ORIGINAL ARTICLE

Acta Orthop Traumatol Turc 2014;48(3):262-270
doi: 10.3944/AOTT.2014.3259

Treatment of diaphyseal forearm atrophic nonunions with intramedullary nails and modified Nicoll's technique in adults

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Objective: The aim of this study was to evaluate the outcome of tricorticocancellous autologous bone grafting with intramedullary forearm nails in the treatment of radius or ulna aseptic nonunion.

Methods: The study included 8 patients (mean age: 39 years; range: 19 to 55 years) who underwent plate-screw osteosynthesis for the treatment of nonunion (6 ulna, 2 radius) following forearm fracture. In all cases, the length of the applied tricortical graft was below 3 cm. Patients were evaluated using the visual analog scale, Grace and Eversmann scale and DASH score. Wrist flexion and extension and postoperative hand and forearm grip strength were assessed.

Results: Graft incorporation and union was completed at a mean of 22 (range: 18 to 28) weeks. No patient had nonunion, deep infection or radioulnar synostosis. Follow-up ranged from 18 to 52 months. Radiographic union was achieved in all patients. Mean visual analog scale pain score was 1 (range: 0 to 3). Grace and Eversmann ratings were excellent in 5 and good in 3 patients. Mean DASH score was 10.7 (range: 1.7 to 21.7) points.

Conclusion: Intramedullary nailing and tricorticocancellous iliac bone block grafting appears to be a technically easy and reliable procedure that enables early postoperative rehabilitation in the treatment of nonunion of the forearm.

Key words: Forearm; intramedullary nail; nonunion; tricorticocancellous bone graft.

Aseptic radius and ulna nonunions are rare complications of diaphyseal fractures of the forearm. Typical rates reported for forearm nonunions in large series range between 2 and 10%.[1-3] Nonunions of the forearm diaphysis cause severe anatomic and functional impairment related to disturbance of the interosseous membrane and dysfunction of the adjacent joints, elbow and wrist.[4-7] The management of nonunion with bone gap following forearm fractures is an important problem. Despite new surgical techniques and instruments, results are not completely satisfactory and debate regarding the optimal technique continues.[1,6,8-12]

Many surgical procedures have been described in the literature.[13-19] Additionally, numerous studies have been published regarding the treatment of forearm nonunions with a wide variety of surgical options (Table 1). The

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Submitted: April 15, 2013 **Accepted:** April 24, 2014

Available online at
www.aott.org.tr
doi: 10.3944/AOTT.2014.3259
QR (Quick Response) Code

Table 1. Studies of surgical options for treatment of forearm nonunions.

Year of study	Authors	Surgical options
1954	Spira[16]	Iliac graft fixed with an intramedullary nail
1956	Nicoll[17]	Cancellous bone graft and plate fixation
1971	Dabezies et al.[37]	Iliac bone graft fixed with plate
1972	Ilizarov et al.[38]	Ilizarov bone transport technique
1979	Müller et al.[39]	Compression plate combined with bone graft
1989	Williamson et al.[40]	Vascularized fibular graft
1991	Tetsworth et al.[18]	Lengthening and deformity correction of the upper extremity by the Ilizarov technique
1995	Moroni et al.[9]	Intercalary autograft and opposite allograft fixed with a plate
2004	Ring et al.[10]	Iliac intercalary autograft and compression plate
2006	Hong et al.[23]	Iliac bone graft and interlocking intramedullary nail
2009	Faldini et al.[28]	Plate with opposite and intercalary fibular autograft
2013	Kamrani et al.[41]	Regional vascularized bone graft

aims of surgical treatment of forearm nonunions are to provide proper bone length, restore the anatomy of the forearm and improve function. Closed locked nailing is successful in treating femoral, tibial, and humeral shaft nonunions.[20-22] However, little has been published on treating nonunions of a diaphyseal fracture of the radius or ulna with an interlocking intramedullary (IM) nail.[12,16,23]

In 1956, Nicoll proposed a new treatment method for forearm pseudarthrosis with bone loss.[17] In this method, a tricorticocancellous iliac graft is fixed with a plate-screw in the forearm nonunion area. In our study, the classical Nicoll method was modified to remove the disadvantages of plate-screw fixation by using IM nail and tricorticocancellous block iliac crest graft. However, the use of conventional interlocking nails presents several complications, including distal locking in the ulna. The forearm IM nails that we used in the modified Nicoll's technique for fixation were preferred due to several advantages; they are minimally invasive and provide better biological fixation and optimal rotational stability and the forearm muscle contractions allow dynamic axial compression provide a positive contribution to the union.

The aim of our study was to assess the outcomes of the modified Nicoll's technique using a corticocancellous graft block and IM radius or ulna nails in nonunions with radial and ulnar bone loss (Fig. 1).

Fig. 1. Illustration of fixation of radius and ulna nonunions with the intramedullary **(a)** radius and **(b)** ulna nails and tricorticocancelleous iliac bone graft. [Color figure can be viewed in the online issue, which is available at www.aott.org.tr]

Patients and methods

The study included 8 patients (5 males and 3 females; mean age: 37 years; range: 19 to 55 years) with nonunion of the forearm treated between January 2008 and September 2011. Of these, 6 patients had ulnar and 2 radial nonunion with bone gap. All patients had received prior treatment with plate-screw osteosynthesis at a different clinic prior to admission in our department. The primary injury mechanism included traffic accidents in 5 cases, falls in 2 and industrial injury in 1. One patient had an open fracture at the time of initial injury. The mean time between the treatment of initial fracture and surgical treatment of the nonunion was 18 (range: 9 to 42) months. Mean length of hospital stay was 5 (range: 4 to 7) days. Mean follow-up period was 32 (range: 18 to 52) months. In all cases, the length of the applied tricortical graft was below 3 cm after debridement. Written informed consent was obtained from all patients.

Inclusion criteria were; an atrophic nonunion with a segmental defect measuring between 0.5 and 3 cm in length, treatment with autogenous tricorticocancellous bone grafting, absence of other fractures in the same limb at the time of the primary forearm injury, and no infection after the primary fracture. Atrophic nonunion was defined as an unstable fracture with no signs of healing at a minimum of four months after the injury. Patients with hypertrophic or infected nonunions were excluded.

All nonunions were stabilized using interlocking IM forearm nails (TST Rakor Tıbbi Aletler San. ve Tic. Ltd. Şti., Istanbul, Turkey). Made from a titanium alloy, the radius nail has a parabolic body. Its distal end is angled anteriorly at 15° and the proximal end is angled anteriorly at 10°. The design of the proximal and distal ends provides rotational stability and restores radial bowing. Distal static locking can be achieved with a locking screw. The proximal 3 cm of the nail is oblong and angled anteriorly at 10°.

The ulna IM nail is solid, round and unreamed. Distal locking can be achieved by one or more locking screws passing through the eight transverse grooves on the distal 3 cm of the nail. The nail allows for static, dynamic and single-cortex interlocking by round, oval and proximal oblique holes. Transverse, lateromedial and posteroanterior dynamic interlocking can be made through the oval hole, which allows for a 7-mm compression 30 mm distal to the proximal part of the nail. Transverse, lateromedial and posteroanterior static interlocking at 40 mm distal from the proximal nail can be achieved through the round hole.

All patients were operated under general anesthesia. The length of the contralateral forearm bone was measured radiographically in order to correctly restore the length of the damaged bone correctly. Following exposure of the nonunion site, fibrotic tissues and sclerotic bone ends were excised. In all cases, the medullary canal was opened using a drill to ensure bone bleeding. A gentle traction and countertraction was given to measure the gap between the bony fragments. The iliac crest was exposed anteriorly and a tricorticocancellous iliac crest bone block was harvested. Tricorticocancellous iliac bone block graft was reamed to the diameter of the nail. Finally, the corticocancellous bone block was placed to fill the gap and fixed with the IM nail. Under traction, a graft approximately 2 to 3 mm longer than the defect length was placed to fill the gap. After traction, the IM nail passing through the graft was placed under optimum compression provided by the soft tissue. Bone blocks were stabilized with radius or ulna IM nails. Proper length was determined using an intraoperative image intensifier. A first-generation cephalosporin was used in all patients and was continued for 72 hours. Arms were immobilized in a cast for the first 2 postoperatively weeks. Patients were advised to move their arms gently and not to lift heavy weights for 3 to 4 months. Patients were followed-up once a month until radiological union occurred.

Postoperative radiological and functional outcome was evaluated on radiographs taken on a monthly basis after revision surgery. Bony union was defined as the presence of a minimum of three bridging cortices in plain X-rays of the forearm in anteroposterior and lateral views, and absence of pain at the nonunion site. Clinical bone union was defined as a non-tender fracture site. The degree and location of the maximal radial bow were determined using criteria described by Schemitsch and Richards.[4]

Postoperative pain was evaluated using the visual analogue scale (VAS) scored from 0 to 10 with 0 representing the 'absence of pain' and 10 'maximum pain'.[24] Functional outcome was assessed with the Grace and Eversmann rating system,[25] which is based on union and rotation of the forearm. Patient-reported outcomes were assessed using the Disabilities of the Arm Shoulder and Hand (DASH) questionnaire scores.[26] Wrist flexion and extension were measured with a goniometer.

Postoperative hand and forearm grip strength were measured using a hydraulic hand dynamometer (Baseline®; Chattanooga Group, Hixon, TN, USA). Grip strength was measured with the patient seated, the shoulder in adduction and neutral rotation, the elbow flexed at 90º, and the forearm and wrist in the neutral

position. The average of three measurements was recorded. Measurements were taken at least 2 minutes after the previous application to avoid muscle fatigue.[27] The uninjured forearm was used as a control for each patient. The degree of strength lost during surgery was calculated as the difference between measurements of the injured and uninjured forearm.

At the final follow-up, clinical and functional results were evaluated. Diagnosis of nonunion was based on clinical and radiologic findings.

Statistical analysis was performed using the NCSS Statistical Software (Number Cruncher Statistical System, 2007 & PASS 2008, Utah, USA). Non-normally distributed independent variables were compared us-

Fig. 2. **(a)** Anteroposterior and lateral radiographs showing atrophic nonunion of the radius in a 38-year-old man. **(b)** Anteroposterior and lateral postoperative radiographs showing a tricortical graft and fixation with radius intramedullary nail. **(c)** Complete remodeling of the grafts was evident at the 18th month follow-up.

Fig. 3. **(a)** Anteroposterior and lateral radiographs showing bone defect, implant failure and isolated atrophic nonunion of the ulna in a 55-year-old man. **(b)** Anteroposterior and lateral radiographs taken 3 months after surgery. Signs of bone healing are evident. **(c)** Complete remodeling of the grafts at the 18th month follow-up.

Table 2. Details of patients treated for nonunion of the radius or ulna by the modified Nicoll bone grafting and intramedullary forearm nails.

Patient	Age/Sex	Side	PIM	Pain (VAS)	Bone	Gap (mm)	ADLL	GSL (pound) Un./Op.	DASH score	GES	FP (months)	TU (weeks)	Flex./Ext. (elbow) Op.	Flex./Ext. (wrist) Op.	Pron. Right/Left	Supin. Right/Left	MRB Un./Op.	L MRB Un./Op.	Radial length Un./Op.
1. BH	38/M	Left	Traffic accident	1	R	30	No	95/80	14.2	Good	18	28	130/Full	40/75	90/70	90/50	15.47/13.15	60.91/61.57	23.45/23.06
2. AC	42/M	Left	Fall	0	R	20	No	108/108	1.7	Excellent	27	18	130/Full	45/65	90/50	90/90	15.85 / 9.32	59.88/53.48	20.97/20.0
3. AD	34/F	Right	Traffic accident	2	U	15	Slight	88/80	12.9	Excellent	22	18	130/Full	60/70	65/90	70/90	15.33/13.97	61.78/59.52	21.11/20.86
4. FA	53/F	Left	Traffic accident	2	U	25	Slight	85/80	15.2	Good	20	22	120/Full	80/80	90/70	90/90	15.82/14.12	61.48/59.12	21.18/20.32
5. MG	55/M	Left	Endustrial injury	2	U	20	Slight	103/75	18.2	Excellent	37	20	130/Full	40/70	90/50	90/80	17.59/17.06	60.79/61.57	21.01/20.65
6. TO	37/M	Left	Traffic accident	1	U	10	No	135/115	1.7	Excellent	52	21	120/Full	80/80	90/90	90/60	16.66/15.70	66.10/60.12	19.83/20.92
7. TK	19/M	Left	Fall	1	U	5	No	97/102	0	Excellent	36	26	130/Full	80/90	80/90	90/90	15.6/15.6	57.57/56.39	23.5/23.5
8. AU	38/F	Right	Traffic accident	2	U	15	Slight	84/65	21.7	Good	51	24	120/Full	45/65	50/90	85/90	13.79/13.79	61.90/61.11	18.10/18.44

ADLL: Activities of daily living limitation (no, slight, severe), DASH: Disabilities of the Arm Shoulder and Hand, Ext: Extension, F: Female, Flex: Flexion, FP: Follow-up period, GES: Grace-Eversmann score, GSL: Grip strength limitation, L MRB: Location of maximal radial bowing, M: Male, MRB: Maximal radial bowing, Op: Operated, PIM: Primary injury mechanism, Pron: Pronation, R: Radius, Supin: Supination, TU: Time of union (weeks), U: Ulna, Un: Uninjured, VAS: Visual analog scale.

ing the Wilcoxon rank-sum tests and the relationship between grip strength, pronation, and supination with maximal radial bowing degree and location was assessed using Pearson's correlation coefficients. The Spearman's correlation coefficient was used for the analysis of the relationship between the parameters. Significance level was set at $p<0.05$ and all tests were two-tailed.

Results

There were no intraoperative or postoperative complications and no early or late infections. Average union time was 22 (range: 18 to 28) weeks for all patients. At the final follow-up, all forearm bones had remodeled (Figs. 2 and 3). There were no cases of implant loosening or breakage. None of the patients had hardware removal after consolidation. Final range of motion details are summarized in Table 2.

Radiographically, union occurred in all the patients between 18 and 28 (mean: 22.13±3.64) weeks. The mean amount and location of the difference in the maximum radial bow between the injured and uninjured side were 1.67±2.12 mm ($p=0.028$; $p<0.05$) and 2.19±2.73% ($p=0.036$; $p<0.05$), respectively. These differences were statistically significant. The difference in radial length measurements between the uninjured and injured extremities was not statistically meaningful (Table 3). There was no statistically significant relationship between maximal radial bowing and location of the maximal radial bowing levels and grip strength in the injured side (Table 4). Additional clinical and functional results of the patients are summarized in Table 3.

According to the Grace and Eversmann scores, 5 patients had excellent and 3 good results. Overall mean DASH score was 10.7 and mean VAS score was 1.5 (Table 2).

Discussion

Aseptic nonunion is a rare complication in the management of forearm fractures. Nonunion can be caused by factors such as comminuted or segmental fractures, bone defects, interposition at the fracture site, disruption of the blood supply in the fracture fragments, inadequate stabilization and local infection.[6,7,28,29] Forearm nonunions may lead to crucial functional problems in the elbow and wrist joint and interosseous membrane. Treatment of forearm nonunions is a debated topic and many surgical techniques have been described (Table 1). The success of treatment in a forearm nonunion with bone gap relies on many clinical parameters such as the length of delay from initial injury, the number of previous surgical interven-

Table 3. Outcomes of the patients treated with forearm intramedullary nails.

Variable	Injured Forearm (n=8)
Mean time to union, weeks (range)	22 (20-28)
Range of motion at last follow-up, degrees (range)	
Supination	78 (50-90)
Pronation	68 (50-90)
Maximal radial bowing, mm (SD)	
Fractured forearm	14.09 (2.31)
Normal forearm	15.76 (1.09)
Location of maximal radial bowing, mean % (SD), [range]	
Fractured forearm	59.11 (2.84) [53.48-61.57]
Normal forearm	61.30 (2.39) [57.57-66.1]
Grace and Eversmann score	
Excellent	5
Good	3
DASH score, mean (range)	10.7 (2.7-21.7)
Difference in grip strength, mean (SD)	
Fractured forearm	85.6 (20.3)
Uninjured forearm	99.4 (16.7)
Mean radial length, cm (SD)	
Fractured forearm	20.9 (1.63)
Uninjured forearm	21.1 (1.77)
Mean wrist extension, degrees (range)	74 (65-90)
Mean wrist flexion, degrees (range)	59 (40-80)

tions, the presence of infection, the length of the bone gap and, finally, the type of fixation methods. Surgical treatment aims to regain proper length, restore the anatomy and recover function of the forearm.[23]

Hong et al.[23] reported the results of 26 forearm nonunions in 15 patients treated with open reamerization, iliac bone grafting and ForeSight® IM nails. Mean bone loss for all patients in their series was 20 (range: 10 to 30) mm. The authors reported radiographic union in 14 patients (93%). Mean union time for the radius and ulna were 14 and 15 weeks, respectively. However, functional results were excellent in 2, sufficient in 6 and inadequate and poor in 7 patients. The mean DASH score in this series was 35 points; the authors reported that this value showed moderate residual regurgitation. Therefore, the authors did not propose this technique as an alternative to a plate-screw osteosynthesis.[23,29]

In a series with 14 patients, Krzykawski et al.[30] reported an average graft length of below 5 cm. Graft incorporation and bone healing occurred between 26 and 33 weeks for single-bone nonunions and after the 33rd week in the forearm double-bone nonunions. The authors reported that elbow and wrist functions of all patients in their series were sufficient.

Table 4. Relationship between the postoperative degree of maximal radial bowing and the location of the maximal radial bow with grip strength in forearms with factures treated with forearm intramedullary nail.

	Grip strength (operated)		Grip strength (uninjured)	
	r	r	r	p
Maximal radial bowing, mm (operated)	-0.024	0.955	–	–
Location of maximal radial bowing, % (operated)	-0.331	0.423	–	–
Maximal radial bowing, mm (uninjured)	–	–	0.786	0.021*
Location of maximal radial bowing, % (uninjured)	–	–	-0.234	0.570

r: Spearman's correlation coefficient. *p<0.05

One of the important factors in functional success is the restoration of radial bowing. Schemitsch and Richards reported that patients in whom the maximum radial bow was within 1.5 mm of that in the normal arm or in whom the location of the maximum radial bow was within 4.3% of the normal arm had a significantly better active arc of forearm motion ($p<0.05$).[4] In Case 2 in our series, the maximal radial bow value was 6.53 mm and the difference in location of the maximal radial bow was 10.7% between the injured and uninjured sides. Despite these higher values, this patient's functional result was evaluated as excellent.

Interlocking IM nailing has been used successfully in treating nonunions of the long bones such as the humerus, femur and tibia.[20-22,31] Plate and screw fixation is the most commonly used method for diaphyseal nonunions.[32] However, plate osteosynthesis causes disruption of the periosteal blood supply which can prevent periosteal revascularization.[33] Furthermore, osteoporosis at the nonunion site may decrease the strength of purchase of the screws holding the plate, resulting in inadequate fixation.[9] The IM nailing technique results in less damage to the soft tissues and vascular supply compared to open techniques. In addition, unlike removal of plate and screws that require major surgery, the removal of the nail is a minor procedure and does not require exposure of the grafted area. Unlike a compression plate, an IM nail is stress-sharing rather than stress-shielding, which leads to peripheral periosteal callus that may produce a stronger fracture union.[12,34]

Autogenous bone grafting is often performed in orthopedic surgery for the treatment of nonunions. The iliac crest is the most common donor site for obtaining autogenous bone graft. Autografts do not have any risk of immunological response and transfer of disease. A review of the literature suggests that nonunions of the ulnar and radial diaphyseal defects of up to 6 cm can be treated with autologous cancellous bone grafts.[10] The Nicoll technique is recommended only in the absence of infection and if the bony gap does not exceed 50 mm.[35] Nicoll's bone grafting technique is less successful in treating long defects, especially defects longer than 60 mm.[35] Iliac grafts, which are longer than this, make it difficult to obtain adequate compression due to the curve of the bone. The success of this technique depends on the consolidation of the corticocancellous bone graft. The prolongation of graft incorporation is proportional to the extent of bone defect. The slowest graft incorporation and bone remodeling is seen with bone grafts longer than 3 cm.[36] In our series, none of the patients had an implant or graft failure.

All the patients treated for diaphyseal forearm aseptic nonunion in our study achieved bone healing using the described approach. The length of the iliac bone graft segments ranged from 0.5 to 3 cm. There was a high success rate regarding forearm alignment and functional results and all patients were able to return to daily activities. Functionally, all patients had a better range of motion and grip strength than before surgery. However, there were several limitations to this study, including the relatively small number of patients, the different implants used for primary fracture fixation and the small (less than 3 cm) length of graft material used.

In conclusion, the modified Nicoll's technique using IM nails and iliac bone block graft appears to be effective for the treatment of aseptic diaphyseal forearm atrophic nonunions. This technique allows for early postoperative rehabilitation and does not require additional external support. These nails offer a promising alternative to standard plate-screw osteosynthesis in the treatment of nonunions.

Conflicts of Interest: No conflicts declared.

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