

Research Article

Comparison of the clinical and radiographic outcomes of plate fixation versus new-generation locked intramedullary nail in the management of adult forearm diaphyseal fractures

Oktay Polat¹, Serdar Toy²¹Clinic of Orthopedics and Traumatology, Sultanbeyli State Hospital, İstanbul, Turkey²Clinic of Orthopedics and Traumatology, Basakşehir Çam and Sakura City Hospital, İstanbul, Turkey

ARTICLE INFO

Article history:

Submitted May 8, 2021

Received in revised form

March 12, 2022

Last revision received

September 4, 2022

Accepted October 2, 2022

Publication Date October 19, 2022

Keywords:

Forearm

Internal fixation

Intramedullary nail

Open reduction

ORCID iDs of the authors:

O.P. 0000-0001-7130-2434;

S.T. 0000-0001-8074-4672.

ABSTRACT

Objective: This study aimed to compare functional and radiographical outcomes following intramedullary nailing (IMN) versus plate and screw osteosynthesis in managing patients with diaphyseal forearm fractures.

Methods: Forty-six patients (27 male, 19 female) were included in this retrospective study. Of these, 25 were treated with plate osteosynthesis and 21 with IMN. The mean age was 32.4 (range, 19–67) years in the plate group and 28.8 (range, 18–64) years in the IMN group. The mean follow-up was 22.3 (range, 12–36) months in the IMN group and 24.8 (range, 12–48) months in the plate group. Functional outcomes were evaluated based on the forearm pronation/supination range of motion, grip strength, Disabilities of the Arm, Shoulder, and Hand (DASH) score, and Grace-Eversmann scoring criteria.

Results: The median time to union was 13.6 weeks in the plate group and 10.9 weeks in the IMN group ($p < 0.05$). Union was achieved in 24 of 25 patients in the plate group (96%) and all patients in the IMN group (100%). The mean operative time was 69.7 (range, 45–110) minutes in the IMN group and 88.2 (range, 50–130) minutes in the plate group. The mean fluoroscopy time was 2.7 seconds in the plate group and 21.3 seconds in the IMN group. The mean length of hospital stay was five (range, 3–9) days in the plate group and four (range, 3–10) days in the IMN group. The mean operative time was significantly shorter in the IMN group ($p < 0.05$), while the mean fluoroscopy time was longer in the IMN group ($p < 0.05$). There was no significant difference between the groups in forearm pronation and supination, grip strength, DASH score, and Grace-Eversmann scoring criteria.

Conclusion: Locked IMNs seem a viable alternative to ORIF with plate osteosynthesis for adult diaphyseal forearm fractures with similar healing rates, functional scores, and shorter operative times.

Level of Evidence: Level III, Therapeutic Study

Introduction

Forearm fractures are common in young adults after direct trauma, such as traffic accidents, falls from height, and sports activities. The kinematics between the proximal radioulnar joint, forearm, and distal radioulnar joint is critical in hand placement in 3-dimensional space and load transfer along the upper extremity.¹ The proximal radius and distal ulna form an axis around which the forearm rotates.^{2,3} Because of the functional and anatomical characteristics of the forearm bones, diaphyseal fractures of the forearm should be considered as intra-articular fractures.^{4,5} Surgical interventions are performed to restore anatomic alignment and preserve the function of the forearm complex.

Plaster casting, osteosynthesis with a plate, intramedullary K-wire, and intramedullary locking nails are used to treat forearm fractures in adults. The plaster cast is used only in rare cases.⁶⁻⁸ The main challenge in the surgical treatment of forearm fractures is achieving uniform axial and rotational reduction and fixation. The axial angle should be $<10^\circ$ to attain satisfactory results.⁶

Open reduction and internal fixation (ORIF) with plate osteosynthesis is generally accepted as the standard treatment method for diaphyseal forearm fractures in adults. This method provides adequate reduction, high union rates, and satisfactory functional results. However, ORIF with plate osteosynthesis has many disadvantages. Problems such as large skin incisions, impaired blood supply, risk of soft tissue and periosteal injury, interruption of periosteal circulation due to the contact pressure of the plate, skin irritation from the implants, refracture after plate removal, and drainage of the fracture hematoma can lead to delayed union, nonunion, and infection.⁷⁻¹¹ In 1913, a study on fracture fixation with K-wires and Steinmann nails (first generation) was conducted. However, it showed high nonunion rates due to rotational instability.¹² Nails (second generation) adapted to the forearm anatomy were introduced by Sage in 1959.¹³ The second-generation nails did not have a locking mechanism or compression function, and union with plate fixation could not be performed because they did not provide rotational stability.¹⁴ For this reason, intramedullary nails (IMNs) have not been used in the treatment of forearm fractures for many years.

Corresponding author:

Serdar Toy

serdartyoy737@gmail.com



Content of this journal is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

Cite this article as: Polat O, Toy S. Comparison of the clinical and radiographic outcomes of plate fixation versus new-generation locked intramedullary nail in the management of adult forearm diaphyseal fractures. *Acta Orthop Traumatol Turc.* 2022;56(5):321-326.

Recently, IMNs with locking and compression functions have become available for the treatment of diaphyseal forearm fractures. This method offers shorter operative time, less dissection of soft tissues, better cosmetic appearance, satisfactory functional results, higher union rates similar to ORIF, and lower fracture risk.¹⁵⁻¹⁹ We believe that the new-generation intramedullary locking nail could be used as an alternative fixation method to plate osteosynthesis in the treatment of forearm fractures.

This study retrospectively evaluated patients who underwent ORIF with plate osteosynthesis and IMN for diaphyseal forearm fractures and compared the radiologic and functional outcomes and patient satisfaction of these 2 methods.

Materials and Methods

Patients who underwent ORIF with plate osteosynthesis and IMNs for diaphyseal forearm fractures between 2014 and 2018 were retrospectively evaluated. Written informed consent was obtained from all patients, and ethics committee approval was obtained (IRB date/number: November 19, 2018/HNEAH-KAEK 2018/45). This study conforms to the Strengthening the Reporting of Observational Studies in Epidemiology criteria.

Patients were included in this study based on the following criteria: the bony maturation was complete. Fractures were treated while they were still in the acute phase. Fractures of the radius and ulna were simultaneously treated. Both radial and ulnar fractures were treated with either plate and screw osteosynthesis or IMN. Patients were followed for at least 1 year.

Patients with open epiphysis and additional injuries to the same limb, isolated diaphyseal forearm single-bone fractures (radius or ulna only), Monteggia and Galeazzi fractures, pathologic fractures, proximal and distal metaphyseal fractures, open type 3 fractures, or head trauma were excluded from the study.

Patient demographics

In this study, 46 patients who met the criteria were included. Of these, 25 were treated with plate osteosynthesis and 21 with IMNs. Fractures were categorized according to the Association for Osteosynthesis/Orthopedic Trauma Association classification (AO/OTA). Radiography of the forearm was performed in the posterior-anterior (PA) and lateral views upon admission to the emergency department. Long-arm splints were used in all patients until surgery. Twenty-nine fractures were closed (63%), and according to the Gustilo and Anderson classification, 8 patients had open type 1 fractures and 9 patients had open type 2 fractures.

Patient preparation

Surgeons selected implants based on their personal preferences before surgery. Seven different surgeons performed the surgeries; 5 surgeons performed plate and screw osteosynthesis and 2 surgeons applied IMN.

All patients underwent surgery either under general anesthesia or with an axillary block. All patients received 1 g of intravenous cefazolin 30 minutes preoperatively. Surgeons performed the procedures using a pneumatic tourniquet with a pressure of 250 mmHg. Surgery was started in the less-fragmented bone to facilitate reduction and restore length. Patients with open fractures were transferred to the operating room for irrigation and debridement on admission. After debridement, osteosynthesis and primary wound closure were performed. No graft was used in any of the patients.

Surgical technique

In the plate group, surgical treatment for radius and ulna fractures was performed with separate incisions. Patients in the plate group underwent surgery with 3.5-mm limited contact dynamic compression plates (TST Rakor Medical Instruments Industry and Trade Limited Company, Istanbul, Turkey). For radius, the volar Henry approach was used for mid and distal diaphyseal fractures, and the dorsal Thompson approach was used for mid and proximal diaphyseal fractures. Ulnar shaft fractures were accessed through an incision at the subcutaneous margin. Only the area where the plate was to be inserted was prepared subperiosteally. The soft tissue connections of the fragments were preserved when possible. After the blood, clots, and soft tissues in the fracture line were removed, reduction was achieved and then, the plates were inserted. The distal and proximal parts of the fracture line were fixed with at least 3 screws (6 cortices). In osteoporotic and comminuted fractures, additional screws were used. In 7 cases, lag screws were also used (Figure 1). The tourniquet was opened, hemostasis was achieved, and a drain was placed. The drain was removed 48 hours postoperatively.

In the IMN group, radial fractures were treated with a single type of IMN (TST Rakor Medical Instruments Industry and Trade Limited Company, Istanbul, Turkey). The radial nail, which is coated with a titanium alloy, is firm, and round and is inserted without reaming. The radial nail body is parabolic, and the proximal 3 cm has a 10° angle, while the distal 3 cm has a 15° angle and static locking hole. Digital radiography in the PA and lateral views was performed preoperatively to select appropriate nails. Nail length was calculated by subtracting 2-3 cm from the distance between the radial styloid process and radial neck. Surgeons used the distance between the 2 cortices at the narrowest point of the medulla on the PA and lateral radiographs to calculate nail size. This approach has a 10% margin of error.

A 2-cm incision was made over Lister's tubercle. The second compartment was opened, the extensor carpi radialis longus and brevis tendons were pulled laterally, and an awl was used to provide vertical access to the radius. The entry point was extended to the medullary canal with a curved drill bit. A nail of appropriate size and diameter was advanced proximally with rotational movements using a nail holder. When the nail tip reached the fracture line, the nail was advanced intramedullary after closed reduction or, if this was not possible, a mini-open incision was made. The nail was fixed to the radius with the final penetrator. A distal locking hole at the distal end of the nail had a 17° angle in the volar and proximal directions and was designed for a 2.7-mm locking screw. The drill sleeve was inserted into the distal hole of the nail, the distal radius was

HIGHLIGHTS

- Open reduction and internal fixation (ORIF) with plates is generally accepted as the standard treatment for diaphyseal forearm fractures in adults. Newer intramedullary nails with locking and compression functions may offer an alternative to ORIF with plates. This study aimed to compare these two fixation methods.
- The results showed that the operation time and union time are shorter in new-generation distal locking forearm nails however, osteosynthesis with the plate for forearm fractures has less fluoroscopy time.
- This study indicates that especially due to the new-generation distal locking forearm nails' ability to allow early movement and mobilization they may be considered as viable alternatives to open reduction and internal fixation for adult diaphyseal forearm fractures.



Figure 1. A-D. Preoperative posterior-anterior and lateral radiographs of a 56-year-old male with a right diaphyseal forearm fracture (A, B); postoperative posterior-anterior and lateral radiographs at 12 months (C, D).

bicortically reamed with a 2.00-mm drill bit, and a locking screw of appropriate length was inserted.

One type of ulnar nail was used for all patients in the IMN group (TST Rakor Medical Instruments Industry and Trade Limited Company). Digital radiographs were obtained preoperatively at the PA and lateral views to select the appropriate ulnar nail. The length of the ulnar nail was calculated by subtracting 2 cm from the distance between the ulnar styloid process and olecranon. The nail diameter was calculated by measuring the distance between the 2 cortices at the narrowest point of the medulla in the PA and lateral radiographs. However, a 10% margin of error may exist with this method. Ulnar IMNs were fixed by a non-stretching approach. Distal locking was performed by inserting 1 or more locking screws into the 8 transverse clefts in the distal 3 cm portion of the nail; proximal locking was performed with an external guide through the round, oval, and proximal oblique holes. A 1.5-2.0 cm incision was made from the olecranon tip at the elbow at 90° flexion, and a 2 mm Kirchner (K) wire was inserted into the bone marrow from the olecranon tip. After a 3 cm zone was drilled over the K-wire with a cannulated drill, nails of appropriate size and diameter were advanced distally with rotation. Closed reduction or mini-open incisions were used to cross the fracture line. Distal locking was achieved by inserting 3 mm screws through the double cortex. Depending on the surgeon's choice, proximal locking was performed as static, dynamic, or oblique locking (Figure 2).

Postoperative rehabilitation

Patients were hospitalized for follow-up, pain control, and rehabilitation in the early postoperative period. During the postoperative period, patients did not have regular visits. We examined the dates of patient's visits and made assessments accordingly. While all patients were called in the 2nd and 3rd postoperative weeks, follow-up was mainly in the 1st, 3rd, and 12th postoperative months.

Active and passive movements of the wrist, elbow, and forearm were observed on the first day in the IMN group. The reason for the early onset of motion in patients undergoing IMN was that surgeons emphasized stability. Elbow, forearm, and wrist motions were observed in the plate group after applying a cast above the elbow with 90° flexion of the elbow and neutral rotation of the forearm for 2-3 weeks. Surgeons who performed osteosynthesis with plates and screws used a cast after surgery in all patients.

During the follow-up, fracture union was assessed by pain sensation in the fracture line and union in 3 of 4 cortices on AP and lateral radiographs.²⁰⁻²⁷ At 6 months, the absence of union in 3 of 4 cortices on AP and lateral radiographs was considered as nonunion.^{28,29} Functional outcomes were evaluated using the Grace-Eversmann scoring system and the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire. Forearm rotation was measured using a goniometer while the elbow was flexed at 90°. Grip strength was

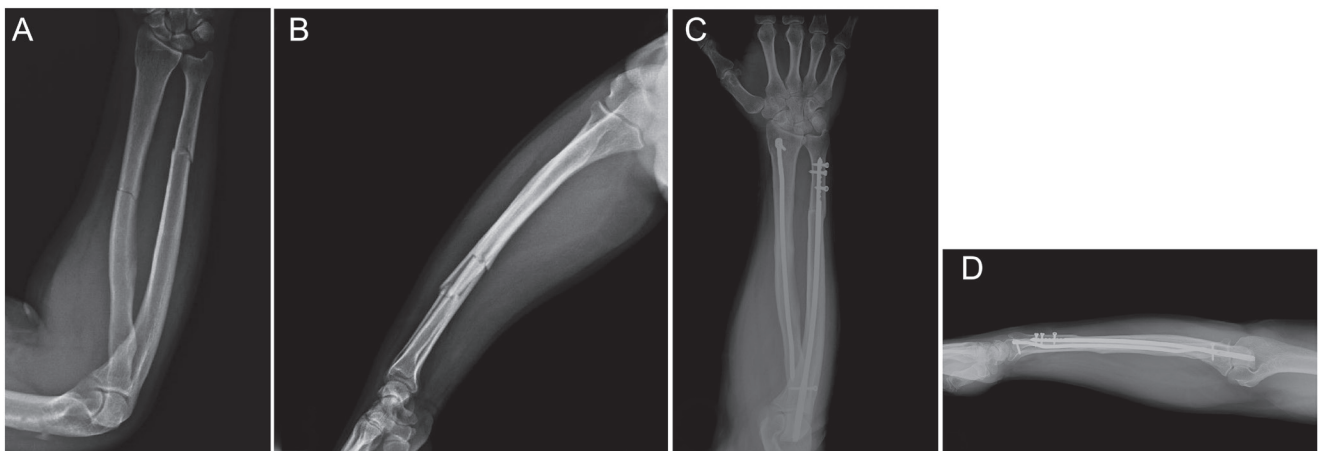


Figure 2. A-D. Preoperative posterior-anterior and lateral radiographs of a 49-year-old male with right diaphyseal forearm fracture (A, B); postoperative posterior-anterior and lateral radiographs of 12 months (C, D).

measured using a Saehan hydraulic hand dynamometer. Intermittent measurements were performed 3 times while the patient was in the following positions: sitting position, shoulder adducted position, elbow flexed at 90° position, and neutral position of the forearm and wrist. Then, the average values were obtained.

Statistical analysis

Power analysis was performed using G*Power (G*Power version 3.1.9.4; University of Kiel, Kiel, Germany) for the Mann-Whitney U test with an alpha of 0.05, power of 80%, and sample size of 46, resulting in detectable effect size of 0.8 (large effect).³⁰

International Business Machines Statistical Package for the Social Sciences Statistics 22 (IBM SPSS Corp., Armonk, NY, USA) was used to analyze the results obtained in this study. The normality of parameter distributions was assessed using the Shapiro-Wilk test. The Mann-Whitney U test and Student's t-test were used to compare parameters between the 2 groups. Wilcoxon signed-rank tests were used for within-group comparisons of nonnormally distributed parameters. Pearson's chi-square test, Fisher's exact test, Fisher-Freeman-Halton test, and Yates correction for continuity were used to compare qualitative data. Significance was assessed at a P-value <.05.

Results

Of 46 patients, 27 (58.7%) were men and 19 (41.3%) were women. The mean age of the plate group was 32.4 (range, 19-67) years and that of the IMN group was 28.8 (range, 18-64) years. The right diaphyseal forearm was affected in 23 patients and the left side in 23 patients. The dominant side was affected in 23 (50.0%) patients. No patient had bilateral forearm fractures. The injury was caused by an assault in 2 patients, traffic accident in 6 patients, work accident in 8 patients, sports in 8 patients, and fall in 22 patients. The fractures were classified according to the AO/OTA classification: 20 were type A (simple, 43.5%), 18 were type B (wedge-shaped, 39.1%), and 8 were

type C (complex, 17.4%). A detailed analysis of the 2 groups is presented in Table 1.

The mean length of hospital stay was 5 (range, 3-9) days in the plate group and 4 (range, 3-10) days in the IMN group. The mean follow-up duration was 22.3 (range, 12-36) months in the IMN group and 24.8 (range, 12-48) months in the plate group. Surgery was performed within a mean of 3.8 (range, 1-10) days; this duration was 3.6 (range, 1-9) days in the IMN group and 4.1 (range, 1-10) days in the plate group. The mean operative time was 69.7 (range, 45-110) minutes in the IMN group and 88.2 (range, 50-130) minutes in the plate group. The mean fluoroscopy time was 21.3 seconds in the IMN group and 2.7 seconds in the plate group. The mean operative time was significantly shorter in the IMN group (*P* < .05), while the mean fluoroscopy time was longer in the IMN group (*P* < .05).

The mean union time was 10.9 weeks in the IMN group and 13.2 weeks in the plate group. The difference was statistically significant (*P* < .05). No nonunion was observed in the IMN group, and union was achieved in 24 of 25 (96%) patients in the plate group. In patients in the plate group in whom union could not be achieved by postoperative month 12, autografts from the iliac wing and longer plates were used; union was achieved at an additional 4 months after revision surgery.

In the plate group, loss of extension of the elbow to 20° relative to the other limb was observed in 1 patient, but no specific intervention was performed to correct this problem. In all other patients, the full range of motion of the wrist and elbow was preserved. The differences between the groups in terms of DASH score, Grace-Eversmann criteria, grip strength, and supination and pronation of the forearm were not statistically significant (*P* > .05). The summary of the results is given in Table 2.

Fracture reduction was achieved by mini-open incisions in the 7 radius fractures and 5 ulna fractures in the IMN group. Superficial infections developed in 3 patients in the plate group, all of whom recovered with

Table 1. Evaluation of parameters between groups

		IMN group (n=21)	Plate group (n=25)	P
Mean age (range)		28.8 (18-64)	32.4 (19-67)	0.465
Sex (n)	Male	11	16	0.430
	Female	10	9	
Trauma mechanism	Fall	10	12	0.359
	Traffic accident	4	2	
	Work accident	4	4	
	Sports	3	5	
	Assault	0	2	
Side	Right	12	11	0.380
	Left	9	14	
Fracture classification (AO/ASIF)	A1	4	1	0.570
	A2	4	5	
	A3	1	5	
	B1	3	4	
	B2	4	3	
	B3	2	2	
	C1	1	3	
	C2	1	1	
	C3	1	1	
Dominant extremity (n, %)		12 (57.1%)	11 (44.0%)	0.380

IMN, intramedullary nailing; AO, Association for Osteosynthesis; ASIF, Association for the Study of Internal Fixation.

Table 2. Evaluation of results between groups

		IMN group	Plate group	P
Mean surgery waiting time (day) (range)		3.6 (1-9)	4.1 (1-10)	0.416
Anesthesia type	General	9	9	0.639
	Axillary block	12	16	
Mean operative time (minute) (range)		69.7 (45-110)	88.2 (50-130)	0.008*
Mean follow-up time (month) (range)		22.3 (12-36)	24.8 (12-48)	0.535
Mean pronation (degree) (range)		81.4 (70-90)	80 (60-90)	0.517
Mean supination (degree) (range)		81.4 (70-90)	79.8 (60-90)	0.521
Mean grip strength (kg)		38.9	39.2	0.991
Mean DASH score (range)		6.8 (0-15)	8.4 (0-30)	0.689
Grace-Eversmann evaluation (n)	Excellent	13	17	0.916
	Good	8	5	
	Acceptable	0	2	
	Nonacceptable	0	1	
Open fracture (n)	Type 1	5	6	0.857
	Type 2	3	3	
Fluoroscopy time (second)		21.3	2.7	<0.001*
Mean union time (week)		10.9	13.2	0.028*

**P* < .05.

IMN, intramedullary nailing; DASH, Disabilities of the Arm, Shoulder, and Hand.

oral antibiotic therapy and local wound care. One patient in the plate group had deep infection that recovered after debridement and 1 week of parenteral antibiotics. Three patients in the IMN group had superficial infections that completely resolved with oral antibiotic therapy and local wound care. No deep infection was observed in the IMN group. In the plate group, pain and implant irritation developed in 3 patients, and implants were removed after an average of 20 (range, 18-24) months. No refracture was observed after implant extraction. In the IMN group, no implant was removed from any patient. In the plate group, 1 patient had transient posterior interosseous nerve palsy, but this was completely resolved without any intervention. In the IMN group, 1 patient had neuropraxia of the superficial branch of the radial nerve, which completely resolved without intervention.

Discussion

Surgical treatment is generally accepted for forearm fractures in adults. Many studies recommend ORIF with plate osteosynthesis.^{10,31-33} Recently, third-generation IMNs have been introduced. These nails have locking mechanisms and compression effects and provide rotational stability.^{16,18,34-36} In our study, functional and radiologic outcomes were similar in the 2 patient groups. However, it was challenging to ensure anatomic fixation and proper rotation when using IMN. Prolonged radiation exposure during IMN was also a significant obstacle. However, soft tissue damage and less bleeding were observed with IMN than with ORIF with plate osteosynthesis.

There are few studies on the outcomes of plate osteosynthesis and third-generation IMN used to treat diaphyseal forearm fractures in adults. These studies compared the outcomes of 2 different surgical options for diaphyseal forearm fractures in terms of operative times, fluoroscopy times, union times, Grace–Eversmann criteria, DASH scores, and complications.

When the studies in the literature were examined, it was found that the operative time in patients with forearm fractures was shorter in the patient groups in which IMN (range, 43-61 minutes) was applied than in the patient groups in which osteosynthesis with the plate (range, 63-74 minutes) was used.^{17,18,35,37} Patients in the IMN group had a much shorter operative time (69.7 [range, 45-110] minutes) than patients in the plate group (88.2 [range, 50-130] minutes) in our study. As the incisions were small and the procedure was simple, the surgery required less time.

In previous studies on adult forearm fractures, the fluoroscopy time in patients who underwent IMN (1.2-7 minutes) was significantly longer than that in patients who were treated with plate osteosynthesis (0-2 minutes).^{14,17,18,35,37,38} In our study, which is consistent with the literature, fluoroscopy time was significantly longer in patients who underwent IMN (21.3 seconds) than in patients who underwent plate osteosynthesis (2.7 seconds). The long fluoroscopy time was the major disadvantage of using IMNs.

Lee et al¹⁷ reported that union was achieved at 10 weeks in the plate group and 14 weeks in the IMN group. Kose et al³⁷ found that union was achieved at 12.3 weeks in the plate group and 12 weeks in the IMN group. Kibar et al¹⁸ reported that union was achieved at 12.2 weeks in the plate group and 12.1 weeks in the IMN group. Cevik et al¹⁴ noted that union was achieved at 12.3 weeks in the plate group and 12.0 weeks in the IMN group. In our study, the mean time to union in patients undergoing plate osteosynthesis was 13.2 weeks, whereas the mean time to union in patients treated with IMN was

10.9 weeks. In our study, the mean time to union in patients who underwent plate osteosynthesis was consistent with those in the literature, whereas the mean time to union in patients who underwent IMN was significantly shorter than those in the literature.

In our study, according to the Grace–Eversmann criteria, excellent results were obtained in 17 patients, good results in 5 patients, moderate results in 2 patients, and an unacceptable result in 1 patient in the plate group. The mean DASH score of patients who underwent plate osteosynthesis was 8.4. In the plate group, the mean pronation angle of patients was 80°, and the mean supination angle was 79.8°. Based on the Grace–Eversmann criteria, in patients who underwent IMN surgery, 13 had excellent results and 8 had good results. The mean DASH score for patients who were treated with IMN was 6.8. The mean pronation angle of patients in the IMN group was 81.4°, and the mean supination angle was 81.4°. The results of this study were consistent with those of previous studies, and there was no significant difference in functional scores between the 2 groups as reported in the literature.^{14,17,34,39}

In this study, we used IMNs with elastic and parabolic structures. These nails provide 3-point stabilization and rotational stability, thanks to their distal screws. The radius nail also restores the curvature of the radius. Fracture compression of up to 7 mm is also possible with the dynamic locking approach. The ulnar nail also has a static clamping mechanism. Lee et al¹⁷ used the new-generation forearm nails, which did not have the distal locking mechanism. Therefore, they could not initiate early mobilization in the patients they treated postoperatively with IMN and applied a long-arm splint to these patients for 6 weeks. Many authors had used long-arm splints to monitor forearm fractures treated with ORIF for a period after surgery, as we did in our study.^{8,40} Because the IMN we used in our study provided distal locking mechanism and increased rotational stability, we encouraged patients to undergo treatment with IMN to mobilize them early. Thus, our study found that the time to union was shorter and the functional outcomes were better in our patients who underwent treatment with IMN than in other studies.

Lee et al³⁴ found that only 1 bone was fractured in 16 patients (radius in 7 and ulna in 9), and both forearm bones were fractured in 11 patients. Gradl et al³⁹ investigated isolated radius fractures in their study. Saka et al¹⁵ investigated 43 patients with 59 forearm fractures in their study. Their study reported that 14 patients had isolated radius fractures, 17 patients had isolated ulna fractures, and 28 patients had both radius and ulna fractures. Kose et al³⁷ considered both isolated radius and ulna fractures and fractures of both forearms. Kibar et al^{18,35} considered isolated radius and isolated ulna fractures in their studies. Azboy et al^{32,33} included isolated radius or isolated ulna fractures in their studies. After reviewing the literature, most studies on diaphyseal forearm fractures were heterogeneous. The heterogeneity could affect the results of the studies. Our study included patients who had both radius and ulna fractures in both patient groups. Thus, unlike other studies, our study achieved homogeneity in both groups.

Complications such as posterior interosseous nerve injury, infection, fractures after implant removal, synostosis, tendon rupture, and vascular injury have been reported after forearm fracture surgery.^{17,34,41-43} In our study, no patient had fractures, tendon damage, and vascular complications after implant removal surgery.

This study had some limitations. Major limitations were the small number of patients and retrospective design. Because this was a

retrospective study, the patient groups did not include equal numbers of patients, different surgeons performed the surgeries, and the number of screws placed and the number of cortices was not uniform. Patient follow-up periods were also not standardized. Future prospective studies performed on more patients in multiple centers would contribute significantly to the literature.

In conclusion, the mean operative time and mean union time were shorter in the IMN group because of the minimal incision, intact periosteum, and lack of opportunity to evacuate the hematoma. However, a significant disadvantage of IMNs was the prolonged use of fluoroscopy. Because the interlocking IMNs provided relative stability, patients could be mobilized early, thus increasing the union rate and shortening the union time. To the best of our knowledge, this is the only study that compared the new-generation distal locking forearm nails in the treatment of forearm double fractures and plate osteosynthesis, where only both bone fractures (isolated radius or ulna fractures) were not taken alone. Thus, locked IMNs are a viable alternative to ORIF with plate osteosynthesis for adult diaphyseal forearm fractures with similar union rates, functional scores, and shorter operative times.

Ethics Committee Approval: Ethical approval (IRB date/No: November 19, 2018/HNEAH-KAEK 2018/45) was obtained from the Local Ethical Committee of Haydarpaşa Numune Training and Research Hospital.

Informed Consent: Written informed consent was obtained from all patients.

Author Contributions: Concept - O.P., S.T.; Design - O.P., S.T.; Supervision - S.T.; Materials - O.P., S.T.; Data Collection and/or Processing - O.P.; Analysis and/or Interpretation - S.T.; Literature Review - O.P.; Writing - O.P., S.T.; Critical Review - S.T.

Acknowledgments: The authors thank Birkan Kibar, MD., for his crucial suggestions and contributions.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: The authors declared that this study has received no financial support.

References

- Orbay JL, Cambo RA. Biomechanical factors in stability of the forearm. *Hand Clin.* 2020;36(4):407-415. [CrossRef]
- LaStayo PC, Lee MJ. The forearm complex: anatomy, biomechanics and clinical considerations. *J Hand Ther.* 2006;19(2):137-144. [CrossRef]
- Soubeyrand M, Assabah B, Bégin M, Laemmel E, Dos Santos A, Crézé M. Pronation and supination of the hand: anatomy and biomechanics. *Hand Surg Rehabil.* 2017;36(1):2-11. [CrossRef]
- Crenshaw Jr AH, Perez EA. Fractures of shoulder, arm and forearm. *Campbell's Oper Orthop.* 2003;3:2985-3069.
- Markolf KL, Lamey D, Yang S, Meals R, Hotchkiss R. Radioulnar load-sharing in the forearm. A study in cadavera. *J Bone Joint Surg Am.* 1998;80(6):879-888. [CrossRef]
- Schemitsch EH, Richards RR. The effect of malunion on functional outcome after plate fixation of fractures of both bones of the forearm in adults. *J Bone Joint Surg Am.* 1992;74(7):1068-1078. [CrossRef]
- Blažević D, Benčić I, Čuti T, et al. Intramedullary nailing of adult forearm fractures: results and complications. *Injury.* 2021;52(suppl 5):S44-S48. [CrossRef]
- Gadegone W, Salphale YS, Lokhande V. Screw elastic intramedullary nail for the management of adult forearm fractures. *Indian J Orthop.* 2012;46(1):65-70. [CrossRef]
- Saikia K, Bhuyan S, Bhattacharya T, Borgohain M, Jitesh P, Ahmed F. Internal fixation of fractures of both bones forearm: comparison of locked compression and limited contact dynamic compression plate. *Indian J Orthop.* 2011;45(5):417-421. [CrossRef]
- Chapman MW, Gordon JE, Zissimos AG. Compression-plate fixation of acute fractures of the diaphyses of the radius and ulna. *J Bone Joint Surg Am.* 1989;71(2):159-169. [CrossRef]
- Moss JP, Bynum DK. Diaphyseal fractures of the radius and ulna in adults. *Hand Clin.* 2007;23(2):143-151. [CrossRef]
- Bartoniček J, Kozánek M, Jupiter JB. History of operative treatment of forearm diaphyseal fractures. *J Hand Surg Am.* 2014;39(2):335-342. [CrossRef]
- Sage FP. Medullary fixation of fractures of the forearm: a study of the medullary canal of the radius and a report of fifty fractures of the radius treated with a prebent triangular nail. *J Bone Joint Surg Am.* 1959;41-A(8):1489-1516. [CrossRef]
- Çevik N, Akalın Y, Öztürk A. The functional and radiological comparison of the surgical treatment results of forearm diaphyseal fractures in adults treated with open reduction internal fixation and intramedullary locking nail. *Eur Res J.* 2020;6(5):500-507.
- Saka G, Saglam N, Kurtulmuş T, et al. New interlocking intramedullary radius and ulna nails for treating forearm diaphyseal fractures in adults: a retrospective study. *Injury.* 2014;45(suppl 1):S16-S23. [CrossRef]
- Köse A, Aydın A, Ezirmik N, Topal M, Can CE, Yılar S. Intramedullary nailing of adult isolated diaphyseal radius fractures. *Ulus Travma Acil Cerrahi Derg.* 2016;22(2):184-191. [CrossRef]
- Lee SK, Kim KJ, Lee JW, Choy WS. Plate osteosynthesis versus intramedullary nailing for both forearm bones fractures. *Eur J Orthop Surg Traumatol.* 2014;24(5):769-776. [CrossRef]
- Kibar B, Kurtulmuş T. Comparison of new design locked intramedullary nails and plate osteosynthesis in adult isolated diaphyseal radius fractures. *Eur J Trauma Emerg Surg.* 2019:1-7.
- Ozkaya U, Kiliç A, Özdoğan U, Beng K, Kabukcuoğlu Y. Comparison between locked intramedullary nailing and plate osteosynthesis in the management of adult forearm fractures. *Acta Orthop Traumatol Turc.* 2009;43(1):14-20. [CrossRef]
- Morshed S, Corrales L, Genant H, Miclau III T. Outcome assessment in clinical trials of fracture-healing. *J Bone Joint Surg Am.* 2008;90(suppl 1):62-67. [CrossRef]
- Bhandari M, Guyatt GH, Swiontkowski MF, Tornetta Iii P, Sprague S, Schemitsch EH. A lack of consensus in the assessment of fracture healing among orthopaedic surgeons. *J Orthop Trauma.* 2002;16(8):562-566. [CrossRef]
- Corrales LA, Morshed S, Bhandari M, Miclau III T. Variability in the assessment of fracture-healing in orthopaedic trauma studies. *J Bone Joint Surg Am.* 2008;90(9):1862-1868. [CrossRef]
- Dijkman BG, Sprague S, Schemitsch EH, Bhandari M. When is a fracture healed? Radiographic and clinical criteria revisited. *J Orthop Trauma.* 2010;24(suppl 1):S76-S80. [CrossRef]
- Vannabouathong C, Sprague S, Bhandari M. Guidelines for fracture healing assessments in clinical trials. Part i: definitions and endpoint committees. *Injury.* 2011;42(3):314-316. [CrossRef]
- Morshed S. Current options for determining fracture union. *Adv Med.* 2014;2014:708574. [CrossRef]
- Eastaugh-Waring SJ, Joslin CC, Hardy JR, Cunningham JL. Quantification of fracture healing from radiographs using the maximum callus index. *Clin Orthop Relat Res.* 2009;467(8):1986-1991. [CrossRef]
- Wittauer M, Burch MA, McNally M, et al. Definition of long-bone nonunion: a scoping review of prospective clinical trials to evaluate current practice. *Injury.* 2021;52(11):3200-3205. [CrossRef]
- Marsh D. Concepts of fracture union, delayed union, and nonunion. *Clin Orthop Relat Res.* 1998;355(suppl):S22-S30. [CrossRef]
- Fisher JS, Kazam JJ, Fufa D, Bartolotta RJ. Radiologic evaluation of fracture healing. *Skelet Radiol.* 2019;48(3):349-361. [CrossRef]
- Cohen J. Statistical power analysis for the behavioral sciences. Hillsdale, NJ: Lawrence Erlbaum Associates. 1988:18-74.
- Anderson LD, Sisk D, Tooms RE, Park 3rd WI. Compression-plate fixation in acute diaphyseal fractures of the radius and ulna. *J Bone Joint Surg Am.* 1975;57(3):287-297. [CrossRef]
- Azboy I, Demirtas A, Uçar BY, Bulut M, Alemdar C, Özkul E. Effectiveness of locking versus dynamic compression plates for diaphyseal forearm fractures. *Orthopedics.* 2013;36(7):e917-e922. [CrossRef]
- Azboy I, Demirtaş A, Alemdar C, Gem M, Uzel K, Arslan H. A newly designed intramedullary nail for the treatment of diaphyseal forearm fractures in adults. *Indian J Orthop.* 2017;51(6):697-703. [CrossRef]
- Lee YH, Lee SK, Chung MS, Baek GH, Gong HS, Kim KH. Interlocking contoured intramedullary nail fixation for selected diaphyseal fractures of the forearm in adults. *J Bone Joint Surg Am.* 2008;90(9):1891-1898. [CrossRef]
- Kibar B, Kurtulmuş T. Treatment of adult isolated ulnar diaphyseal fractures: a comparison of new-generation locked intramedullary nail and plate fixation. *Eklem Hastalik Cerrahisi.* 2019;30(3):246-251. [CrossRef]
- Weckbach A, Blatter TR, Weisser Ch. Interlocking nailing of forearm fractures. *Arch Orthop Trauma Surg.* 2006;126(5):309-315. [CrossRef]
- Köse A, Aydın A, Ezirmik N, Yıldırım ÖS. A comparison of the treatment results of open reduction internal fixation and intramedullary nailing in adult forearm diaphyseal fractures. *Ulus Travma Acil Cerrahi Derg.* 2017;23(3):235-244. [CrossRef]
- Lee SK, Kim YH, Kim SM, Choy WS. A comparative study of three different surgical methods for both-forearm-bone fractures in adults. *Acta Orthop Belg.* 2019;85(3):305-316.
- Gratl G, Mielsch N, Wendt M, et al. Intramedullary nail versus volar plate fixation of extra-articular distal radius fractures. Two year results of a prospective randomized trial. *Injury.* 2014;45(suppl 1):S3-S8. [CrossRef]
- Al-Sadek TA, Niklev D, Al-Sadek A. Diaphyseal fractures of the forearm in adults, plating or intramedullary nailing is a better option for the treatment? *Open Access Maced J Med Sci.* 2016;4(4):670-673. [CrossRef]
- Behnke NM, Redjal HR, Nguyen VT, Zinar DM. Internal fixation of diaphyseal fractures of the forearm: A retrospective comparison of hybrid fixation versus dual plating. *J Orthop Trauma.* 2012;26(11):611-616. [CrossRef]
- Gao H, Luo CF, Zhang CQ, Shi HP, Fan CY, Zen BF. Internal fixation of diaphyseal fractures of the forearm by interlocking intramedullary nail: short-term results in eighteen patients. *J Orthop Trauma.* 2005;19(6):384-391. [CrossRef]
- Fanuele J, Blazar P. Extensor pollicis longus tendon rupture in an adult after intramedullary nailing of a radius fracture: case report. *J Hand Surg Am.* 2009;34(4):627-629. [CrossRef]