Original article

Plating in diaphyseal fractures of the forearm

Claudio Iacobellis, Carlo Biz

Orthopaedic and Traumatological Clinic - Department of Surgery, Oncology and Gastroenterology DiSCOG - University of Padua, Italy

Abstract. *Background and aim of the work:* Currently, open reduction and internal plate-screw fixation is generally accepted as the gold standard treatment of diaphyseal forearm fractures. The purpose of this retrospective study was to evaluate the clinical and radiographic outcomes of open reduction and internal fixation by using the Locking Compression Plate (LCP) implant system of radial, ulnar or combined shaft fractures of a skeletally mature patients group treated at our institution. *Methods:* We examined 47 patients, 44 men and 3 women, mean age 35 years (range 14–74) operated for diaphyseal fractures of the forearm. Overall 64 segments were treated: 32 ulnar and 32 radial. All patients received 3.5-mm titanium LCPs (Locking Compression Plates) with "combi-holes". Follow-ups included standard X-rays and clinical assessment according to Anderson's criteria and the DASH questionnaire. *Results:* Mean follow-up was 11 months (range 6-39). The number of the patients who achieved complete consolidation was 43 with a union rate of 91.5%. They showed 37 excellent results and 6 satisfactory results according to Anderson criteria, while non-union occurred in 4 out of 64 segments (2 ulnar and 2 radial) with a non-union rate per patient of 8,5%. The mean score of the DASH scale was 13.5 (range 0-46.7). *Conclusions:* Our data show that internal plating gives good functional outcomes in the treatment of forearm diaphyseal fractures, as long as the surgical technique is perfect and carried out by expert surgeons. However, further research is desirable to better identify fracture types for which LCPs should be used. (www.actabiomedica.it)

Key words: Diaphyseal forearm fractures, radius fractures; ulna fractures; LCP (Locking Compression Plate).

Introduction

Currently, open reduction and internal plate-screw fixation for the treatment of diaphyseal forearm fractures in adults is the most commonly used technique. It represents the procedure of choice for several authors (1-3), and is generally accepted as the gold standard treatment (4-10). There are very few indications for closed treatment of forearm fractures in adults, especially if both bone are involved. Only isolated non-displaced or minimally displaced (less than 50%) fractures can be treated by applying a long arm cast or functional fracture brace (11). Further, before AO (Association for Osteosynthesis) age, other fixation techniques of these fractures have been described, such as: intramedullary K-wire fixation (12), intramedullary nailing (13-16), and external fixation (17). They are still relevant today; however, they have been demonstrated to be successful only in restricted cases, with a high rate of non-unions and additional need of plaster casting (18,19).

Instead, anatomical reduction and bridging plate internal fixation with locking compression plates (LCP) is frequently reported as a largely successful strategy (20). These plates were devised by combining the features of an LC-DCD and a PC-Fix (21).

The forearm anatomy directly impacts the biomechanics of the ulna, relatively straight, and the radius, a gentle lateral bow (22). Therefore, several authors (19,23,24) have emphasized the importance of

restoring not only the straightness of the ulna, but also the radial bow and the normal interosseous space. As the forearm provides a particular anatomical relationship between radius and ulna, and a stable link between elbow and wrist, a non-anatomical reduction with rotational error is responsible for decreased forearm rotation and limited range of motion of the two joints (25,26). Hence, this procedure allows the restoration of the length of the two bones, their axial alignment and normal rotational alignment in order to restore proper range of pronation and supination, and to avoid functional deficits of the elbow and wrist.

Although correct reduction and plating lead to an immediate mobilization and satisfactory healing, several disadvantages and serious complications due to the technique have been described in the literature (27-30): extensive soft tissue damage, evacuation of the fracture hematoma, blood supply outage, and inhibition of periosteal revascularization. Moreover, nonunion (rate 2.3% to 4%) (31,32), refracture following plate removal (rate 1.9% to 30.4%) (33-37), and infection (rate 0.8% to 2.3%) have been reported by several authors (4,5,8,38).

The purpose of this retrospective study was to evaluate the clinical and radiographic outcome of open reduction and fixation by using the LCP implant system of radial, ulnar or combined shaft fractures of a homogeneous cohort of skeletally mature patients treated at our institution.

Materials and methods (Tab 1)

This retrospective study reports a consecutive series of 47 patients, who underwent open reduction and internal plate-screw fixation with 3.5mm locking compression plates (LCPs) for acute diaphyseal fractures of the forearm at the Orthopaedic and Traumatological Clinic of the University of Padua between January 2008 and December 2010. To be selected for this study, the patients had to be between 14 and 75 years old, skeletally mature, with an acute diaphyseal fracture of the radius, ulna or both bones as defined by the AO, fresh (<7days), closed or exposed according to Gustilo's classification. Exclusion criteria were: fracture of the same-side humerus, associated fractures of the proximal or distal radius-ulna, Monteggia and Galeazzi injuries, pathological and osteoporotic bone fractures, history of long-term steroid therapy, neurological and vascular pathologies, and motor nerve injury to the same-side upper limb. At the time of surgery, the mean patient age was 35 years (range, 14-74). There were 3 women and 44 men.

The original 47 cases presented overall a total of 64 diaphyseal fractures: 32 of the radius and 32 of the ulna. The fracture involved only one bone in 30 cases: the radius alone in 15 forearms, the ulna alone also in 15 forearms and both bones in 17 cases. The right side was implicated in 18 patients and the left in 29. Nineteen (40.4%) patients sustained low-energy trauma, while 28 (59.6%) had high-energy trauma. The mechanism of injury were a traffic accidents in 17 patients (36.2%), falls from a height in 14 (29.8%), sports injuries in 10 (21.2%), industrial accidents in 3 (6.4%) and assault in 3 (6.4%).

The fractures were distinguished according to the AO classification system (39): type A1 (10 cases), A2 (12), A3 (9); B2 (3), B3 (6); C1 (6) and C2 (1); no patients had type B1 or C3. Among the fractures, there were three open fractures (3/64), which were classified according to the classification system of Gustilo and Anderson (40) as type I (one radius, type B2 according to AO) and type 2 (one radius, type B2; and 1 ulna, type C1). No patient had type III.

Fractures fixation was performed in a standard fashion by a single surgeon, the main author of this paper, who had previous experience with this technique. Within 48 hours of trauma all fractures were stabilised by using 3.5-mm titanium plate osteosynthesis (Locking Compression Plate, Synthes, Switzerland) (29,41-43) with combi-holes suitable for screws for dynamic compression or angular screws. In double fractures, the less complex fracture was always treated first. If the fractures were similar, the ulna was treated first, in order to restore the correct length of the forearm. The elbow was bent to its maximum in ulnar operations. Bone grafting was not performed.

A tourniquet was used in all subjects, applied to the proximal arm with a pressure of 250-300 mmHg. The patient was supine on a radiolucent table with the superior arm abducted on radiolucent lateral support and regional anaesthesia was performed. The type and

Table 1. CASES

Patients	Gendar years	Classification AO 22-	Segment	Injury mechanism	LCP 3,5 n° holes		Complications	Callus Consolidation (months)	
					Radius	Ulna		Radius	Ulna
1.	M 41	A1	U	H		7			4
2.	M 32	A1	U	L		7			3
3.	M 45	A3	U	H		7			3
4.	M 55	C2	RU	L	8	8		4,5	4,5
5.	M 22	C1	RU + O	H	7	7	ulna Gustilo II	3	3
6.	F 74	B2	R	H	8			18 (delayed union)	
7.	M 38	C1	U	L		12			4
8.	M 19	A2	R	L	8			3	
9.	M 36	A2	R	L	6			3	
10.	M 18	A3	RU	H	6	5		3	3
11.	M 44	A3	RU	H	8	7		3,5	3,5
12.	M 47	A1	U	H		7			4
13.	M 40	A2	R	L	7			3	
14.	M 27	A2	R	L	10			3	
15.	M 35	A3	RU	H	8	8		3,5	3,5
16.	M 26	A2	R	L	9			3	
17.	M 57	A1	U	H		7			6
18.	M 36	B3	RU	H	8	7		12 (delayed union)	12 (delayed union)
19.	M 27	A2	R	H	7			3	
20.	M 68	A1	U	H		8			3
21.	M 68	A1	U	H		6			3
22.	M 41	A1	U	L		8			3,5
23.	F 14	A3	RU	L	8	8		5	5
24.	M 40	A2	R	L	8	7		4,5	
25.	M 36	B3	RU	H	9	9		5	5
26.	M 15	A3	RU	L	8	6		4,5	4,5
27.	M 22	B3	RU	L	9	8		4	4
28.	M 15	B3	RU	H	9	9	radial n.paresthesia	4	4
29.	M 20	C1	RU	H	8	10	median n. paresthesia	5	5
30.	M 39	A3	RU	H	8	8	radial n. paresthesia	4	4
31.	M 26	A2	R	L	8			4	
32.	M 32	A1	U	L		7			3
33.	M 46	B2	R + O	H	10		Gustilo I	4	
34.	M 20	A1	U	H		7			4
35.	M 20	B3	U	H		10			5
36.	M 21	A3	RU	H	7	7		4	4
37.	M 62	B3	RU	H	7	9		4	4
38.	M 54	A1	U	L		7			4
39.	M 35	A2	R	L	7		radial n.paresthesia	3	
40.	M 21	A3	RU	H	7	8		5	5
41.	M 29	A2	R	H	8			4	
42.	M 22	A2	R	L	8			4	

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43.	M 45	B2	R	H	9			4	
44.	M 60	A2	R	L	7		plate rupture	Non-union	
45.	M 28	C1	U	H		10			Non-union
46.	M 28	C1	U	H		8			Non-union
47.	F 22	C1	RU + O	H	9	7	radius Gustilo II	Non-union	6

Legend: R (radius), U (ulna), RU (radius and ulna), O (Open fracture), H (High energy), L (Low energy)

duration of antibiotic regimens varied depending on whether the fractures were closed or open, according to the antibiotic protocol in use at our institution. All patients with closed injures received at least one pre-operative 4 mg-dose of intravenous cefazolin antibiotic and four post-operative doses during the following 24 hours. The patients with open fractures received three daily 3mg-doses of intravenous ampicillin and sulbactam antibiotics for 7 days after the trauma. The surgical incision followed the ulnar crest and exposed the fracture, passing between the ulnar extensor and flexor of the carpus. After reduction, the plate was positioned carefully, in order not to create conflict with radial prono-supination (28). The radius was exposed either along Thompson's dorso-lateral line, our preferred route, or Henry's line. The operative strategy was dependent on the fracture type. Plating was carried out with compression of transversal or only slightly oblique fractures, using 2 compression screws on opposite holes with respect to the point of the fracture, and then applying 2 other angular screws at each end. In 11 very oblique fractures, compression was achieved with interfragmentary screws, followed by application of a neutralizing plate with angular screws. Comminuted fractures received a bridging plate with angular screws, to restore correct length and rotation. Plate length was chosen, wherever possible, to allow three screws to be placed in every main fragment. Then, the wound was closed after inserting a suction draining tube, which was removed the day after the operation and a compression dressing was applied for the first few days. The post-operative protocol was not standardized. However, no splints were used for support neither plaster. Passive, active-assisted and then gentle active exercise of the elbow, wrist, and hand were started 24 hours later.

All radiographs were digitally archived and included in the study, to allow the study of consolidation process of the fractures as well as possible complications and failures. All available medical records of the patients were reviewed and all subjects included in this analysis were contacted and invited for a follow-up visit at our clinic, giving their consent for participation in the study.

The results were assessed on the basis of the time of union, functional recovery and complications. Specifically, follow-ups included standard X-rays of elbow and wrist, and clinical assessment with the DASH questionnaire (Disability of the Arm, Shoulder and Hand) (44) in its validated Italian version (45). A score of 0 points indicates a perfectly functioning upper extremity, whereas a score of 100 points indicates complete impairment. Bone union was defined as the presence of bridging callus or the obliteration of the evident line of the fractures on the anteroposterior, lateral, and oblique radiographs of the forearm. In accordance with literature criteria (46-48), consolidation within 6 months was considered normal. Pronation-supination (ROM) was assessed with the arm close to the body and the elbow at 90°, according to Anderson's criteria (46), and bearing in mind the functionality of the opposite limb. The results were considered *excellent* in the case of union with <10° loss of flexion-extension and <25° loss of prono-supination; *satisfactory,* union with <20° loss of flexion-extension and <50° of prono-supination; *unsatisfactory,* union with >30° loss of flexion-estension and >50° loss of prono-supination; and *failure,* non-union with or without loss of movement.

Results (Tab 2)

Medical and radiographic documentation of the 47 patients included in the analysis was available and all subjects accepted to come to our department for a physical examination. None of the patients was lost until the

Table 2. Results

Patients	Follow-up (months)	Less strength	R.O.M.				Anderson's criteria	DASH
			Sup	Pron	Flex	Ext		
1.	18	NO	-10°				Excellent	7,3
2.	18	NO					Excellent	5
3.	6	NO	-10°				Excellent	13,3
4.	19	NO			-20°		Satisfactory	46,7
5.	7	NO					Excellent	18
6.	32	YES		-40°			Satisfactory	48,3
7.	6	YES					Satisfactory	43,2
8.	17	NO					Excellent	5
9.	6	NO	-20°				Excellent	17,3
10.	6	NO					Excellent	5
11.	16	NO					Excellent	18,3
12.	16	NO					Excellent	5,3
13.	7	NO					Excellent	7,3
14.	6	NO					Excellent	5,8
15.	8	YES	-20°				Excellent	23,3
16.	9	YES					Excellent	14,5
17.	8	NO					Excellent	0
18.	13	NO					Excellent	15
19.	6	NO					Excellent	7,3
20.	13	NO					Excellent	7
21.	13	NO					Excellent	13,3
22.	6	NO					Excellent	5
23.	8	NO		-15°			Excellent	7,3
24.	10	NO	-15°				Excellent	15
25.	6	NO		-10°			Excellent	17,3
26.	8	NO					Excellent	3
27.	20	NO					Excellent	7
28.	13	NO	-10°				Excellent	7,3
29.	14	NO		-10°	-20°		Satisfactory	13,3
30.	6	YES		-15°	-10°	-10°	Satisfactory	28,3
31.	6	NO					Excellent	3
32.	7	NO					Excellent	7
33.	10	YES		-10°		-10°	Excellent	25,3
34.	6	NO					Excellent	5
35.	10	YES					Satisfactory	29,2
36.	8	YES		-15°			Excellent	18
37.	39	NO	-10°				Excellent	13,3
38.	6	NO					Excellent	5
39.	6	NO					Excellent	3
40.	11	NO					Excellent	5
41.	10	NO					Excellent	5
42.	6	NO					Excellent	18,7
43.	6	YES				-10°	Excellent	15,3
44 – 47	Failures (Non-unions)							

consolidation of the fractures and the last follow-up. The mean patient follow-up was 11 months (range 6-39 months). No cases of vascular complications during and after surgery, compartment syndrome, superficial wound infection or deep infections, malunion and synostosis between the forearms bone were observed. After surgery, loss of sensation of the radial nerve was noted in 3 cases and median nerves just in one. All were resolved spontaneously.

The number of the patients who achieved complete consolidation was 43 (91.5%). They showed 6 satisfactory and 37 excellent results according to Anderson's method. The mean score on the DASH scale was 13.5 (range 0-46.7 points). In 41 (87.2%) patients, the mean union time was 3.8 months for the radius (range 3-5 months) and 4.5 for the ulna (range 3-6 months). Overall, 2 delayed unions were observed among the cases with fractures were caused by high-energy trauma, in which consolidation took 18 months (case 6: radius fracture, type 22-B2) and 12 months (case 18: combined fractures, type 22-B3). In our series of 64 fractures treated, 30 of ulnae and 30 of radii (93.8%) reached consolidation. However, there were 4 cases of non-union (6.2%), which occurred in 2 ulnae and in 2 radii of 4 patients, 3 men and 1 woman, mean age 34.5 (range 22-60 years). Thus, the non-union rate per patient was 8.5%. The cases of non-union involved the following kind of fractures, according to the AO classification: 3 type C1, of which one of these was open, Gustilo II and one type A2. The first three types were complicated fractures: 1 bifocal ulnar fracture (case *n.*45), 1 comminuted ulnar fracture (*n.*46), 1 open fracture of the radius, Gustilo II (*n.*47). In the last one (*n.*44), plate rupture took place due to poor patient compliance. Thus, these patients underwent a second stabilization operation.

At the time of follow-up none of the implants was removed from the consolidated fractures, neither did any patient ask to have his/her plate removed. No refracture was observed in our series.

Discussion

Open anatomic reduction and internal fixation (ORIF) with plates is the gold standard treatment of forearm fractures in adults (1-10,49). In particular, the use of LCPs represents an effective treatment in terms of union rate, pain and functional outcomes. LCPs can be used as compression plates, bridging fixators, or a combination of both, depending on the part of screw hole and the type of screw used, both in closed and open injuries. During these procedures, bone grafting was not performed for any patient, as we consider the additional use of bone grafting only in selected cases, such as bone loss, delayed union and non-union (11, 22,31,32).

The goal of this retrospective study was to assess the clinical and radiographic outcomes of open reduction and fixation by using the LCP implant system of radial, ulnar or combined shaft fractures of a skeletally mature patients group. Thus, this paper reports our experience in the early treatment of 64 consecutive acute forearm fractures in adults, by open reduction and internal fixation with LCPs, over a mean follow-up period of 11 months (range 6-39 months).

The cases presented did not involve any particular vascular or neurological complications, malunion or synostosis. No cases of early or late infections were observed, while in literature, between 0.8% to 2.3% (5,8) have been reported. In our series, 4 patients experienced non-union. They were 3 cases with complicated fractures (*n.*45: C1, bifocal ulnar fracture; *n.*46: C1, comminuted ulnar fracture; *n.*47: C1, Gustilo II, radial fractures) and 1 case (*n.*44: A2, radial fracture), in which poor patient compliance caused the early rupture of the plate. This would mean a non-union rate per patient of 8,5%, which is compatible with values reported by several other authors (7,49-51).

For the remaining 43 patients (91.5%), who achieved normal union, we also obtained overall satisfactory (12.8%) and excellent (78.7%) functional results in 91.5% of patients, according to Anderson values. Thus, these results are not far from those reported for the first time in 1975 by Anderson and colleagues (46) (union rate 97%; satisfactory and excellent outcomes 85%) and very similar to those achieved by Chapman (8) (union rate 98%; satisfactory and excellent outcomes 91%) and Moed (7) (union rate 91%;satisfactory and excellent outcomes 85%). None of our patients was immobilized during post-operative time, and they started early range of motion rehabilitation. Hence, our results, in accordance with other

authors (7,52), confirmed that loss of motion is most likely to occur in patients with post-operative cast immobilization.

The average DASH scores (13.5 points) was also satisfactory. It was lower than the mean DASH scores found by Droll (53) (18.6 points) and analogous to that found by Goldfarb (24) (12 points). However, it was greater than the mean DASH scores (10.1 points) in healthy individuals in the United Stated (24,53,54), than those reported by Arjan (8 points) (55) and in other Dutch studies (56).

Regarding the surgical technique, care must be paid to the length of the plate, the positioning of screws and the degree of compression. In spiral fractures, 1 or 2 screws may be necessary to compress fragments properly (41). Lindvall and Sagi (57) report excellent results in treating 75 diaphyseal fractures of radii and ulnae using plates with 7 holes but only 4 screws, 2 near the fracture and 2 at the ends of the plate (each screw being separated from the next by one hole). The biomechanical studies of Dennis et al. (58), Sanders et al. (59), Stoffel et al. (60) and Tornkvist et al. (61), have shown that the number of screws is less important than the length of the plate and preferable to shorter plates with all their holes occupied by screws. Leung and Chow (48), reporting 45 forearm fractures treated with no cases of non-union, state that one or even 2 plate holes near the fracture gap should be omitted, to increase the flexibility of the construct. In 6 of our patients (cases 14,25,27,33,35, and 37) we used plates with some holes left empty next to the fracture and the results were good (Fig. 1). However, we acknowledge that the number of patients in this group is low to confirm this statement. In the other 36 cases with good results we used plates with all holes occupied by screws except the holes on the fracture (Fig. 2). Compression is essential for proper repair (41), as reported constantly (62), and does not exclude the possibility of being able to use long plates.

It could be argued that this is a retrospective review, involving a limited number of subjects and allowing bias. However, to our knowledge, only one prospective research study on diaphyseal forearm adult fractures treated by using locking compression plates has been published (63) recently. Further, our group of patients was homogenous and treated early by the same surgeon, the main author of this paper. Another potential weakness of this analysis is the limited aver-

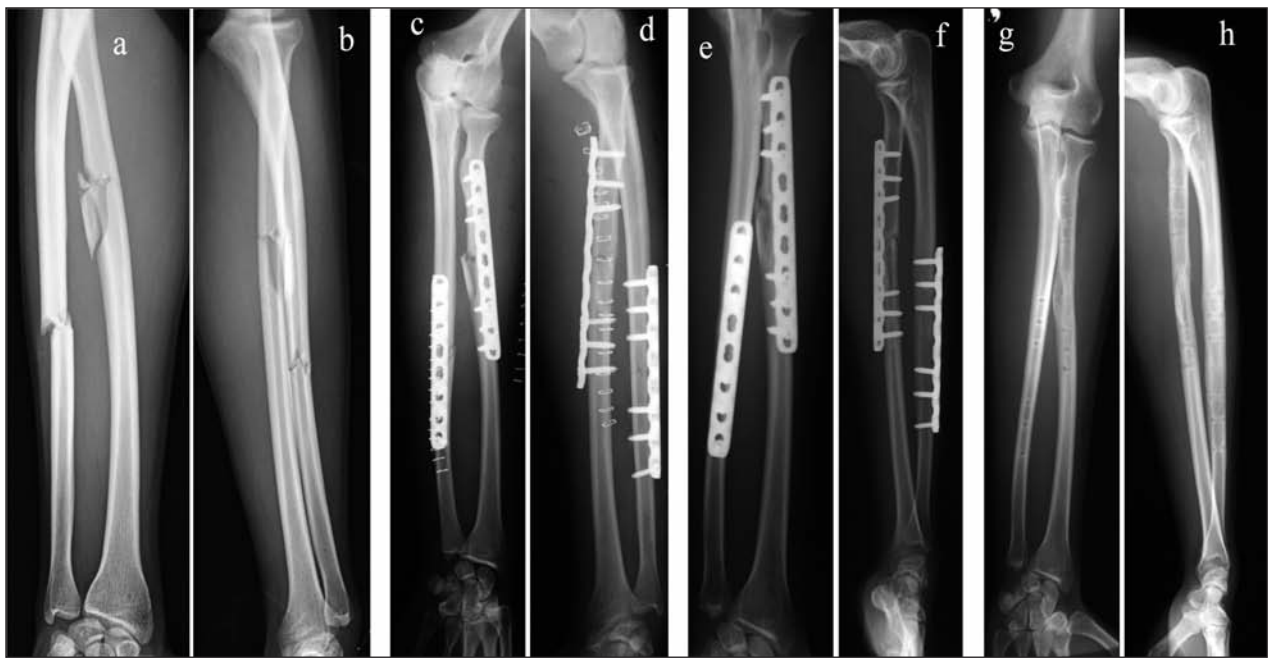

Figure 1. Case 27, male, aged 22: a-b) pre-operative X-ray; c-d) postoperative check-up; e-f) follow-up 4 months later; g-h) follow-up 18 months later.

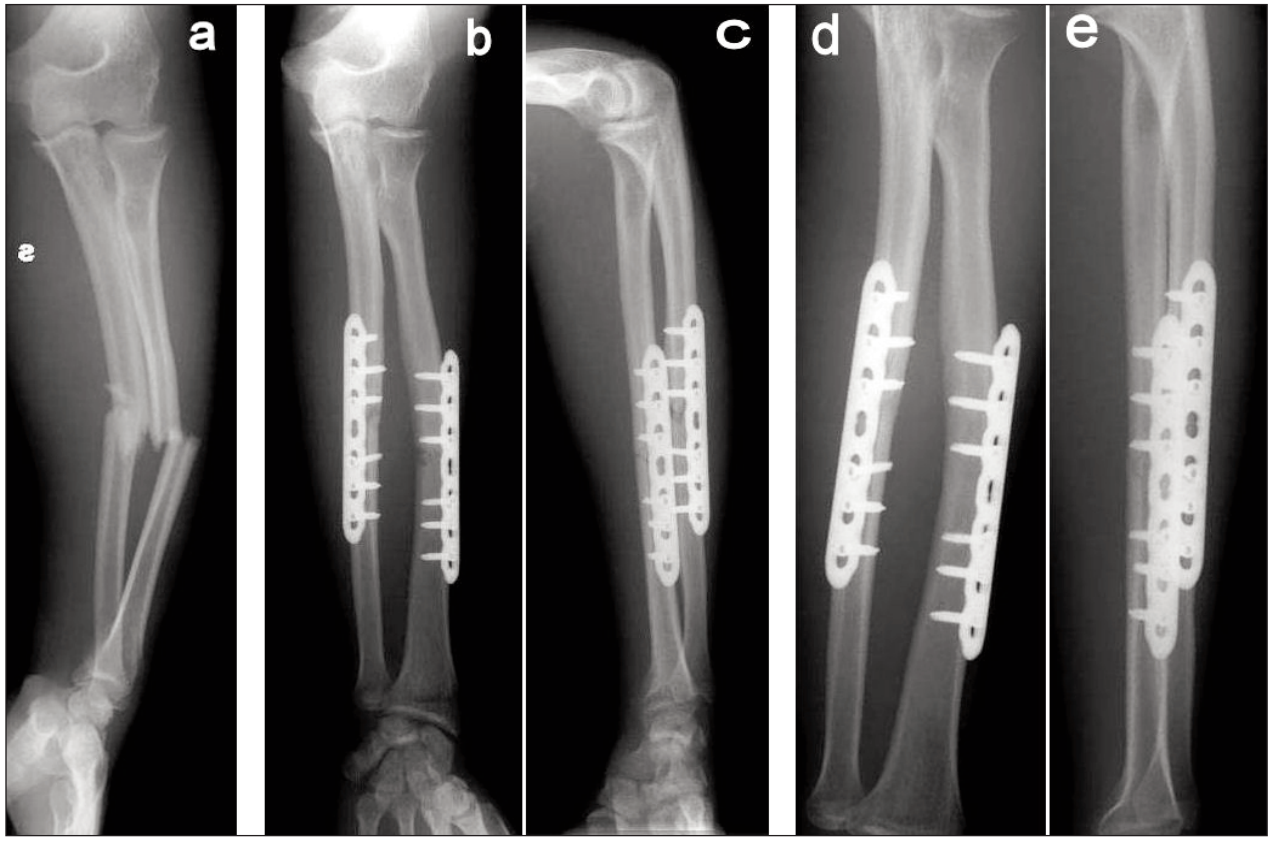

Figure 2. Case 36, male, aged 21: a-b) pre-operative X-ray; c-d) follow-up 1 month later; e-f) follow-up 8 months later

age follow-up of 11 months (range 6-39 months). Nevertheless, it is possible to demonstrate the consolidation of fractures after 6 months, according to the literature (46-48).

No refracture has occurred in this series of patients, where all plates have been left in place at the last follow-up. In fact, the risk of refracture after removal of a plate has been reported to be 4% to 25% (8,14,35,46,64,65). Thus, in agreement with other authors (11), we do not suggest routine plate removal. Even if the patient asks to have his plate removed, we carry it out not earlier than 18-24 months from the index procedure.

In conclusion, isolated or combined displaced fractures of the radius and ulna should usually be treated by using 3.5-mm compression plates, according to the methods recommended by the AO Foundation. On the basis of these data, we strongly believe that internal plating gives good functional results in the treatment of forearm diaphyseal fractures, as long as the surgical technique is perfect and carried out by expert surgeons. However, further research and prospective, randomized controlled trial, using validated outcome measures are desirable, in order to better identify fracture types for which the use of LCPs should be indicated.

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Correspondence:
Claudio Iacobellis, MD
Clinica Ortopedica, Via Giustiniani 2, 35100 Padova
Tel. 049/8213343
Fax 049/8213365
E-mail: claudio.iacobellis@unipd.it