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Treatment of diaphyseal non-unions of the ulna and radius

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Abstract
Introduction Non-unions of the forearm often cause severe dysfunction of the forearm as they affect the interosseus membrane, elbow and wrist. Treatment of these non-unions can be challenging due to poor bone stock, broken hardware, scarring and stiffness due to long-term immobilisation.
Method We retrospectively reviewed a large cohort of forearm non-unions treated by using a uniform surgical approach during a period of 33 years (1975–2008) in a single trauma centre. All non-unions were managed following the AO-principles of compression plate fixation and autologous bone grafting if needed.
Patients The study cohort consisted of 47 patients with 51 non-unions of the radius and/or ulna. The initial injury was a fracture of the diaphyseal radius and ulna in 22 patients, an isolated fracture of the diaphyseal ulna in 13, an isolated fracture of the diaphyseal radius in 5, a Monteggia fracture in 5, and a Galeazzi fracture-dislocation of the forearm in 2 patients. Index surgery for non-union consisted of open reduction and plate fixation in combination with a graft in 30 cases (59%), open reduction and plate fixation alone in 14 cases (27%), and only a graft in 7 cases (14%). The functional result was assessed in accordance to the system used by Anderson and colleagues.
Results Average follow-up time was 75 months (range 12–315 months). All non-unions healed within a median of 7 months. According to the system of Anderson and colleagues, 29 patients (62%) had an excellent result, 8 (17%) had a satisfactory result, and 10 (21%) had an unsatisfactory result. Complications were seen in six patients (13%).
Conclusion Our results show that treatment of diaphyseal forearm non-unions using classic techniques of compression plating osteosynthesis and autologous bone grafting if needed will lead to a high union rate (100% in our series). Despite clinical and radiographic bone healing, however, a substantial subset of patients will have a less than optimal functional outcome.

Keywords Non-union · Radius · Ulna · Internal fixation · Forearm

Introduction

Compression plate-and-screw fixation of diaphyseal fractures of the radius and ulna in adults has been common practice since the late 1950s. Large series have shown this technique to be straightforward with a low complication rate [1–6]. Controversies focused on bone grafting for acute fractures [7–10], the type and length of the plate [5, 11, 12], and the risk of refracture after plate removal [13–16]. Benefits of plate-and-screw fixation are the ability for anatomic and secure reconstruction allowing early motion. Complications of open reduction and internal fixation of forearm function are infection, malunion, non-union, nerve injury, compartment syndrome, bleeding, formation of a synostosis, and limited function [6].

Typical rates reported for forearm non-unions in large cohort studies range between 2 and 10% [1, 5, 7, 8, 17–20]. A diaphyseal forearm non-union is disabling as it effects not only the forearm but also the elbow and wrist. Failure to reconstitute the exact relation between radius and ulna will affect the proximal and distal joints, limiting the ability to

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place the hand in space [21]. Most often the non-union has a multifactorial cause combining fracture characteristics (e.g. low vs. high energy impact, comminution, location, soft tissue damage, open vs. closed), patient characteristics (age, co-morbidities) as well as surgeon-dependent causes (surgical technique and strategy).

We retrospectively reviewed a large cohort of forearm non-unions in adults treated during a period of 33 years (1975–2008) in a single trauma centre. We present their uniform surgical approach, their functional results and rates of union as well as additional surgery and complications.

Patients and methods

All patients treated in our centre for diaphyseal forearm non-unions during the 24-year period between 1975 and 1999 formed the initial cohort. They were extracted from an AO-database into which all patients for fracture care at our hospital were entered during that time. On average, 21 patients per year were treated for diaphyseal fractures of the forearm. The number of patients that was treated yearly for a non-union of the forearm declined during that period for two reasons. Firstly, our department was, and still is, a tertiary referral centre for failed fixation and/or non-unions starting in the 1970s and 1980s. Secondly, the technique of fixation became better known and union rates after primary surgery for forearm fractures improved. Additional cases between 2002 and 2008 were entered into the study cohort at admission for treatment by the senior author (P.K.). A non-union was defined as absence of healing after 4 months, or evident failure of treatment prior to that [22]. All patients with skeletal immaturity, congenital forms of non-union, or a follow-up of <12 months were excluded. As a result, 47 patients were included in the study cohort, which consisted of 35 men and 12 women with an average age of 37 years (range 16–76 years). The indications for treatment of the non-union were pain, limited function, forearm deformity and/or hardware failure.

Twenty-one fractures involved the left arm, 25 fractures involved the right arm and 1 patient fractured both arms. The mechanism of injury was a motorised vehicle accident in 26 patients, a fall in 12, and a crush injury in 9. The pattern of injury was a fracture of the diaphyseal radius and ulna in 18 patients, an isolated fracture of the diaphyseal ulna in 15, an isolated fracture of the diaphyseal radius in 7, a Monteggia fracture in 5, and a Galeazzi fracture-dislocation of the forearm in 2 patients. According to the AO classification of ulnar and radial shaft fractures [23], there were 6 type-A1, 1 type-A2, 7 type-A3, 13 type-B1, 4 type-B2, 11 type-B3, 3 type-C1, and 2 type-C2 fractures. Eighteen fractures (38%) were open; according to the system of Gustilo and Anderson [24, 25], there were six type-1, four type-2, and seven type-3A fractures. For one open fracture the Gustilo and Anderson type could not be determined. Eleven patients were polytraumatic with at least one more fracture in other areas. Ten patients had an associated nerve injury, two ulnar nerve lesions, five radial nerve lesions, a median nerve lesion, a combined radial and median nerve lesion and a brachial plexus lesion. One patient had a radial artery lesion, which was acutely repaired. The percentage of smokers was 58%. Prior treatment consisted of cast immobilisation in eight cases. Thirty-three patients received 1 previous operative treatment, which consisted of plate fixation in 22 (1 with primary grafting), external fixation in 3, and K-wires/Rush pins in 3. Five patients were converted early from a cast to plate fixation after an average of 9 days (range 4–20 days). In one patient external fixation was early switched to plate fixation and in one patient plate fixation was early switched to external fixation. Two patients underwent plate fixation twice, and one patient received an intramedullary nail twice after undergoing plate fixation twice. In one patient previous treatment was unknown. There were 51 non-unions in 47 patients, including a non-union of the radius in 16 patients, the ulna in 27 patients and of both ulna and radius in 4 patients. Four of the 18 patients that had initially broken both forearm bones produced non-unions of both radius and ulna, seven produced a non-union of the radius, and seven produced a non-union of the ulna. Four of the non-unions were classified as atrophic (8%), 13 as hypertrophic (25%) and 34 as oligotrophic (67%) [26].

The time between the injury and the index surgery that resulted in healing averaged 16 months (range 2–312 months). Sixteen surgeons were involved. Principles of surgery were consistently a thorough debridement of avital tissues, removal of failed hardware, restoration of alignment, length, rotation, stable fixation using compression if possible (tensioner device and/or lag screws), optimisation of a bone forming environment (including bone grafting if needed) allowing for early motion. Index surgery for non-union consisted of open reduction and plate fixation in combination with a graft in 30 cases (59%), open reduction and plate fixation alone in 14 cases (27%), and only a graft in 7 cases (14%). Grafting was performed in 32 cases with autogenous cancellous graft. Donor sites were the iliac crest in 24, olecranon in 7 and distal radius in 1. In four cases a tricortical iliac crest block was used and in one case a vascularised fibula graft was used. No use has been made of bone graft substitutes.

Follow-up data were obtained by retrospective review of medical records and selective invitations for a free clinical and radiographic examination when insufficient data were available. The retrospective character of the study withheld us from recording functional scores such as the DASH. The final functional result was therefore assessed in accordance to the system used by Anderson and colleagues [1] at the most recent visit at the orthopaedic outpatient service at our institution. This scoring system, which was recently used by Ring et al. [22] in a comparable study, 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-union, or unresolved chronic osteomyelitis as failure.

Results

The average follow-up time was 75 months (range 12–315 months). All non-unions healed within 18 months after the index procedure (Figs. 1, 2) with a median time to union of 7 months (range 10–84 weeks). Range of motion at the most recent follow-up averaged 64° (range 10°–90°) for wrist flexion, 68° (range 15°–90°) for wrist extension, 64° (range 0°–80°) for pronation, 60° (range 0°–80°) for supination, 139° (range 120°–140°) for elbow flexion, and 2° (range 0°–50°) for elbow flexion contracture. Details on fracture type, treatment and function are summarised in Table 1.

According to the system of Anderson and colleagues 29 patients (62%) had an excellent result, 8 (17%) a satisfactory result, and 10 (21%) had an unsatisfactory result. No treatments resulted in failure. The reasons for the unsatisfactory results were limited range of motion of the wrist in eight patients, elbow stiffness in one and a median nerve lesion in one. Concerning the 18 patients that had an open fracture at the time of injury, 8 patients had an excellent result (44%), 3 patients had a satisfactory result (17%), and 7 patients had an unsatisfactory result (39%).

Complications and additional surgery

Twenty-seven patients had hardware removal after consolidation. This used to be fairly standard at our institution but it is not any more. One patient refractured his radius after hardware removal and underwent renewed plate fixation. One patient underwent manipulation under anaesthesia for wrist stiffness and one had a forearm tenolysis. Two patients had a postoperative nerve injury, of which one developed enduring meralgia paraesthetica after iliac crest bone harvesting, and one had a radial nerve palsy, which ultimately recovered over time. In two cases an infection developed at the graft donor site, one at the iliac crest site and the other at the fibula. In both cases the infections were successfully eradicated with debridement and antibiotics.

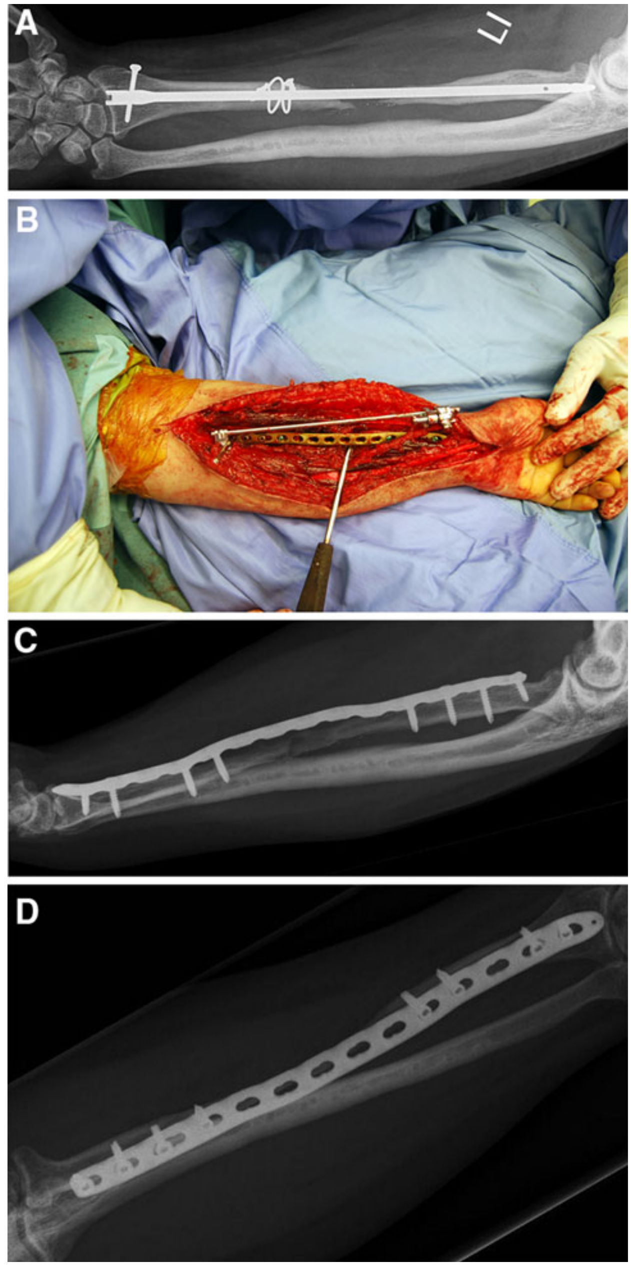

Fig. 1 **a** Anterior–posterior radiograph of an atrophic radius non-union in a 38-year-old female. She had undergone multiple previous attempts to obtain union at an outside hospital. Notice the protruding pin proximally. **b** Wide intra-operative exposure (Henry approach), with a 3.5-mm LCP plate on the radius. Intra-operative distraction maintaining radial length was obtained with a temporary external fixator. **c**, **d** Treatment consisted of autologous corticocancellous bone grafting and 3.5-mm LCP plate fixation. Radiographs at 15 months follow-up show a healed radius

Discussion

The standard technique of compression plate-and-screw fixation in acute diaphyseal forearm fractures is well established [27]. Their union rate has been consistently high

Fig. 2 Lateral radiograph showing a successfully treated hypertrophic ulnar non-union in a 38-year-old male. Fixation was obtained by means of a long compression plate-and-(lag)screw. Although this radiograph clearly shows an ulna minus that might have been exacerbated by using compression (shortening the ulna even more), the patient's wrist and forearm function is normal and he is pain-free at 22 months follow-up

(above 95% healing) with good functional outcomes in up to 85% [1, 2, 4, 5, 9]. Risk factors for development of a non-union are comminution, high energy fractures, open fractures and suboptimal surgical technique. Adherence to a "biologic surgical technique" with preservation of soft tissue attachments is important. There is no role for minimally invasive techniques as limited exposure will likely compromise the ability to obtain anatomic alignment. Stability of fixation is important in achieving early consolidation [5].

Reporting a union rate of 100%, our series shows that treatment of diaphyseal forearm non-unions is straightforward with a high success rate if "classic" principles of non-union surgery are followed. These principles are a thorough debridement of avital tissues, removal of failed hardware, restoration of alignment, length, rotation, stable fixation using compression if possible (tensioner device and/or lag screws), optimisation of a bone forming environment (including bone grafting if needed) allowing for early motion. However, despite clinical and radiological consolidation, a significant number of patients (21% in our series) might have an unsatisfactory long-term functional outcome due to limited range of motion. When limited to open fractures 39% had an unsatisfactory result.

Our results show that oligotrophic non-unions are more common than atrophic- or hypertrophic non-unions. In contrast to another report, we did not find a higher risk for the ulna than for the radius to produce a non-union in both bone fractures [28].

To the best of our knowledge, our cohort presents the largest series of forearm non-unions with a minimum of 12 months follow-up and both functional and radiological outcome in the English literature.

The involvement of 16 surgeons might suggest a wide variety of surgical detail. However, we argue that the high success rate shown in this report suggests that our described technique of treating forearm non-unions is one that is reproducible and can be circulated among surgeons.

As many patients in our patient group were referred to us from outside hospitals, data from the original injury (e.g. soft tissue condition) and surgery were often incomplete. This precluded us to define the exact cause of failure, although we can infer this is likely to be a combination of factors including biology, biomechanics, surgical technique and co-morbidities. It is suggested in the literature that intramedullary wires, K-wires, simple lag screws or one-third tubular plates carry a high risk of providing inadequate fixation [9].

Current fixation of choice is a relatively long 3.5-mm compression plate. Most authors advise six cortices on each side of the fracture; more recently use of only four cortices on each side was suggested [12]. The choice of bone graft has historically been a topic of debate. Nicoll [29] was one of the first to report on the use of (cortico)-cancellous autograft in forearm non-unions. Numerous authors have reported on its (modified) use, as was noted in a review by Faldini and colleagues [19]. Ring and colleagues indeed showed that for atrophic non-unions with segmental defects up to 6 cm non-vascularised autogenous corticocancellous grafts leads to bony union [22]. Recently, Baldy Dos Reis and colleagues [30] showed that treatment with corticocancellous bone grafts and plate fixation for both atrophic and hypertrophic non-unions led to excellent radiological and functional outcome in their cohort of 31 patients. Petalling of both sides (1.5–2 cm) of the non-union, with opening of the medullar canal to remove the sclerotic cap using a drill is a very important aspect of the procedure. We generally take the graft from the iliac crest, if done appropriately, deformity at the donor site is negligible with a low morbidity [31]. Given a compliant well-vascularised soft tissue envelope, vascularisation of corticocancellous graft often is rapid, with incorporation of the graft within a few weeks [22].

The use of non-vascularised bone blocks has been proposed by various authors [19, 26, 29, 32–34]. Of note is that in these studies patients were often protected postoperatively in a cast for a long period.

In review of the literature, it seems that non-unions of the ulnar and radial diaphyseal defects up to 6 cm can be treated with autologous cancellous bone grafts [22]. For defects between 6 and 10.5 cm there are some conflicting reports [32, 34]. Davey et al. [34] warned against the use of a non-vascular bone graft for defects larger than 6 cm. In case of a substantial bone defect in combination with a poor soft tissue environment, the use of an osteocutaneous free flap is a viable option [35–37]. The use of 3.5-mm (DC, LC-DCP, LCP) plates is preferred over 4.5-mm plates as these are too bulky for the forearm. There have been reports on the use of intramedullary nailing of non-unions of the forearm. We chose not to use this technique and would caution lack of compression and rotational control [38–40]. The most recent of these reports concluded that interlocking

Table 1 Demographics, treatment and outcome of the patient population

Age/sex	Fracture type (AO)	Open (G&A)	Non-union location	Non-union type	Time from injury to index surgery (months)	Graft	F.U. (months)	Elbow flex/ext	Forearm pro/sup	Wrist flex/ext	Result
36M	A1		Ulna	Hypertrophic	5		31	140/0	80/80	70/80	Excellent
45M	A1		Ulna	Hypertrophic	10		15	140/0	40/40	70/80	Satisfactory
16F	A1		Ulna	Hypertrophic	312	Olecranon	146	120/−15	30/80	70/80	Satisfactory
66F	A1		Ulna	Hypertrophic	9		13	140/0	80/80	70/80	Excellent
28M	A1		Ulna	Hypertrophic	3		12	130/0	40/80	70/80	Excellent
38M	A1		Ulna	Hypertrophic	6		94	130/0	80/80	70/80	Excellent
35M	A2		Radius	Hypertrophic	5		72	140/0	80/80	70/80	Excellent
28M	A3		Radius	Oligotrophic	16		22	140/0	40/60	40/65	Unsatisfactory
50M	A3	Grade 1	$Radius_1$	Oligotrophic	2		13	140/0	70/70	70/80	Excellent
28M	A3	Grade 1	Radius	Oligotrophic	6	ICBG	248	140/0	80/80	70/80	Excellent
38F	A3		Radius	Atrophic	26	ICBG	15	140/0	40/80	70/80	Excellent
45M	A3		Ulna	Hypertrophic	34	ICBG	55	140/0	80/80	70/80	Excellent
34F	A3		Ulna	Oligotrophic	45	ICBG	84	140/0	80/80	70/80	Excellent
20M	A3		Ulna	Oligotrophic	20	ICBG	34	140/−10	70/60	70/80	Excellent
50M	A3	Grade 1	$Ulna_1$	Oligotrophic	2		13	140/0	70/70	70/80	Excellent
70M	B1 (Galeazzi)		Radius	Oligotrophic	12	ICBG	12	140/0	80/80	Near full	Excellent
50M	B1 (Monteggia)		Ulna	Hypertrophic	7	ICBG	70	140/0	60/60	60/50	Unsatisfactory
41F	B1		Ulna	Hypertrophic	4		13	140/0	80/80	70/80	Excellent
61M	B1 (Monteggia)		Ulna	Oligotrophic	13	ICBG	32	140/0	80/80	70/80	Excellent
42M	B1 (Monteggia)		Ulna	Oligotrophic	5	Olecranon	12	140/0	80/80	70/80	Excellent
39F	B1		Ulna	Oligotrophic	3		91	140/0	80/80	70/80	Excellent
33F	B1		Ulna	Oligotrophic	30	ICBG block	21	140/0	80/80	70/80	Excellent
18M	B1		Ulna	Oligotrophic	6	ICBG	295	140/0	70/30	N/A	Satisfactory
36M	B1		Ulna	Oligotrophic	2		55	140/0	80/80	70/80	Excellent
40M	B1 (Monteggia)	Grade 1	Ulna	Oligotrophic	5	ICBG	156	140/0	80/50	70/80	Excellent
35M	B1	Grade 1	Ulna	Oligotrophic	7		13	140/0	80/80	70/80	Excellent
19M	B1 (Monteggia)	Grade 3A	Ulna	Oligotrophic	12	ICBG	63	Limited	Limited	Limited	Unsatisfactory
28M	B1	Open, grade N/A	Ulna	Oligotrophic	5	ICBG	177	140/0	80/80	70/80	Excellent
63M	B2		Radius	Oligotrophic	3	ICBG block	52	140/0	45/0	45/15	Unsatisfactory
46M	B2		Radius	Oligotrophic	7	ICBG block	315	140/0	80/30	70/80	Satisfactory
24M	B2 (Galeazzi)	Grade 2	Radius	Oligotrophic	4	ICBG block	25	140/0	80/80	70/80	Excellent
28M	B2	Grade 3A	Radius	Oligotrophic	5	ICBG	40	N/A	45/0	Poor	Unsatisfactory
21F	B3		Radius	Hypertrophic	7	Olecranon	93	140/0	80/80	70/80	Excellent
16M	B3	Grade 3A	$Radius_2$	Hypertrophic	5	ICBG	108	140/−5	45/0	15/10	Unsatisfactory
20F	B3		Radius	Oligotrophic	68	ICBG	174	140/0	80/50	70/80	Excellent
37M	B3		Radius	Oligotrophic	6	ICBG	310	140/0	80/80	70/80	Excellent
76F	B3		Radius	Oligotrophic	3	Radius	26	140/0	40/70	40/40	Unsatisfactory
23M	B3	Grade 3A	$Radius_3$	Oligotrophic	3	ICBG	84	140/0	65/70	75/50	Satisfactory
38M	B3	Grade 2	$Radius_4$	Atrophic	5	ICBG	113	130/0	20/45	N/A	Unsatisfactory
16M	B3	Grade 3A	$Ulna_2$	Hypertrophic	5	ICBG	108	140/−5	45/0	15/10	Unsatisfactory
30M	B3		Ulna	Oligotrophic	14	Olecranon	24	140/0	50/60	N/A	Excellent
49F	B3		Ulna	Oligotrophic	4	Olecranon	20	140/0	80/40	70/80	Excellent
22M	B3		Ulna	Oligotrophic	10	Olecranon	98	140/0	80/80	70/80	Excellent
50M	B3	Grade 2	Ulna	Oligotrophic	12	ICBG	13	140/0	40/40	70/80	Satisfactory
23M	B3	Grade 3A	$Ulna_3$	Oligotrophic	3	ICBG	84	140/0	65/70	75/50	Satisfactory
38M	B3	Grade 2	$Ulna_4$	Atrophic	5	ICBG	25	130/0	45/0	15/30	Unsatisfactory

Table 1 continued

Age/sex	Fracture type (AO)	Open (G&A)	Non-union location	Non-union type	Time from injury to index surgery (months)	Graft	F.U. (months)	Elbow flex/ext	Forearm pro/sup	Wrist flex/ext	Result
53M	C1		Radius	Oligotrophic	3	ICBG	24	140/0	70/45	90/75	Satisfactory
21M	C1		Ulna	Oligotrophic	6	Vascularized fibula	114	140/0	0/80	70/90	Satisfactory
47M	C1		Ulna	Atrophic	27	ICBG	30	120/−50	25/25	70/80	Unsatisfactory
65F	C2	Grade 1	Radius	Oligotrophic	7	Olecranon	30	140/0	80/60	70/80	Excellent
31M	C2	Grade 3A	Radius	Oligotrophic	6		32	140/0	45/40	80/15	Unsatisfactory

AO Müller AO classification of fractures, *G&A* Gustillo and Anderson classification of open wound fractures, *F.U.* follow-up time, $_{1234}$ both bone non-union, *ICBG* iliac crest bone graft

intramedullary nailing of non-unions of the diaphysis of ulna or radius should not be considered an alternative to plate fixation [38]. Their functional outcome indicated inferior results to plate-and-screw techniques.

In summary, classic AO technique with adequate debridement, eradication of infection and stable fixation using compression (using lag screws, eccentric drilling and/or AO tensioner device) will lead to successful healing of the vast majority of forearm non-unions. Longer plates (3.5 mm) with a high plate-span/screw ratio are preferred. In case of osseous defects up to 6 cm, autogenous cortico-cancellous bone grafts are recommended [22]. For larger defects free tissue transfer should be considered. Despite a very high chance of obtaining clinical and radiological healing of the non-union, patients should be informed that long-term functional outcome might be disappointing as was shown in this cohort in 21%.

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