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Treatment of radius or ulna diaphysis atrophic non-union with corticocancellous autograft and intramedullary nailing

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ABSTRACT

Aim: The purpose of this study was to present the functional and radiological results of tricortical cancellous iliac wing grafting and intramedullary nailing performed with the modified Nicoll's method for the treatment of cases with radius or ulna atrophic non-union.

Methods: The study which is a retrospective clinical study, included 12 patients (8 ulnas, 4 radiuses) with atrophic non-union as a result of plate-screw osteosynthesis applied for a radius or ulna diaphyseal shaft fractures. Fixation was made with tricorticocancellous autograft and intramedullary nailing with the modified Nicoll's method. In the functional and radiological evaluation, a visual analog scale, grip strengths, the Grace-Eversmann scale and the DASH score were used. Forearm pronation and supination and elbow flexion and extension angles were evaluated with goniometer.

Results: The patients were comprised of 8 (66.7%) males and 4 (33.3%) females All the patients were followed up for mean 40.5 months (range, 12-84 months). Graft incorporation and remodeling was observed in all patients. According to the Grace-Eversmann scores, 9 patients were evaluated as excellent and 3 as good. Overall, the mean DASH score was 15.5 and the mean VAS score was 1.5. There were no complications about the donor site of the autogenous iliac graft.

Conclusion: In cases of isolated radius and ulna non-union with a bone defect (gap) of <2.5cm, the tricorticocancellous autografting and intramedullary nailing with a modified Nicoll's method is a safe treatment method which provides more rigid fixation, does not require prolonged immobilization and allows early rehabilitation.

Key words: *Tricorticocancellous, intramedullar nailing, ulna, radius, nonunion*

Introduction

Adult forearm diaphyseal fractures are accepted as intra-articular fractures due to the unique functions of the radius and ulna provided by complex anatomic alignment of the bones of the forearm. Injury to the radius or ulna results in impairment of the functions of not only the forearm but of the whole upper extremity. So anatomic and stable fixation is imperative for achieving satisfactory functional outcomes in treatment of fractures of the forearm [1,2]. Open reduction and internal

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fixation is the most often preferred and the accepted treatment method [3-6]. Several local and systemic factors have been identified that affect bone union [7-9]. Some of these are, the fracture pattern (bone defects, segmental fractures), the treatment method used, soft tissue interposition in the fracture, failure of stability, impaired circulation between fragments as a result of periosteal stripping and local infection. An uncommon but most severe complication after primary treatment of forearm fractures is atrophic non-union [10-12]. In extensive series, non-union has been reported at rates of 2%-10% [7-14].

Despite new implants and different surgical methods developed for the treatment of atrophic non-unions, it remains a very important problem. Extensive iatrogenic soft tissue injury and periosteal stripping for extraction of the implant from the non-union site causes impaired circulation. This negatively affects remodelling of the graft inserted in non-union surgery. Also debridement of the atrophic non-union site enlarges the bony defect [15-17]. Prolonged plaster cast and splint immobilization in the postoperative period may have negative effects in the long-term on wrist, forearm and elbow functions. Several different treatment methods have been described in treatment of forearm non-unions. Various types of grafts and fixation methods have been proposed and still the optimal treatment is a matter of controversy. The main aim in the treatment of non-union is anatomic restoration of the bone length, anatomic alignment and to achieve stable fixation [17-21].

The purpose of this study was to present the functional and radiological results of tricortical cancellous iliac wing grafting and intamedullary nailing performed with the modified Nicoll's method for the treatment of cases with radius or ulna atrophic non-union.

Materials and Methods

The inclusion criteria of this study were as follows: (1) Atrophic ulna or radius non-union (2) No infection at the surgical site during the follow up period (3) Not having ipsilateral upper extremity fractures (4) Open reduction and internal fixation with plate and screw osteosynthesis at the initial operation (5) Patients who accepted and had undergone non-union surgery with autogenous tricortical iliac wing graft and fixation with intramedullary nails (6) A minimum follow up of 1 year after surgery. The study included 12 patients (8 ulna, 4 radius) who underwent surgery between September 2009 and February 2016. During the operation, the gap after resection was in the range of 1-2.5 cm. We use this technique in atrophic nonunions with segmental defects less then 2,5cms long. Atrophic non-union was defined as a radius or ulna fracture without signs of bony union at least 4-6 months after plate osteosynthesis. Patients with fractures of both radius and ulna, with significant bone loss at the initial trauma, initial Monteggia and Galeazzi type fracture dislocations, with open physis, with hypertrophic and septic non-union were not included in the study. A routine radiographs and CT scans were obtained before the operation. The routine blood analysis, sedimentation rate and C-reactive protein (CRP) parameters were examined in all patients.

Informed consent was obtained from all of the cases before surgery. The patients comprised 8 males and 4 females with a mean age of 37 years (range 24-55 years). All the patients included in the study had undergone plate-screw osteosynthesis at different centres, which had then resulted in atrophic non-unions. The primary fracture etiology was traffic accident in 5 cases, fall in 5 cases and industrial accident in 2 cases. The initial injury was a Type 1 open fracture in 2 cases. The indications for non-union surgery were as follows: (1) Presence of persistent pain, clinical and radiologic signs of non union after 6 months after surgery (2) implant failure due to non-union at the presentation. The mean time from the first fracture to surgery for non-union was 15.5 months (range, 7-26 months) and the mean length of stay in hospital was 5 days (range, 4-6 days). The mean follow-up was recorded as 40.5 months (range, 12-84

Table 1. The demographic, functional and radiological data of patients treated with tricorticocancellous autograft and intramedullary forearm nails.

Patient / Gender	Age / Side	Injury Etiology	Duration of 1st operation	VAS	Bone	Defect (mm)	GS (kgw) healthy / treated	DASH	GES	FU mths	TU (wks)	Operated elbow extension range	Pronation healthy / operated	Supination healthy / operated	MRC healthy / operated (mm)	MRCL healthy / operated (%)	Radiallength healthy / operated (mm)
1 /F	24/L	Fall	9	0	U	20	42/40	0	excellent	84	12	0	90/90	90/80			
2 /M	29/L	Fall	26	0	R	15	68/60	0	excellent	48	14	0	90/80	90/80	15 / 9.32	57.8/52.4	21.5/20.0
3/M	27/R	Traffic accident	12	2	U	10	55/50	3.3	excellent	12	18	0	90/90	90/85			
4/M	36/R	Traffic accident	16	2	U	25	85/80	15	excellent	44	17	15	90/80	90/90			
5/M	32/L	Industrial accident	20	2	U	20	75/55	20	good	60	20	10	90/75	90/75			
6/F	40/L	Traffic accident	24	1	U	10	35/30	9.2	excellent	32	24	5	90/90	90/80			
7M	44/L	Fall	18	1	U	15	75/70	8.3	excellent	20	22	5	90/85	90/90			
8/M	50/L	Traffic accident	6	2	U	15	83/75	7.5	excellent	26	18	0	90/90	90/90			
9/M	43/R	Fall	8	3	R	20	68/63	9.2	excellent	30	16	0	90/80	90/90	16.6/15.5	60.8/61.2	22.3/22.3
10/F	30/R	Fall	10	2	U	10	40/37	12	good	70	18	15	90/75	90/75			
11/F	35/R	Traffic accident	12	1	R	15	35/32	15	good	20	18	10	90/70	9075	13.8/13.7	56.5/56	19.2/19
12/M	55/L	Industrial accident	24	2	R	15	55/43	8.3	excellent	40	20	0	90/80	90/90	15.3/14	60.9/57.5	18.8/19

M-male, F-female: DASH: Disabilities of the Arm Shoulder and Hand, VAS:Visual Analog Scale, GES: Grace-Eversmann score, GS: Grip strength, TU: Time to union, MRCL: Maximum radial curve localization, MRC: Maximum radial curve, FU: Follow-up, U: Ulna

months) (Table 1). The gap measured after debridement of the non-union site and the length of the tricortical graft inserted was betweeen 1cm and 2.5cm's.

Union was defined as bridging callus formation in at least 3 cortices seen on anterior-posterior (AP) and lateral radiographs of the forearm and the absence of pain on palpation of the non-union site. In the cases with radius non-unions, the localization and the degree of maximal radial curve in the treated and the healthy forearm was measured with the Schemitsch and Richards method [7].

A hydraulic hand dynamometer (SAEHAN Hydraulic Hand Dynamometer (SH5001), Gyeongnam, South Korea) was used for evaluation of the grip strenght. Separate measurements were undergone for the treated and The healthy and treated forearms were separately evaluated. 3 minutes breaks were taken between the measeurement in order to prevent muscle fatigue. The mean of three separate measurements was evaluated as the grip strength. . The wrist, forearm and elbow joint range of motions of the patients were measured with a goniometer. Functional evaluation was made ac-

Table 2. Grace and Eversmann functional evaluation criteria.

	Union	Pronation supination comparison ratio with the uninjured arm
Excellent	+	90–100 %
Good	+	80–89 %
Acceptable	+	60–79 %
Unacceptable	-	<60 %

cording to the Grace- Eversmann [11] evaluation criteria (Table 2), the Disabilities of the Arm, Shoulder, and Hand (DASH) [22] questionnaire score and the Visual Analog Scale (VAS) score [23]. Elbow flexion-extension angles in forearm pronation and supination were evaluated with a goniometer.

Surgical Technique

Direct AP and lateral X-ray views of the uninjured foreams were obtained before the surgery in order to determine the size of nails. Length of the ulnar nail was calculated by subtracting 1.5cm from the distance between the ulnar styloid and itp of ulna. Length of the radial nail was calculated by subtracting 3cm from the distance between the radiocapitellar joint and radial styloid. The novel designed radius and ulna nails (TST Rakor Tıbbi Aletler San. ve Tic. Ltd. Sti., Istanbul, Turkey) were used for fixation.

2 gr of 1st generation cephalosporins were administered for infection prophylaxis in all patients. As all patients were to undergo surgery both on the upper extremity and the iliac wing, general anaesthesia was preferred in all of the patients. The site of non-union was explored from the incision of the previous operation.

Fibrotic tissues and the sclerotic bone ends were excised until cortical bleeding was obtained. To increase intramedullary bleeding, the intramedullary canal was opened with a drill of appropriate diameter. The anatomic length of the forearm was measured on the radiograph of the uninjured arm. Radiograph of the operated arm was also taken intraoperatively. The graft length was calculated by extraction of the length of the distal and proximal parts of the bone from the anatom-

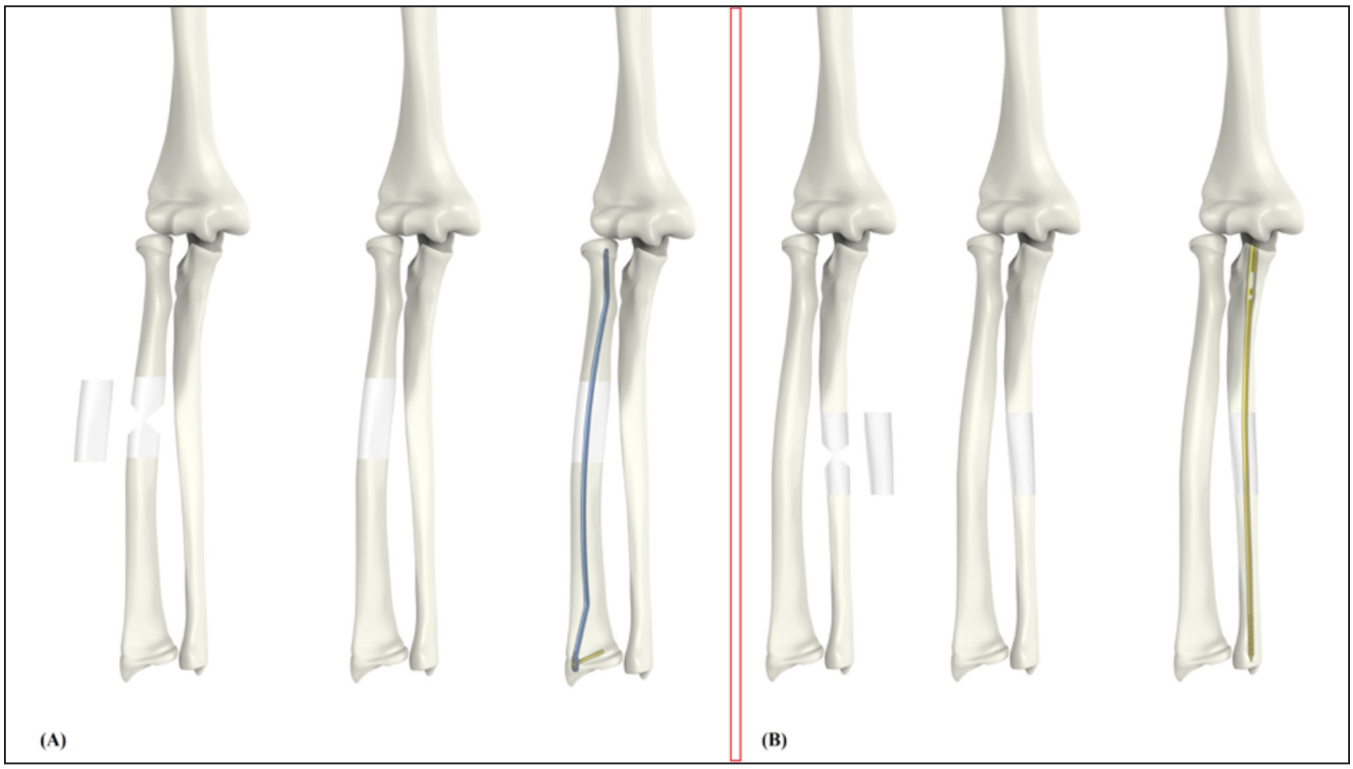

Figure 1. Fixation of radius or ulna non-union with 3rd generation intramedullary (A) radius and (B) ulna nails and tricorticocancellous iliac bone graft.

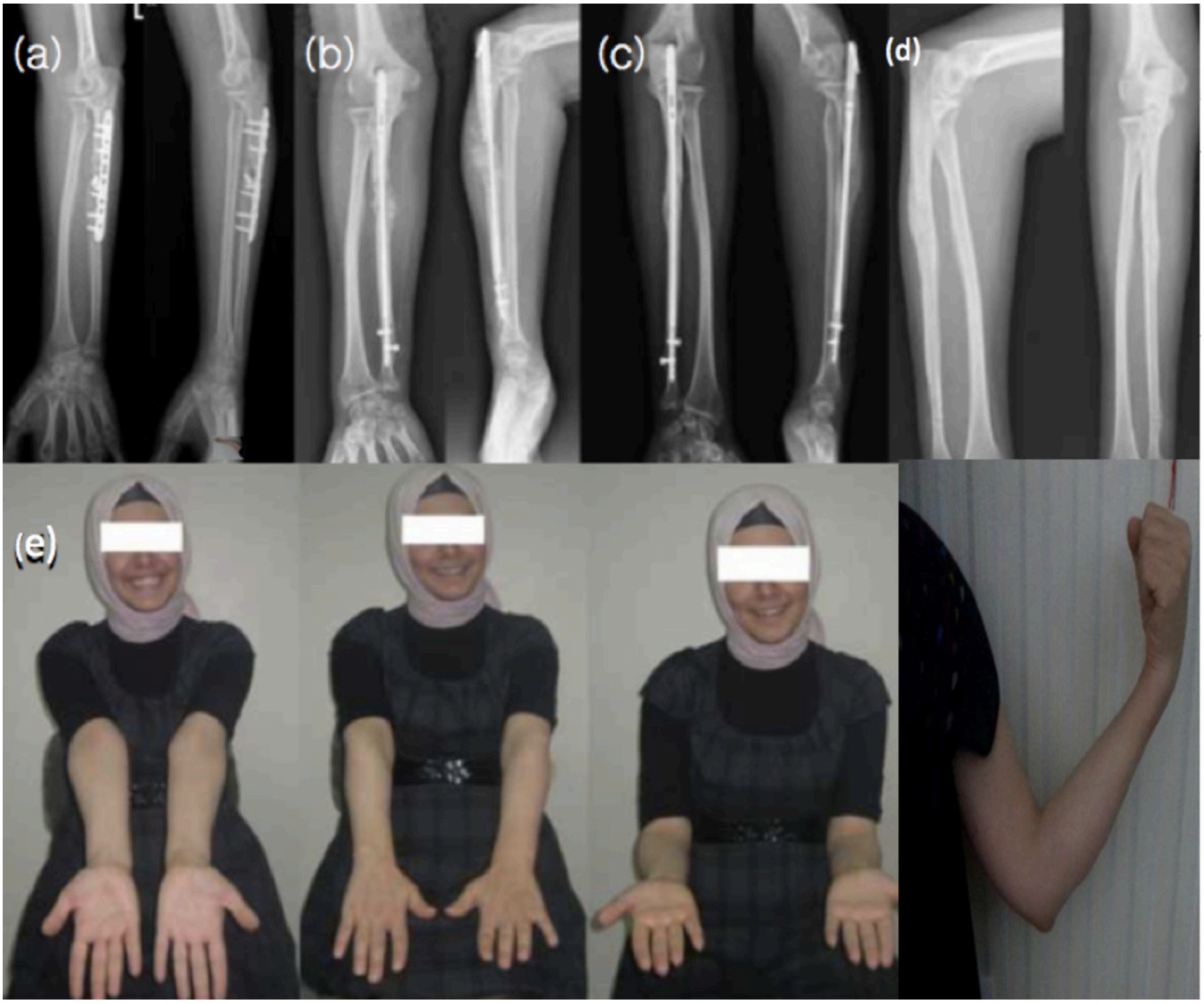

Figure 2. a) 24 –year old female patient with left ulna diaphyseal fracture as a result of a fall during ice-skating. At 9 months after the first treatment of ORIF **b)** Direct AP and lateral radiographs on postoperative Day 1 after the application of tricorticocancellous autograft and locking ulna nail because of ulna non-union **c)** Direct AP and lateral radiographs at 12 months after union **d)** Direct AP and lateral radiographs after removal of the implant at 2 years after union **e)** Photographs showing functions of the elbow and forearm of the patient (extension, pronation, supination, flexion).

ic length. Radial bowing was determined according to the radial length, maximum radial bowing, and localization of the healthy forearm. 3D CT view is used for templating before the surgery. Length and shape of the graft was templated according to the length and tridimensional shape of the sclerotic, atrophic bone tissue, evaluated with the CT and direct X-ray views. After proper debridement of the sclerotic bone and fibrotic tissue intraoperative X –ray views of the operated arm was taken. The proper iliac bone graft is harvested according to the maximum radial bowing and localization on intraoperative X-rays. The gap between the bone fragments was calculated with the use of a sterile duler in traction of the forearm. A block graft which is 2mms longer the measured gap is harvested from the iliac wing in order to provide compression in the graft-bone interface. Holes of the same diameter as the nails were opened in the tricorticocancellous iliac bone graft with a drill. In cases with ulnar non unions, a 2 cm longitudinal skin incision was performed from the apex of

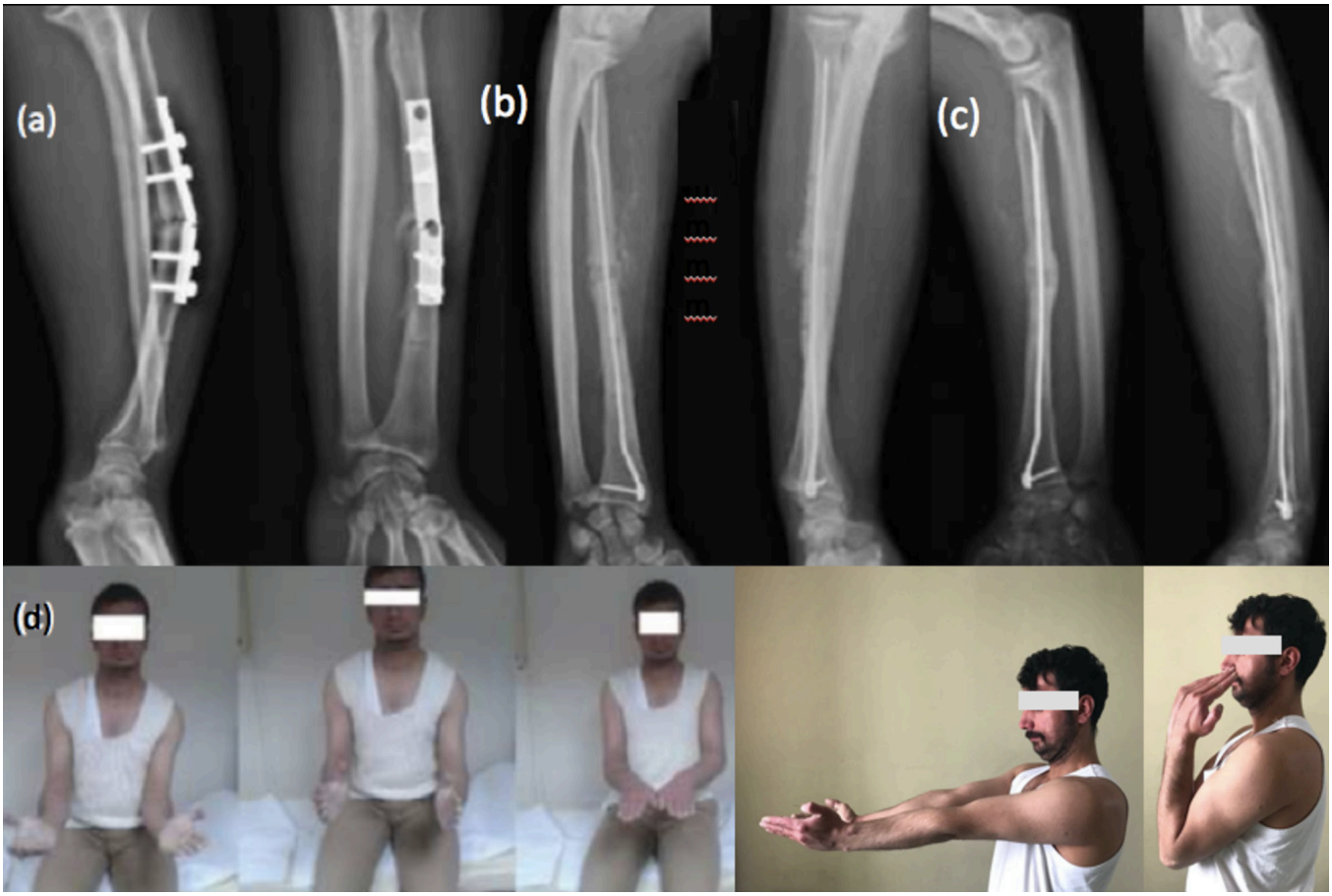

Figure 3. a) 29 –year old male patient with left radius diaphyseal fracture as the result of a simple fall. At 26 months after the first treatment of ORIF **b)** Direct AP and lateral radiographs on postoperative Day 1 after the application of tricorticocancellous autograft and locking radius nail because of radius non-union **c)** Direct AP and lateral radiographs at 14 months after union **d)** Photographs showing functions of the elbow and forearm of the patient (extension, pronation, supination, flexion).

the olecranon The triceps tendon is bluntly dissected and the bone is exposed. 2,0 mm K wire is placed intramedullary at the apex of the olecranon. First 5 cms are drilled with a cannulated drill over the K wire. The nail is advanced with gentle rotational maneuvers. For the radius nail, a 1-1,5cm longitudinal incision is done over the Lister's tubercle at the dorsolateral side of the forearm. Blunt dissection is carried out until clear exposure of the Lister's tubercle can be achieved. Extensor carpi radialis longus and Brevis tendons are exposed. A bent awl is used for the first entry in line with the second extensor compartment. Predetermined radial nail is advanced into the bone.

Fixation was done by placing the intramedullary nail in the hole opened in the graft and the bone (Figure 1). Distal static locking of the radius nails and proximal compression and distal static locking of the ulna nails have been performed.

Postoperative Protocol

Long-arm splint immobilization was done to all of the patients for 4 weeks postoperatively. During the first 4 week of splint immobization period, daily removal of the splint with passive ROM exercises to the elbow and wrist have been performed under the supervision of a physiotherapist. After 4 weeks, the splint was removed and passive ROM exercises were started and kept on for 2 weeks with the use of Mayo orthosis. After 6 weeks, controlled supination and pronation was permitted, but it was recommended to avoid heavy activity and carrying loads. Follow-up examinations were

made weekly for the 1st month and monthly thereafter. Radiographic examination was done monthly until radiological union was seen and functionally normal forearm movements were obtained.

Statistical Analysis

Statistical analysis was performed using Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA). 17.0 software. Data were stated as number (n), percentage (%) mean and standard deviation (SD). Conformity of the data to normal distribution was analysed with the Kolmogorov-Smirnov test. The relationship between independent variables was analysed with the Paired Samples t-test. A value of $p<0.05$ was considered statistically significant.

Results

The mean time to union was 18 weeks (range, 12-24 weeks). Graft consolidation and union was observed in all patients (Figure 2, Figure 3). No lysis in the graft, implant loosening or failurewas observed in any patient. In 1 case with ulna fracture, at 2 years after union the implant was removed at the patient's request. No complications were seen during or after the operation. No early or late stage infection was observed.

The maximum radial curve and localisation of the treated and the healthy radius bones were determined as 2.04±1.24 mm ($p=0.026$; $p<0.05$) and 3.7%±1.3% ($p=0.034$) respectively and the difference was statistically significant. No statistically significant difference was determined between the treated and the healthy extremities in respect of radial length. No statistically significant relationship was determined between the healthy and the treated forearms in terms of maximal radial curve (MRC), maximal radial curve localisation (MRCL), supination and the pronation range of motions and grip strength (Table 3). The other clinical and functional results of the patients are summarised in Table 4.

According to the Grace-Eversmann scores, 9 patients were evaluated as excellent and 3 as good. Overall, the mean DASH score was 15.5 and the mean VAS score was 1.5 (Table 2). There were no complications about the donor site of the autogenous iliac graft.

Discussion

Radius and ulna non-union is rarely seen following primary treatment and there is no gold standard accepted treatment method. The treatment results affect not only the forearm, but the whole upper extremity. Therefore, potential complications which could develop lead to serious problems [19-21]. Several different treatment methods have been applied in the treatment of forearm atrophic non-union. These include compression plate with iliac bone graft, intramedullary nailing, compression plate with cancellous bone graft, Ilızarov distraction technique, vascularised fibula grafting, regional vascularised bone grafting and fibula autografting with compression plate. The success of the treatment method selected is associated with factors such as the gap distance, graft type, surgical fixation material and the postoperative immobilisation period [24-32]. Therefore, appropriate preoperative planning is necessary. Although there are differences in surgical treatment, the main aim is to provide forearm length appropriate to the anatomy and maintain stability. It is aimed to obtain satisfactory functional forearm outcomes with early mobilization [31,32].

In the surgical treatment of atrophic non-unions,

Table 3. The statistical relationship between MRC and MRCL values and functional results.

	Pronation		Supination		Grip Strength		DASH	
	t	p	t	p	t	p	t	p
MRC	-0.35	0.965	-0.63	0.937	-149	0.851	-1.279	0.291
MRCL	-372	0.628	-216	0.784	-045	0.955	-20.054	0

Table 4. A comparison of the treatment applied to forearm non-union with intramedullary nailing and autograft in studies in literature with the current study.

	Hong et al.	Krzykawski et al.	Current study
Age	42.3(26-58)	32 (19-59)	37 (24-55)
Gender	11M-4F	11M- 3F	8M-4F
Side	9R-6L	Null	5R-7L
Bone with non-union	4 Ulna 11 both bones	4 Ulna 3 both bones 7 Radius	8 Radius 4 Ulna
Gap	20 mm (10-30)	1-5 cm	1-2.5
Time to revision	15 months (6-42)	Null	15.4 (6-26)
Mean MRC operated/ healthy	16mm	Null	13.13/15.18
Mean MRCL operated/ healthy	60%	Null	56.78% / 59%
Time to union	R 14 weeks (12-16) U 15 weeks (12-20)	26 weeks (12-36)in 7 patients 33 weeks (26-40)in 4 patients 28 weeks (19-37) in 2 patients 1 infected patient > 40 weeks	18 (12-24)
Pronation	66° (34°-88°)	10 patients full range 4 patients 30° loss	82 (70-90)
Supination	61° (21°-88°)	10 patients full range 4 patients 40° loss	83.3 (75-90)
DASH	35 (16-56)	Null	15.5
Grace-Eversmann	null	Null	8 excellent 4 good
Complications	2 screws moved back 1 non-union	1 patient – locking problem 1patient – nail breakage	None
Grip strength	null	Null	52.9 (32-80)
Radial length operated/ healthy	null	Null	20.08/20.45
Graft type	15 tricorticocancellous 11 cancellous	Tricorticocancellous	Tricorticocancellous
Conclusion	Interlocking IM nailing of non-unions of the diaphysis of the radius or ulna with an open reaming technique should not be considered an adequate alternative to plate fixation for these injuries.	Technically simple, does not require external fixation and allows early post- operative rehabilitation.	Can be used as an alternative method to plate-screw osteosynthesis in suitable patients with a bone defect of <2.5cm.

the common stages that are required in all the treatment methods are the vitalisation of the fracture ends, debridement and removal of material. There is no consensus on the subject of graft and implant selection. Autografts are the most often preferred grafts as there is no risk of immune reaction. Although allograft and xenograft carry no risk of donor site complications, they are not preferred because of the risks of infection and immunereaction. The iliac wing is most frequently used for autogenous bone graft. According to the gap distance, tricorticocancellous graft is often preferred [19,21,32]. It is recommended that the length of the autograft harvested from the iliac wing does not exceed 5cm in isolated radius or ulna atrophic non-union [33]. We did not have any problems during implant removal.

Loss of compression of the graft-bone interface impairs union and remodeling. Graft union and remodelling has been reported to be delayed in application of

autograft of more than 3cm [33]. In addition, the iliac wing anatomic curvature increases after 3 cm. Graft which are longer then 3cms has more bowing which results in graft failure because of insufficient compression and remodeling of the graft [21,33]. Due to the aforementioned issues, Nicolls method is not suggested in cases with defects longer than 3 cms. In the current study, patients were not included if the gap was measured radiologically and surgically less than 2.5 cm. No infection was observed postoperatively in the donor site or in the forearm of any patient. No graft failure or non-union was observed in any patient.

The most frequently used and accepted method in the treatment of atrophic non-union is plate-screw osteosynthesis. When non-union results from the primary treatment, plate and screws must be removed. Extensivesoft tissue injury and periosteal stripping of the fracture impairs the damaged vascularity even more. Furthermore, osteoporosis in the fracture site and around the screws negatively affects the stability of the plate-screw osteosynthesis for in the reciew surgeries. Intramedullary nailing fixation is often used in cases of non-unions of lower extremity long bones. However, it is not often used in forearm non-unions. Stable fixation is obtained with 3rd generation locking forearm nails which are highly resistant to torsional forces [2-4,34]. Due to the stress distribution property of intramedullary implants, periosteal callus formation is increased. They do not disrupt vascular and periosteal circulaton. As force distribution is spread equally along the whole bone, the duration of immobilisation and the need for additional fixation material are decreased [6,8,9,18].

Restoration of the radial curve is recommended to obtain superior functional forearm results in isolated radius non-unions [7]. The autograft can be designed appropriate to the radial curve with preoperative radiological and perioperative surgical planninng. While the gap is compressed, concomitant restoration of the radial curve is important. A proper graft can be harvested by doing the osteotomy in the iliac wing according to the principles and meticulous measurement. Schemitsch and Richards [7] compared the radiological MRC and MRCL values with the values of the healthy forearms. It was shown that >4.3% loss of MRCL and >1.55cm loss of MRC compared to the healthy forearm measurements affected forearm rotation negatively There are several articles which imply that not having an anatomic radial bowing does not affect functional outcomes [1,6]. In the current study, despite the significant difference between the forearm MRC and MRCL values of the treated and healthy sides, there were no statistically significant difference between the functional scores (DASH and ROM values of the elbow and forearm).

There are few studies in literature on intramedullary nailing and autograft for forearm atrophic non-unions. Zykawski et all [33] applied this method to 14 patients with a mean graft length of 1-5 cm. In that series, union was reported in mean 26 weeks (range, 12-36 weeks) in 7 patients with isolated radius fracture, in mean 33 weeks (range, 26-40 weeks) in 4 patients with fractures of both bones and in 19 and 37 weeks respectively in 2 patients with a graft length >5cm. Elbow and wrist functions were reported to be sufficient in all patients. Hong et all [32] treated 26 cases of forearm non-union with iliac bone graft and intramedullary nailing. The mean time to union in that study where the gap was 1-3cm was 14 weeks for isolated radius non-union and 15 weeks for the ulna. In respect of function, the results obtained were excellent in 2 patients, sufficient in 6 and insufficient or poor in 7. In the current study, the treatment was applied with full thickness tricorticocancellous autograft and new generation radius and ulna intramedullary nails. Union was obtained in these patients where the gap was 1-2.5cm. As a consequence of rigid fixation, splint immobilisation was finished in a short time and early movement was applied. Functionally, the range of joint movements and grip strengths obtained were normal. The patients were able to comfortably undertake routine activities without disruption to their daily activities. The comparison of the de-

mographic and statistical data of this study with other studies is presented in Table 3.

Despite the current various treatment methods and fixation materials that have been developed, forearm atrophic non-union remains a serious problem for both patients and surgeons. The radiological and functional results of the treatment depend on several parameters. The type of surgical treatment and the fixation materials used are the main factors determining the efficacy of the treatment. A gold standard treatment method and rehabilitation in forearm atrophic non-unions remains a matter of debate [15-21,24,33]. Therefore; there is a need for further prospective, randomised studies with larger patient series on isolated radius or ulna atrophic non-unions and atrophic non-unions of both bones.

Clarification is needed for a treatment algorithm to be formed to answer the questions of the effect of the time from first surgery on the choice of treatment, the type of graft (full thickness, vascularised graft) to be selected according to the gap distance, the type of implant (plate-screw osteosynthesis, intramedullary nailing), the need for and duration of additional fixation material (plaster cast, splint, external fixator), the duration of immobilisation and when active and passive motion should be started. Primary surgical treatment has a significant role in the development of non-union. Orthopaedic surgeons must obey the rules of osteosynthesis, without leaving anything to chance, in the primary treatment of forearm fractures. The basic aim must be to reduce the risk of the development of non-union to a minimum.

There were some limitations to this study, including the low number of patients, the retrospective nature of the study, use of different implants in the primary and revision surgeries, and, use of grafts with different lengths ranging from of 1-2.5cm. Further prospective, randomised, controlled studies made with different grafts and fixation materials on similar subgroups (groups with similar bone defects) would help to form a consensus on this subject.

Conclusion

In cases of isolated radius and ulna non-union with a bone defect (gap) of <2.5cm, the tricorticocancellous autografting and intramedullary nailing with a modified Nicoll's method is a safe treatment method which provides more rigid fixation, does not require prolonged immobilisation and allows early rehabilitation. Even though the number of patients is low in our series; we can conclude that it is a method which can be used as an alternative to plate-screw osteosynthesis in a selected patient group with <2.5cm bone defect.

Conflict of interest statement

The authors have no conflicts of interest to declare.

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