilizarov circular fixator. A monofocal treatment confined to the nonunion site (simple stabilization of the nonunion with compression and then stimulation of healing by distraction) was used in 23 patients; four of them had infected nonunion. Bifocal compression distraction technique with corticotomy (compression of the nonunion with distraction at the corticotomy) was used in 29 patients; 10 of them were infected.
Results
Bone healing was identified radiologically as callus bridging three cortices in 48 patients after a mean of 6.3 (4–12) months. Twenty patients of 23 treated using the monofocal technique had a mean healing time of 5.6 (4–9) months. Totally, 28 patients of 29 treated with bifocal compression distraction had healing after a mean of 6.8 (4–12) months. Using the criteria proposed by Paley and Maar, 30 patients had excellent functional results, 15 patients had good results, two had fair results, and five had poor results. The bony results were excellent in 35 patients, good in eight, fair in four, and poor in five.
Conclusion
Both monofocal and bifocal compression distraction techniques are effective in the treatment of complex femoral nonunion. Less treatment time is achieved for monofocal cases (mean: 5.6 months). In bifocal cases, acute shortening and lengthening has a much lower treatment time (mean: 5.5 months) compared with bone transport (mean: 9.3 months) and should be used when possible.

Keywords:
complex nonunion, compression distraction, ilizarov, monofocal versus bifocal

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Introduction

Failure of fracture union can occur even with the best treatment applied. Nonunion can occur after high-energy trauma, resulting in an inappropriate biologic environment needed for healing. Failure to meet optimum mechanical stability or infection can also lead to nonunion. In some cases there is no apparent reason [1]. Patient's general condition and special habits such as smoking can have a deleterious effect on the maturation of new bone [2,3].

Complex nonunion is defined as established nonunion of at least 6 months' duration with one of the following criteria: infection, bone defect or shortening of more than 4 cm, deformity, and an attempt to achieve union that failed to heal after at least one supplementary surgical intervention such as bone graft [3].

Many femoral nonunions can be treated satisfactorily by means of internal fixation with the main aim being the improvement of mechanical stability [4,5]. Bone graft may be added as a biologic stimulus [6]. Unfortunately, internal fixation methods are limited in their ability to deal with infection, bone defect, or

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shortening, and they involve extensive dissection around the fracture site for realignment of severe deformity. The Ilizarov method of compression distraction is particularly valuable in these complex cases [7–11].

The aim of this study was to assess both monofocal and bifocal compression distraction techniques for the treatment of complex femoral nonunion using Ilizarov circular fixator.

Patients and methods

Between January 2004 and December 2010, 52 patients were treated for complex femoral nonunion using Ilizarov circular fixator; of them, 14 had infection and 38 were not infected but had at least one criteria of complex nonunion. This study approved by the Ethical committee of Department of Orthopedic Surgery, Faculty of Medicine, Ain Shams University, Cairo, Egypt.

There were 40 male and 12 female patients with a mean age of 34.1 (13–60) years. All patients were presented for treatment after at least 6 months of established nonunion. The mean number of previous operations was 3.3 (0–14). On presentation, 15 patients had undergone internal fixation with plate and screws and four other patients had an external fixator holding their nonunited fractures. Despite being warned that smoking might delay bone healing, 34 patients continued smoking of 10 or more cigarettes per day, and only 18 patients either quit smoking or were not smokers.

Patients with infected nonunion were classified on the basis of whether the infection was active or quiescent, and the amount of bone loss [12] (Table 1). Other nonunions were classified as stiff or mobile on clinical examination and as hypertrophic or atrophic radiologically. Angulation was not recorded for patients with mobile nonunion (Table 2).

A monofocal treatment confined to the nonunion site (simple stabilization of the nonunion with compression and then stimulation of healing by distraction) was used in 23 patients; four of them had infected nonunion.

Table 1 Types of infected nonunion

	Number of cases
A1. Quiescent infection, defect <4 cm	5
A2. Quiescent infection, defect >4 cm	3
B1. Actively discharging sinus, defect <4 cm	4
B2. Actively discharging sinus, defect >4 cm	2

Bifocal compression distraction technique with corticotomy (compression of the nonunion with distraction at the corticotomy) was used in 29 patients; 10 of them were infected. All hardware components were removed with excision of the infected bone in the same surgery with application of an Ilizarov frame (Fig. 1). Samples were taken for culture and sensitivity.

For monofocal correction a preconstructed frame with hinges properly placed to correct both angulation and shortening through the nonunion site was used in 19 patients (Fig. 2). Of them, three patients had an osteotomy close to the nonunion site to facilitate correction and potentiate healing (Fig. 3). The other four patients treated with monofocal technique had infected nonunion: two were of type A1, one was of type B1, and one was of type B2. Debridement of necrotic tissue was performed with preservation of newly formed vascular bone. Acute correction and compression distraction of their nonunion site were performed.

Corticotomy was performed in 29 patients, either proximal or distal to the nonunion site, for bifocal compression distraction, through which lengthening was achieved, meanwhile correcting any angular deformity through distraction of the nonunion site. Of these patients, 13 with mobile nonunion had segmental excision: six for infection and seven for sclerotic avascular bone ends. Acute shortening and relengthening were carried out in nine patients, whereas the other four underwent bone transport. Ten patients treated with bifocal technique had infected nonunion: three were of type A1, three were of type A2, three were of type B1, and one was of type B2.

Distraction of nonunion site was started on the second postoperative day at a rate of 1 mm/day (0.25 mm every 6 h) until full correction of the deformity, whereas

Figure 1

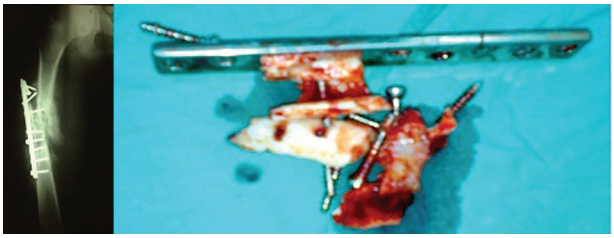


Plate and screws removed with sequestrated bone from a patient with type B2 infected nonunion of the femur.

Table 2 Patient's data

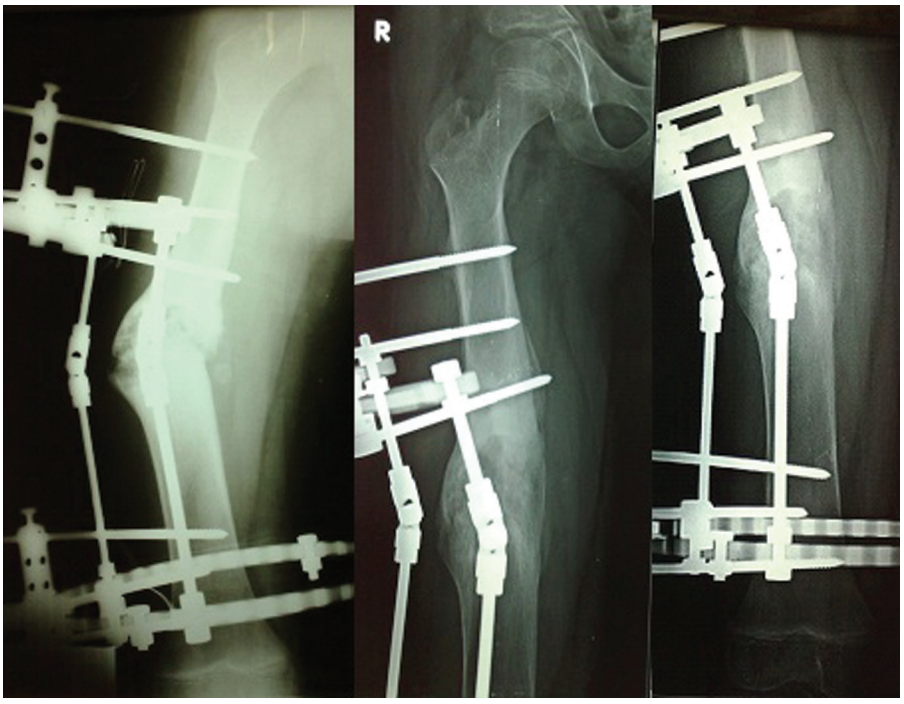
Case no.	Age (years)	Sex	Special habit	Duration of nonunion	Number of previous operations	Type of infection[a]	Angulation for stiff nonunion or with IF	Shortening/ defect (cm)	Technique used
1	40	Male	Smoking	18	3	A2	15° varus	5	Bifocal
2	32	Male	Smoking	9	2		30° varus	4	Monofocal
3	24	Female	Nonsmoking	12	3		10° varus	2	Monofocal
4	45	Male	Smoking	20	3		20° varus	5	Bifocal
5	14	Male	Nonsmoking	15	0		45° varus/20° procurvatum	4	Monofocal
6	37	Male	Smoking	36	14	B1	Mobile nonunion	2	Monofocal
7	28	Male	Nonsmoking	14	3		12° varus	2	Monofocal
8	19	Male	Nonsmoking	24	4		Mobile nonunion	5	Monofocal
9	35	Female	Nonsmoking	14	3		15° varus	4	Bifocal
10	44	Male	Smoking	12	2		20° varus	4	Monofocal
11	15	Male	Nonsmoking	15	4		55° varus	4	Monofocal
12	33	Male	Smoking	8	1	A1	20° procurvatum	3	Monofocal
13	26	Male	Nonsmoking	18	4		Mobile nonunion	4	Bifocal/acute shortening/bone graft
14	47	Male	Smoking	8	4	B1	25° varus	3	Bifocal
15	50	Male	Smoking	16	4		10° varus	2	Monofocal
16	17	Female	Nonsmoking	84	0		Mobile nonunion	10	Bifocal
17	28	Male	Smoking	22	3	A2	Mobile nonunion	5	Bifocal/bone transport
18	34	Male	Smoking	12	3		20° valgus40° procurvatum	3	Monofocal
19	45	Female	Smoking	12	4		20° recurvatum	2	Monofocal
20	58	Male	Smoking	14	3		Mobile nonunion	4	Bifocal/acute shortening/bone graft
21	13	Male	Nonsmoking	9	2	B2	Mobile nonunion	7	Bifocal/bone transport
22	21	Female	Smoking	18	3		10° varus 10° procurvatum	4	Bifocal
23	43	Male	Nonsmoking	36	2		Mobile nonunion	4	Bifocal/acute shortening/bone graft
24	36	Female	Nonsmoking	16	4		20° varus	3	Monofocal
25	38	Male	Smoking	12	4		Mobile nonunion	4	Bifocal/acute shortening/bone graft
26	25	Female	Smoking	6	2	A1	Mobile nonunion	3	Bifocal/acute shortening
27	52	Male	Smoking	18	3		20° varus 10° procurvatum	4	Bifocal
28	54	Male	Smoking	12	4		15° varus	4	Monofocal
29	23	Male	Smoking	12	4		Mobile nonunion	4	Bifocal/acute shortening/bone graft
30	35	Male	Smoking	15	3		30° varus	4	Monofocal
31	41	Female	Smoking	9	3		20° varus	3	Bifocal
32	54	Male	Smoking	40	5	A1	Mobile Nonunion	3	Monofocal
33	37	Male	Nonsmoking	16	0		15° varus	5	Bifocal
34	28	Female	Smoking	8	4		Mobile nonunion	3	Bifocal/acute shortening/bone graft
35	18	Male	Nonsmoking	7	4	B2	20° varus 20° recurvatum	4	Monofocal
36	22	Male	Smoking	14	5		15° varus	5	Bifocal
37	45	Male	Smoking	12	4		10° varus	3	Monofocal
38	42	Female	Smoking	20	5		30° varus	5	Bifocal

(*Continued*)

Table 2 (*Continued*)

Case no.	Age (years)	Sex	Special habit	Duration of nonunion	Number of previous operations	Type of infection[a]	Angulation for stiff nonunion or with IF	Shortening/ defect (cm)	Technique used
39	60	Male	Smoking	22	5	A2	Mobile nonunion	6	Bifocal/bone transport
40	25	Male	Smoking	16	4		20° varus	3	Monofocal
41	24	Male	Nonsmoking	12	2		15° varus	3	Monofocal
42	28	Female	Nonsmoking	6	3	A1	35° varus	3	Bifocal
43	36	Male	Smoking	8	3		20° varus 30° recurvatum	3	Monofocal
44	45	Female	Nonsmoking	12	3		–	4	Bifocal
45	27	Male	Smoking	9	4	B1	Mobile nonunion	4	Bifocal/acute shortening
46	19	Male	Nonsmoking	12	3		40° varus20° recurvatum	4	Bifocal
47	32	Male	Smoking	18	4	A1	–	3	Bifocal
48	26	Male	Smoking	8	0		40° varus	4	Monofocal
49	35	Male	Smoking	36	4		45° procurvatum	7	Bifocal
50	48	Male	Smoking	10	4	B1	Mobile nonunion	3	Bifocal/acute shortening
51	30	Male	Smoking	12	3		Mobile nonunion	6	Bifocal/bone transport
52	41	Male	Nonsmoking	18	4		40° valgus	4	Monofocal

Figure 2



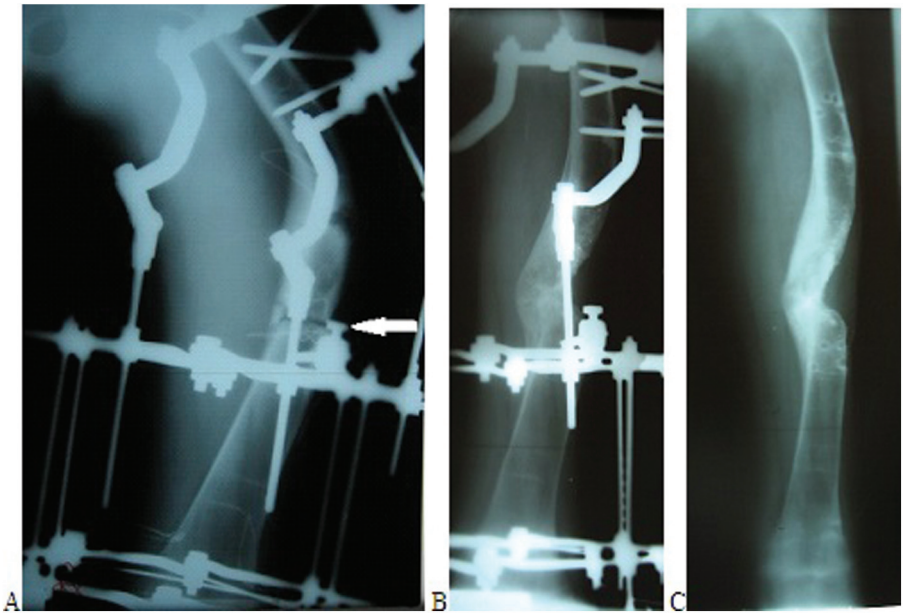
Monofocal gradual correction with hinges properly placed to correct both angulation and shortening through the nonunion site.

distraction at corticotomy site in bifocal surgery was started after 7 days' latency period with the same rate and frequency.

Primary iliac crest cancellous bone graft was used in six patients after debridement of sclerotic ends and acute shortening.

Patients were followed up biweekly until frame removal with some minor adjustments performed in the outpatient clinic in most patients. Physiotherapy program including joints' range of motion exercises, muscle strengthening, and partial-to-full weight-bearing as tolerated by the patient was carried out.

Figure 3



(a) Osteotomy performed just distal to the nonunion site to potentiate healing and correct the deformity; (b) after correction of the deformity with healing at both osteotomy and nonunion sites; (c) final radiography with good alignment and healing.

The Ilizarov fixator was removed after healing, which was defined as the presence of at least three cortices on standard anteroposterior and lateral radiographs, together with absence of pain during weight-bearing after frame dynamization.

Patients were followed up monthly for 3 months and then every 3 months for 2 years. Follow-up beyond 2 years was not necessary as significant improvement continues up to, but not beyond, 2 years [13].

Results

Bone healing was identified radiologically as callus bridging three cortices in 48 patients after a mean of 6.3 (4–12) months.

Totally, 20 patients of 23 treated using the monofocal technique had a mean healing time of 5.6 (4–9) months.

Totally, 28 patients of 29 treated with bifocal compression distraction had healing after a mean of 6.8 (4–12) months. Three patients of four treated using bone transport had a mean time to union of 9.3 (7–12) months, whereas nine patients treated with acute shortening and lengthening had a mean healing time of 5.5 (4–8) months. Sixteen patients underwent compression distraction confined to the nonunion site correcting associated deformities and lengthening through a corticotomy with a mean healing time of 7 (5–12) months (Fig. 4).

The mean length gained was 3.8 cm (2–9). Frontal plane malalignment (varus in 27 patients and valgus in two patients) was corrected in 29 patients as compared with preoperative values [mean: 23.8° (10–55°)]. However, sagittal plane malalignment (recurvatum in four patients and procurvatum in six) was corrected in 10 patients with a mean of 23.5 (10–45). Residual deformity was detected in three patients, one having 10° of recurvatum, one with 20° of procurvatum, and one with 30° of valgus. One patient treated with monofocal technique had a refracture at 2 months of follow-up after trivial trauma; he was treated with a locked plate as he refused fixation with the Ilizarov fixator.

In four patients the fracture was nonunited: three of them were treated using the monofocal technique (one of them had type B1 infection) and one was treated with bifocal compression distraction (with type A2 infection) and had nonunion at the docking site. All four patients were heavy smokers.

Infection was controlled in nine patients and five patients had persistent infection with draining sinuses (two of them remained with nonunited fracture). Pin tract infection occurred in almost all patients and was controlled using oral antibiotics and local use antiseptic solution instead of normal saline.

At final follow-up, 39 patients had improved knee range of movement compared with their preoperative values; 24 of them had a mean arc of knee movement of 100°

Figure 4

(a and b) Anteroposterior and lateral radiography for a nonunited femur with shortening; (c) during bifocal compression distraction; (d–f) anteroposterior and lateral radiography showing healing of the nonunion site and the length gained with 10° of recurvatum and final good bone result; (g) full range of knee motion and final excellent functional result.

(0–120°) and 15 had full range of movement. Eight patients had reduced arc of knee movement with a mean of 15° (0–30°). The knee range of movement was not evaluated in five patients, four with nonunion and one patient with refracture, as these were considered failure with poor results.

Patients were assessed using the criteria proposed by Paley and Maar [14]. Thirty patients had excellent functional results, 15 had good results, two had fair results, and five had poor results. The bony results were excellent in 35 patients, good in eight patients, fair in four patients, and poor in five patients (Table 3).

Discussion

Complex nonunion of the femur poses a challenge to both patients and treating surgeon. The Ilizarov method in treating such problems has long been successful, but it is not a remedy for all problems, as in this case series 10 patients had been treated previously with Ilizarov fixator and the fractures of four patients remained nonunited afterwards. However, other forms of internal fixation are not suitable for the treatment of such complex nonunion with problems of shortening, deformity, or the presence of infection.

The Ilizarov method offers both mechanical and biologic environment needed for healing. Callus that can proliferate under tension reflects the capability of tissue healing with stable fixation, adequate vascularity, and functional use of the limb. The abolition of shear forces rather than compression is needed for healing and callus maturation. Under these conditions, compression distraction can successfully produce bone union while simultaneously correcting length and angulation either using monofocal or bifocal techniques [9–11,15].

Table 3 Results

Case no.	Residual deformity	Length gained	Duration of treatment (months)	Functional result	Bone results
1	None	4	5	Excellent	Excellent
2	None	4	5	Excellent	Excellent
3	None	2	4	Excellent	Excellent
4	None	5	9	Good	Excellent
5	None	4	7	Excellent	Excellent
6	None	2	8	Poor	Poor
7	None	2	4	Good	Excellent
8	None	4	6	Good	Good
9	None	4	7	Good	Good
10	None	4	6	Excellent	Excellent
11	None	4	9	Good	Excellent
12	None	3	4	Excellent	Excellent
13	None	2	6	Good	Good
14	None	3	6	Excellent	Excellent
15	None	2	4	Excellent	Excellent
16	10 recurvatum	9	11	Excellent	Good
17	None	5	7	Poor	Poor
18	None	3	5	Good	Excellent
19	None	2	6	Poor	Poor
20	None	4	6	Excellent	Excellent
21	None	7	7	Excellent	Excellent
22	None	4	5	Excellent	Good
23	None	4	5	Excellent	Excellent
24	None	3	4	Excellent	Excellent
25	None	4	8	Good	Good
26	None	3	4	Excellent	Excellent
27	None	4	7	Good	Excellent
28	None	4	9	Poor	Poor
29	None	4	6	Excellent	Excellent
30	None	3	6	Excellent	Excellent
31	None	3	5	Excellent	Excellent
32	None	0	5	Good	Excellent
33	None	2	8	Good	Good
34	None	3	5	Excellent	Excellent
35	None	2	6	Good	Fair
36	None	5	8	Good	Excellent
37	None	3	6	Excellent	Excellent
38	None	5	7	Excellent	Excellent
39	None	6	12	Good	Fair
40	None	3	4	Excellent	Excellent
41	None	3	4	Excellent	Excellent
42	None	3	5	Excellent	Excellent
43	None	3	9	Poor	Poor
44	None	4	7	Excellent	Excellent
45	None	4	6	Good	Excellent
46	None	4	6	Excellent	Excellent
47	None	3	5	Excellent	Excellent
48	None	4	5	Excellent	Excellent
49	20 procurvatum	7	12	Fair	Good
50	None	3	4	Excellent	Fair
51	None	6	9	Excellent	Excellent
52	30 valgus	0	9	Fair	Fair

Totally, 29 patients were treated using the bifocal compression distraction technique; 10 of them were infected. Nine of 10 infected patients had successful union but two of them had fractures that remained with draining sinuses. One patient continued to have infected nonunion. Thirteen patients underwent segment excision followed by either bone transport or acute shortening and lengthening. Patients treated

with acute shortening and lengthening had a much shorter healing time (mean: 5.5 months) compared with those treated with bone transport (mean: 9.3 months). Acute shortening and lengthening is less complicated compared with bone transport with shorter healing time and should be used instead whenever possible. Bifocal compression distraction produced excellent functional results in 18 patients, good results in nine, fair results in one, and poor results in one patient. Bone results were excellent in 19 patients, good in seven patients, fair in two patients, and poor in one patient.

Totally, 23 patients were treated with monofocal compression distraction; four of them were infected on presentation, one had persistent infection but fracture union, and one fracture remained infected and nonunited. The monofocal technique was confined to patients with hypertrophic callus as seen on preoperative radiography or those with immature callus and vascular bone ends as seen during debridement and hardware removal, as such nonunions have the ability to heal with compression distraction under appropriate conditions [11]. Functional results for patients treated with monofocal compression distraction were excellent in 12, good in six, fair in one, and poor in four patients. Bone results were excellent in 16 patients, good in one, fair in two, and poor in four patients.

Although smoking can have a deleterious effect on the maturation of new bone formed by callus distraction [2,3], in this series there was no difference in the mean healing time for smokers and nonsmokers, which was 6 months. This may be attributed to the variability of the technique, monofocal versus bifocal, and the amount of lengthening and deformity correction achieved for each patients. However, the four patients who had fractures that remained nonunited were heavy smokers (more than 20 cigarettes per day).

Judging fracture union in complex cases is not always straightforward. Despite using stringent criteria and frame dynamization before removal, four patients' fractures remained nonunited and one patient later a refracture that was judged as healed while the fracture remained nonunited. In doubtful cases, a computed tomography scan is helpful and should be ordered [2].

Internal fixation methods can improve the mechanical stability of femoral nonunions with better bone and functional results, but unfortunately these methods are limited in their ability to treat complex nonunions associated with deformity, shortening and bone defects, or infection [4,5,16].

The Ilizarov method of compression distraction is particularly valuable in these complex cases [7–11]. The only limitation for use of this method seems to be noncompliant patients.

Pin tract infection, which occurred in almost all patients, was controlled with oral antibiotics and aggressive dressing protocols [17] using compression dressings and alcoholic chlorhexidine solution to abolish pain, which can interfere with patients' compliance for functional loading and knee range of movement exercises. In this case series, excellent functional results were achieved in 30 (57.6%) patients, good functional results in 15 (28.8%) patients, fair in two (3.8%) patients, and poor in five (9.6%) patients. Excellent bone result was achieved in 35 (67.3%) patients, good result in eight (15.3%), fair result in four (7.7%) patients, and poor result in five (9.6%) patients.

These results were comparable to those published by Patil and Montgomery [3]; they had excellent functional results in 43.75% of their patients, good results in 43.75%, fair results in 6.25%, and poor in 6.25%. Bone results were excellent in 41.4% of patients, good in 34%, fair in 9.7%, and poor in 14.6%.

Moreover, the bone results achieved in this work were comparable to those of Krishnan *et al.* [18], who achieved excellent bone results in 68.4% of their patients, good results in 21%, fair results in 5.2%, and poor results in 5.2%. However, their functional results were inferior to those achieved in the present series of patients, as they had excellent functional result in 15.7% of their patients, good results in 47.3%, fair results in 15.7%, and poor results in 21%.

Conclusion

Both monofocal and bifocal compression distraction techniques are effective in the treatment of complex femoral nonunion. Less treatment time is achieved for monofocal cases (mean: 5.6 months). In bifocal cases, acute shortening and lengthening has a much lower treatment time (mean: 5.5 months) compared with bone transport (mean: 9.3 months) and should be used when possible.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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