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ORIGINAL ARTICLE

Treatment of the ulna non-unions using dynamic compression plate fixation, iliac bone grafting and autologous platelet concentrate

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Abstract Clinical study of a series of ten patients treated between 2004 and 2009 for non-unions of the ulna. The patients have been treated with osteosynthesis using a dynamic compression plate and biological enhancement of the consolidation using bone graft and autologous platelet injection. The follow-up consisted of clinical and radiographic assessment. Functional scores used were the Visual Analogue Scale (VAS) for pain and the Disability Assessment for the Shoulder and Hand (DASH) questionnaire. The mean time of follow-up was 21 months. Considering both clinical and radiological criteria, bony union was achieved in 9/10 cases on average time of 4 months. According to the system of Anderson, 5 patients provided an excellent result, 2 a satisfactory result, 2 an unsatisfactory result and 1 treatment resulted in failure. At follow-up, the mean VAS score for pain in the upper limb was 1 (range, 0–4) at rest and 2 (range, 0–7) during activities. The physical function and symptoms of the upper limb, evaluated with the DASH questionnaire, scored 17 points. In conclusion, at a mean 21 months follow-up, there was high success regarding both forearm alignment, clinical and functional results. The use of three combined methods provides high success regarding both radiological and clinical results, even if we have no information on the prevalent efficacy of one particular method.

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Background

Few reports have been published to help in guiding the treatment of diaphyseal forearm non-unions [1, 2] and in particular regarding isolated ulna non-unions [3]. Forearm non-unions are usually associated with a complex injury, inadequate initial reduction of the fracture, a complication such as infection, unstable fracture fixation, or early limb mobilization [4]. Typical occurrence rates reported for forearm non-unions in large cohort studies range between 2 and 10% [5, 6]. Diaphyseal fractures of the forearm differ from other diaphyseal fractures because of the intimate relationship between the radius of an ulna and their reciprocal movement [1], so that they could be considered like articular fractures [1]. Pronation and supination of the forearm occur at the radiohumeral, proximal radioulnar and distal radioulnar joints. Failure to reconstitute the exact relation between radius and ulna will affect the proximal and distal joints, with impairment of forearm function [1]. Moreover, the shape, length and distance between radius and ulna influence also the movements of the wrist. Therefore, a surgical technique must provide bone stability, stimulate bone repair and reconstitute the original anatomic alignment and length of the forearm bones to regain normal flexion–extension of the elbow, pronation, supination and grip strength of the wrist. For the most part, treatment has been based on stable plate fixation combined with either intercalary non-vascularized structural (corticocancellous) bone grafts [7] or vascularized grafts [8, 9]. The latter are typically required for defects larger than 6 cm with the fibula, being a suitable size match for the bones of the forearm [9]. In the

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Table 1 Subject's characteristics, type of injury and preoperative data

Patient	Age/gender	Smoking	Mechanism of injury	Primary injury and side (R/L)	Classification	Primary surgical treatment	Elapsed time (months)	Radiographic classification	Bone defect (cm)
1	25 M	Yes	MC	Monteggia, R	Bado type III	ORIF nail	11	Atrophic	3
2	35 M	No	MC	Ulnar and radial shaft, L	A1	Cast	7	Atrophic	3.5
3	16 M	No	Fall	Ulnar and radial shaft, R	A3	ORIF plate	9	Atrophic	2.5
4	47 F	Yes	Fall	Monteggia, R	Bado type III	ORIF Nail	8	Atrophic	5
5	34 M	Yes	MC	Ulnar and radial shaft, L	A3	ORIF plate	32	Atrophic	4.5
6	31 M	Yes	MC	Monteggia, R	Bado type IV	ORIF plate	7	Atrophic	3.5
7	36 M	No	MC	Ulnar and radial shaft, R	B3	ORIF plate	15	Atrophic	3
8	50 F	No	Fall	Ulnar shaft, R	B1	ORIF plate	7	Hypertrophic	–
9	63 F	No	Fall	Ulnar and radial shaft, L	B3	ORIF plate	8	Atrophic	2.5
10	28 M	No	Sport injury	Ulnar and radial shaft, L	B3	ORIF plate	7	Atrophic	2

ORIF open reduction and internal fixation, *MC* motorcycle crash, *R* right side, *L* left side

case of atrophic non-unions, biological enhancement is essential as the cellular and molecular environment of the fracture need to be optimized [10]. Recently, autologous platelet-rich plasma (PRP) in the form of activated platelet gel has been introduced in healing bone non-unions. Platelet gel (PG) can be considered an autologous source of concentrated growth factors involved in cellular reparative processes through the activation of proliferation and chemotaxis of mesenchymal cells, osteoblasts and chondrocytes [11]. Few studies exist on the clinical usefulness of PG in non-unions or delayed unions of long bones and they report variable results [12, 13]. In the present study, we retrospectively evaluated 10 patients with isolated established ulna non-unions with bone defect up to 5 cm treated by a corticocancellous iliac graft, a dynamic compression plate and injection of autologous platelet gel.

Materials and methods

During a 6-year period between 2004 and 2009, 10 patients with isolated non-unions of the ulna were treated. For that purpose, a non-union was defined as an unstable fracture with no signs of healing at a minimum of 7 months after the injury. The criteria for inclusion in the present study were a non-union with a segmental defect measuring between 1 and 5 cm in length secondary to a traumatic fracture of the ulna, in the absence of an acute infection. Patients with non-traumatic ulna non-unions, associate non-unions of the radius, infected non-unions or with an associated neurological impairment of the ipsilateral upper extremity, which may preclude from an adequate functional assessment, were excluded. There were 7 men and 3 women with an average age of 36.5 years (range, 16–50 years) (Table 1). Among them, 6 were right and 4 left limbs. The average time between the initial fracture and the index operative treatment of the non-unions was 11.5 months (range, 7–32 months). The mechanism of injury was a motorcycle accident for 5 patients, a fall for 4 and a sports injury in the remaining case. The pattern of injury in all subjects is reported in Table 1. The initial treatment of the fracture consisted in plate and screw fixation in 6 patients, intramedullary nail fixation in 2 and cast immobilization in 1 (Table 1).

Surgical procedure

The non-union site was approached by a direct posterior incision, with extreme care to avoid excessive detachment of the muscles and remaining periosteum. The technique of preparing the non-unions site should include the excision of all fibrous issue and sclerotic bone from the fracture site. Bone ends should be debrided until healthy, and bleeding bone is encountered. The healing response is stimulated additionally by drilling the sclerotic ends of the fracture fragments. The defect was measured so that a single block of corticocancellous bone of correct length can be harvested from the iliac crest. Autogenous cancellous bone graft from the iliac crest was applied in all patients. We adopted the Nicoll's technique modified by Davey and Simonis [14] consisting in sculpting the bone defect into trapezoidal shape and fashioning the bone graft to a matching trapezoidal shape; the bone graft is then keyed into the created trapezoidal defect (Fig. 1). The advantage of this technique consists in increasing the area of bony contact and allowing the graft to be wedged securely in place. The defect is completely filled with bone, and over it is placed a 3.5 mm limited-contact dynamic compression plate (LC-DCP, Synthes, Paoli, PA), with an average 10 holes length (range, 7–12 holes), with three cortical screws on either side of the non-union (Fig. 1). The cortical surface of the graft is positioned opposite the plate to allow firm compres-

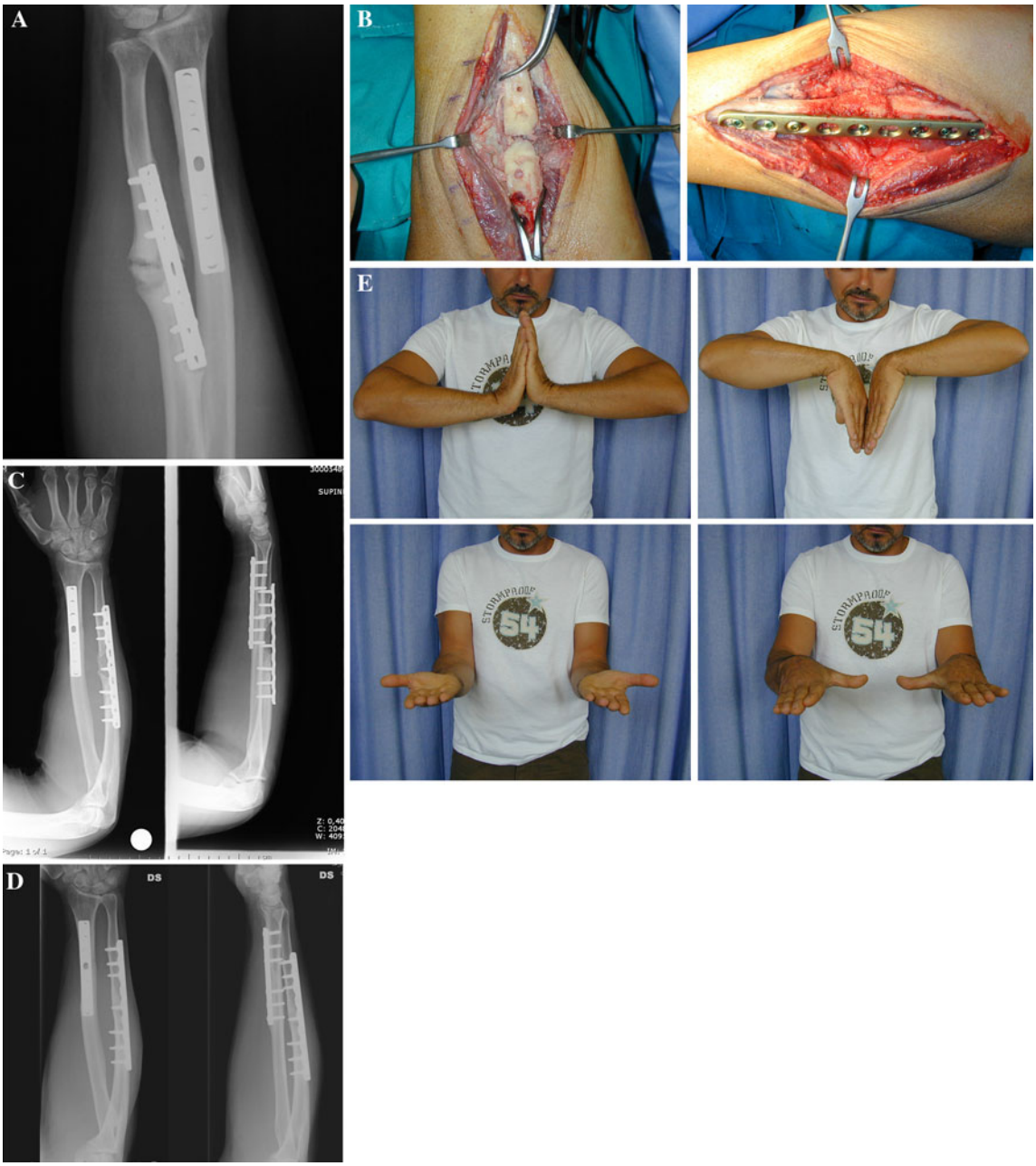

Fig. 1 **a** Hypertrophic non-union of the ulnar shaft treated with plate and screws. **b** Intraoperative view of the modified Nicoll's technique with the trapezoidal-shaped bone graft. **c** X-ray view after 1 month. **d** Complete healing of the graft on X-ray view after 6 months. **e** Clinical evaluation after 6 months

sion without crushing. The proper length and alignment was restored using an intraoperative image intensifier control in three projections: AP, lateral and oblique. The arm was initially immobilized in a cast for 20–30 days with the elbow flexed 90° and the forearm in intermediate rotation. To favour upper limb circulation, maintain muscle tone and prevent disuse osteopenia, patients were instructed before discharge to move the fingers of the surgically treated arm (extension and flexion) daily 10 min every hour until cast removal.

Platelet gel preparation

Two days before surgery, 450 cc of venous blood was obtained from each patient and drawn into tubes containing citrate/citric acid/dextrose. The tubes were centrifuged for 20 min at 180*g* resulting in the three following layers: the inferior layer composed of red cells, the intermediate layer composed of white cells and the superior layer made up of plasma. The plasma layer was further centrifuged for 15 min at 580*g* in order to obtain a two-part plasma: the

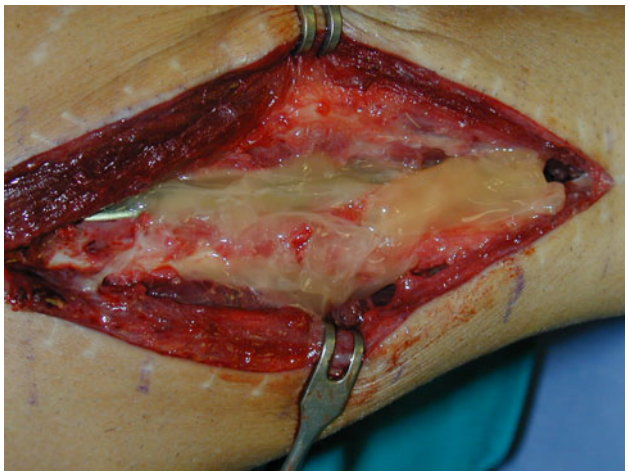

Fig. 2 Intraoperative view of the ulnar shaft non-union, treated with plate and covered with PG

upper part (80%) consisting of poor-platelet plasma (PPP) and the lower part (20%) consisting of platelet-rich plasma (PRP). PPP and calcium gluconate were mixed to prepare autologous thrombin, which was obtained by eliminating the clot. On the same day of surgery, PRP was activated by the addition of autologous thrombin and calcium gluconate, and then, the PG formed was ready to be injected in the non-union rim (Fig. 2).

Evaluation

The preoperative plan included plain X-rays of the forearm, wrist and elbow, in antero-posterior (AP) and lateral views. Radiological and clinical outcome were determined at an average 21 months follow-up after revision surgery, ranging from a minimum of 7–40 months follow-up. The three radiographic key parameters for the evaluation of the non-union healing were as follows: bridging of the fracture site by bone, callus or trabeculae; bridging of the fracture seen at the cortices; and obliteration of the fracture line or cortical continuity. We considered the graft remodelled on the basis of both radiological and clinical criteria. Radiological criteria are represented by the presence of callus bridging on at least three of the four cortices and by the integration of the graft with the native bones on X-ray and, in some cases, CT studies. Clinical criteria include the patient's ability to bear weight on the injured limb and perform activities of daily living, and the presence of pain at the fracture site upon palpation and physical stress. Forearm function was evaluated using the Anderson system [15], which rates an united fracture with <10° loss of elbow or wrist motion and <25% loss of forearm rotation as excellent; a healed fracture with <20% loss of elbow or wrist motion and <50% loss of forearm rotation as satisfactory; a healed fracture with more than 30° loss of elbow or wrist motion and more than 50% loss of forearm rotation as unsatisfactory, and a malunion, non-unions or unresolved chronic osteomyelitis as failure. Pain in the upper limb was evaluated using the Visual Analogue Scale (VAS) from 0 to 10, in which 0 represents the absence of pain and 10 represents maximum pain. The pain level was evaluated both at rest and during daily life activities. Upper limb disability was measured by the Disabilities of Arm, Shoulder, Hand (DASH). It consists in a 30-item questionnaire measuring both physical and social function and upper limb symptoms and produces a score between 0 and 100, in which a high DASH score indicates severe disability [16].

Results

According to the Weber and Cech classification [17], 9 cases were defined as atrophic non-unions and only 1 case resulted in hypertrophic (Table 1). One patient required a further revision surgery due to the rupture of the LCP plate 2 months after the index surgery. At a 40 months follow-up, the graft failed to unite at the distal end; however, it united proximally and filled the defect in the ulna. Besides this case, no postoperative failure of fixation was seen in any patient, and no other complications, such as infections, were observed. Else, no complications were observed in the donor area, except for pain in the first postoperative days, which subsided spontaneously and did not interfere with walking and daily life activities. The mean patient's follow-up was 21 months (range, 7–40 months) (Table 2). Considering both radiological and clinical criteria, the graft was considered remodelled with an average healing of 4.11 months (Table 2). In particular, in six cases with a mean bone defect of 2.25 cm (range, 2–3.5 cm), the mean healing time was 3.67 months (range, 3–5 months), whereas in the remaining three subjects with a bone defect of 4.33 cm (range, 3.5–5 cm), the mean healing time was 5 months (range, 5–6 months). The ulna healed with <10° of angular deformity in all cases. The average postoperative range of motion in all patients was from an elbow flexion contracture of 2° (range, 0°–12°) to 135° (range, 125°–145°) of elbow flexion. Rotation of the forearm averaged 69° pronation (range, 54°–78°) and 74° supination (range, 63°–85°). At the wrist, the average range of flexion was 69° (range, 56°–80°) and extension was 65° (range, 50°–70°) (Fig. 1). According to the system of Anderson, 5 patients had an excellent result, 2 of them a satisfactory result, 2 an unsatisfactory result and the remaining treatment resulted in failure. None of the 10 patients experienced problems with weakness or instability of the elbow after treatment. At follow-up, the mean VAS score for pain in the upper limb was 1 (range, 0–4) at rest and 2 (range, 0–7) during activities. The physical function and symptoms of the upper

Table 2 Postoperative data

Patient	F.U. (months)	Healing time (months)	Return to work (months)	Sport activities resume (months)	Pain at rest (VAS)	Pain during activities (VAS)	Elbow Flex/ext (°)	Forearm Pro/sup (°)	Wrist Flex/ext (°)	Result (Anderson)	DASH
1	40	–	8	36	5	7	128/12	77/65	60/64	Failure	36.7
2	7	3	4	4	0	0	140/2	72/80	74/68	Excellent	4.2
3	8	3	–	3	0	0	125/0	70/72	68/64	Satisfactory	26.7
4	17	5	5	–	0	3	137/0	60/66	57/62	Unsatisfactory	25
5	7	4	3	5	0	2	135/0	69/72	80/68	Excellent	12.1
6	29	6	4	6	2	4	130/5	54/63	56/50	Unsatisfactory	29.2
7	24	4	5	3	0	0	143/0	78/85	72/70	Excellent	0
8	32	4	2	–	0	1	138/0	74/78	77/70	Excellent	6.9
9	20	5	–	–	2	3	127/4	65/80	70/63	Satisfactory	20.8
10	26	3	4	4	0	2	145/0	75/78	74/68	Excellent	8.6

F.U. follow-up time, *DASH* disabilities of the arm, shoulder and hand

limb, evaluated with the DASH questionnaire, scored 17 points (range, 0–36.7) (Table 2). Patients resumed their original work activity in 4 months on average after surgery. Young and active patients restart sport activities from 3 to 36 months after surgery.

Discussion

The presence of an isolated ulna non-union with bone defect represents an obstacle for the healing, limiting the ability of the forearm bones to shorten and to achieve apposition of the fragments. Therefore, the aims of surgical treatment are restoration of alignment and length in order to re-establish the relationship between forearm bones and recovery function of the forearm in terms of flexion–extension of the elbow and wrist, pronation and supination. Contoured plate fixation and autogenous bone grafting are a straightforward technique that allows the restoration of alignment and length and provides a solid assembly that early mobilization is possible, with a quicker and more complete recovery. Nicoll was one of the first to report on the use of corticocancellous bone graft in the forearm non-unions [18]. Several authors have reported on its use [2, 6, 7]. Autograft is the most commonly used type of bone graft [11]. It can come from a variety of areas, including the iliac crest, distal femur, proximal tibia, fibula, distal radius and olecranon. The iliac crest is, by far, the most common source of autograft bone due to its rich source of progenitor cells and growth factors, limited donor site morbidity, fair bone quantity and relative ease of harvest [19]. In the present study, the use of a corticocancellous iliac graft, a dynamic compression plate and injection of autologous platelet gel proved to be a reliable and effective surgical procedure for the treatment of acquired, aseptic, isolated ulna non-unions, even if we have no information on the prevalent efficacy of one particular method. Considering both clinical and radiological criteria, bony union was achieved in 9/10 cases on average time of 4.11 months, resulting in longer time to healing for subjects with larger bone defect. We believe that the ability to obtain the final healing depends on the vitality of the bone ends, rather than the length of the graft, whereas the latter may influence the healing time. The average range of motion, measured at the last follow-up, resulted comparable with the results of similar studies [2, 3]. In particular, Kloen et al. retrospectively reviewed 51 cases of non-union of the radius and/or ulna, treated with compression plate fixation and autologous bone grafting if needed. Considering an average 75 month follow-up, all non-unions healed within 18 months after the index procedure, with a median time for union of 7 months. Range of motion averaged 2° (range, 0°–50°) for elbow flexion contracture, and 139° (range, 120°–140°) for elbow flexion, 64° (range, 0°–80°) for pronation, and 60° (range, 0°–80°)

for supination, 64° (range, 10°–90°) for wrist flexion, and 68° (range, 15°–90°) for wrist extension. According to the system of Anderson, an excellent result was obtained in 62% of cases, satisfactory result in 17% and unsatisfactory in 21% [20]. In the current research, bony union was achieved on average time of 4 months, resulting in agreement with the healing time reported in the pertinent literature without PG supplementation [3, 19]. This observation can support the hypothesis that isolated PG supplementation is not effective in reducing the healing time of long bone non-unions, although caution should be exercised in interpreting this result because of the absence of a control group, the small number of subjects and the presence of other probable confounding factors, such as the surgical technique and the PG preparation procedure. Discouraging results with the use of PG were reported in both spinal [21] and long bone non-union [13] surgery, even if positive results were reported in oral and maxillofacial [22] surgery. Among the studied population, the mean pain level, measured with the VAS scale, appeared similar to that reported by Faldini et al. [6]. Nevertheless, reviewing the available literature, we did not find any study that used the DASH score to measure the upper limb disability level following the treatment of ulna non-unions. However, some recent studies regarding the treatment of acute ulnar and/or radial shaft fractures [23, 24] reported mean DASH scores and range of motions comparable with those obtained in our study. This may suggests that our surgical approach for ulnar non-union may provide similar results in terms of range of motion, physical function and symptoms of the upper limb with respect to the treatment of acute ulnar and/or radial shaft fractures. Although the effects of cigarette smoking on union in forearm fractures are not directly known, Chen et al. [25] have demonstrated that in elective ulna shortening osteotomies, smokers healed an average of 3 months later than non-smokers and had a 30% incidence of delayed union or non-union. There were no non-unions among non-smokers in their series [25]. In our research, the smoking habit seems to influence the healing process, in fact the only case of non-healing occurred in a smoker and the other three subjects with the smoking habits required a mean longer time to healing with respect to non-smokers. The key finding in this pilot study is that corticocancellous iliac graft, a dynamic compression plate and injection of autologous platelet gel are a feasible procedure for the treatment of acquired, aseptic, isolated ulna non-unions. Future controlled studies with a larger sample size are desirable to compare this combined approach with the other techniques reported in the literature using this group of patients.

Conflict of interest The authors declare that they have no conflicts of interest concerning this article.

References

1. Richard MJ, Ruch DS, Aldridge JM III (2007) Malunions and nonunions of the forearm. Hand Clin 23:235–243
2. Ring D, Allende C, Jafarnia K, Allende BT, Jupiter JB (2004) Ununited diaphyseal forearm fractures with segmental defects: plate fixation and autogenous cancellous bone-grafting. J Bone Joint Surg [Am] 86:2440–2445
3. Ring D, Jupiter JB, Gulotta L (2003) Atrophic nonunions of the proximal ulna. Clin Orthop Relat Res 409:268–274
4. Chapman MW, Gordon JE, Zissimos AG (1989) Compression-plate fixation of acute fractures of the diaphyses of the radius and ulna. J Bone Joint Surg [Am] 71:159–169
5. Wey SY, Born CT, Abene A, Ong A, Hayda R, DeLong WG Jr (1999) Diaphyseal forearm fractures treated with and without bone graft. J Trauma 6:1045–1048
6. Faldini C, Pagkrati S, Nanni M, Menachem S, Giannini S (2009) Aseptic forearm non-unions treated by plate and opposite fibular autograft strut. Clin Orthop Relat Res 467:2125–2134
7. Enneking WF, Eady JL, Burchardt H (1980) Autogenous cortical bone grafts in the reconstruction of segmental skeletal defects. J Bone Joint Surg [Am] 62:1039–1058
8. Adani R, Delcroix L, Innocenti M, Marcoccio I, Tarallo L, Celli A, Ceruso M (2004) Reconstruction of large posttraumatic skeletal defects of the forearm by vascularized free fibular graft. Microsurgery 24:423–429
9. Adani R, Delcroix L, Tarallo L, Baccarani A, Innocenti M (2008) Reconstruction of posttraumatic bone defects of the humerus with vascularized fibular graft. J Shoulder Elbow Surg 17:578–584
10. Panagiotis M (2005) Classification of non-union. Injury 36:S30–S37
11. Lieberman JR, Daluiski A, Einhorn TA (2002) The role of growth factors in the repair of bone. Biology and clinical applications. J Bone Joint Surg [Am] 84:1032–1044
12. Kanthan SR, Kavitha G, Addi S, Choon DS, Kamarul T (2011) Platelet-rich plasma (PRP) enhances bone healing in non-united critical-sized defects: A preliminary study involving rabbit model. Injury 42:782–789
13. Calori GM, Tagliabue L, Gala L, D'Imporzano M, Peretti G, Albisetti W (2008) Application of rhBMP-7 and platelet-rich plasma in the treatment of long bone non-unions: a prospective randomised clinical study on 120 patients. Injury 39:1391–1402
14. Davey PA, Simonis RB (2002) Modification of the Nicoll bone-grafting technique for non-union of the radius and/or ulna. J Bone Joint Surg [Br] 84:30–33
15. Anderson LD (1965) Compression plate fixation and the effect of different types of internal fixation on fracture healing. J Bone Joint Surg [Am] 47:191–208
16. Hudak PL, Amadio PC, Bombardier C (1996) Development of an upper extremity outcome measure: the DASH (Disabilities of the Arm, Shoulder, and Hand) (corrected). The Upper Extremity Collaborative Group (UECG). Am J Ind Med 29:602–608
17. Weber BG, Cech O (1976) In pseudoarthrosis: pathology, biomechanics, therapy, results. Hans Huber Medical Publisher, Berne, pp 13–43
18. Nicoll EA (1956) The treatment of the gaps in long bones by cancellous insert grafts. J Bone Joint Surg [Br] 1:70–82
19. Sen MK, Miclau T (2007) Autologous iliac crest bone graft: should it still be the gold standard for treating non-unions. Injury 38:S75–S80
20. Kloen P, Wiggers JK, Buijze GA (2010) Treatment of diaphyseal non-unions of the ulna and radius. Arch Orthop Trauma Surg 130:1439–1445

21. Carreon LY, Glassman SD, Anekstein Y, Puno RM (2005) Platelet gel (AGF) fails to increase fusion rates in instrumented posterolateral fusions. Spine 30:E243–E246
22. Marx RE (2004) Platelet-rich plasma: evidence to support its use. J Oral Maxillofac Surg 62:489–496
23. Siebenlist S, Torsiglieri T, Kraus T, Burghardt RD, Stöckle U, Lucke M (2010) Comminuted fractures of the proximal ulna–Preliminary results with an anatomically preshaped locking compression plate (LCP) system. Injury 41:1306–1311
24. Henle P, Ortlieb K, Kuminack K, Mueller CA, Suedkamp NP (2011) Problems of bridging plate fixation for the treatment of forearm shaft fractures with the locking compression plate. Arch Orthop Trauma Surg 131:85–91
25. Chen F, Osterman AL, Mahoney K (2001) Smoking and bony union after ulna-shortening osteotomy. Am J Orthop 30:486–489