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ORIGINAL STUDY

A comparative study of three different surgical methods for both-forearm-bone fractures in adults

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The purpose of this study was to evaluate and compare the results of plate osteosynthesis, intramedullary nailing (IMN), and hybrid fixation for the treatment of both-forearm-bone shaft fractures in adults. One-hundred-one cases of both-forearm-bone shaft fractures were retrospectively reviewed. All fractures were divided into the following three groups, according to the method used for internal fixation : open reduction and internal fixation ORIF group (plate osteosynthesis), IMN group, and HYBRID group (plate osteosynthesis for the radius and intramedullary nail for the ulna). The results were assessed based on the time to union, functional recovery, restoration of the ulna and radial bow, operating time, complications, and patient satisfaction. In the ORIF, IMN, and HYBRID groups, the average union time was 10.8, 14.9, and 11.5 weeks, respectively. No intergroup differences were observed in the functional outcomes. The ORIF and HYBRID groups had a significantly better radial bow ratio compared to the IMN group. All patients in the three groups achieved union, with the exception of a single case of nonunion in the IMN group. ORIF and HYBRID fixation resulted in a more anatomical restoration of radial bow ratio, compared to the contralateral side. Such significant differences in the restoration of the radial bow had no effect on the final functional outcomes and minimal effect on forearm range of motion. Although there are statistically significant effects on the final forearm range of motion, the difference was only 5°. Thus, if the indication is properly selected, our results suggest that hybrid fixation would be acceptable and effective treatment options for both-forearm-bone fractures in adults.

Keywords : both forearm bone fracture, plate osteosynthesis, intramedullary nailing, hybrid fixation.

INTRODUCTION

The gold standard treatment for operative stabilization of diaphyseal fractures of both forearm bones in adults is dual plate osteosynthesis using open reduction and internal fixation (ORIF) *(16,31)*. Plate osteosynthesis results in stable fixation, high union rates and good functional outcomes. However, it has several disadvantages, including extensive soft tissue damage, evacuation of the fracture hematoma, periosteal damage due to periosteal stripping, which has been reported to be a risk factor for nonunion, direct contact pressure from the plate and stress shielding, and refracture following plate removal, which has been reported to occur in 11-20% of cases *(16,17,28,30)*. Additionally, this approach has some limitations in patients with extensive soft tissue damage, severe swelling, open fractures, and limited operation time due to the patient's condition.

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In an effort to circumvent these problems, intramedullary nailing (IMN) has been proposed as an alternative method for surgical treatment of both-forearm-bone fractures *(18,19)*. The IMN technique results in improved cosmesis, less damage to the soft tissues and vascular supply, reduced periosteal stripping, increased secondary periosteal callus formation due to stress sharing, and lower refracture rates *(2,14,24,26)*.

Due to the more parabolic shape of the radius, as opposed to the ulna, IMN has a limitation in restoring the normal anatomical bowing of the radius. A cadaveric study demonstrated that the normal magnitude and location of the radial bow is more difficult to restore with intramedullary fixation *(22)*. Therefore, we speculated that hybrid fixation, in which the radial bow is restored with anatomical reduction and the straighter ulna is fixed with IMN, might be a good option for stabilizing both-forearm-bone fractures operatively. Dual plating and dual IMN, which are surgical treatment methods for both-forearm-bone fractures, have been compared frequently in previous studies *(13,23,27,31)*. Hybrid fixation was recently reported to be effective since it is not significantly different from dual plating in terms of bony union, functional outcomes, and complications *(1,32)*. There are, however, no studies yet that have compared the three methods of dual plating, dual IMN, and hybrid fixation.

Therefore, the purpose of this study was to evaluate the radiologic and functional outcomes, as well as the complication of these three different fixation methods for both-forearm-bone fractures in adults. Our hypothesis was that ORIF was superior to IMN and hybrid fixation with regard to time to bone union, restoration of the radial bow, postoperative forearm range of motion (ROM), patient satisfaction and complications.

MATERIAL AND METHODS

This retrospective study was performed from February 2007 to March 2015. The Institutional Review Board approved the study, and all patients treated with the three procedures during the study period were available for review. We performed a chart review of all skeletally mature patients who underwent surgical fixation of both-forearm-bone fractures, specifically patients who underwent dual plate fixation, dual IMN, and plate-nail hybrid fixation. The inclusion criteria were as follows : (1) simple and moderately comminuted diaphyseal fractures (i.e., those with a single butterfly fragment : AO/ASIF classification type A3 or B3) *(12)* in both bones of the forearm) ; (2) grades I, II, or IIIA open fractures *(5,6)* ; (3) segmental fractures ; (4) normal upper extremity function before the occurrence of the injury ; and (5) follow-up in our clinics for at least 2 years. The exclusion criteria included the following : severely segmental comminuted fractures (more than one butterfly segment), intra-articular involvement, isolated forearm diaphyseal fractures (radius or ulna only), Monteggia and Galeazzi fractures, fractures treated with external fixation or flexible nails, patients without adequate follow-up, and neurological symptoms of the upper extremities after injury that could affect the clinical outcomes. Among the excluded patients, those with severely segmental comminuted fractures, intra-articular involvement fractures, and Monteggia or Galeazzi fractures were treated using ORIF with plate osteosynthesis because precise length preservation was required. Isolated forearm diaphyseal fractures, osteoporotic bones, and neurological symptoms of the upper extremities after injury were treated using ORIF with plate osteosynthesis or IMN, but these patients were excluded to avoid confounding the results.

Based on the inclusion criteria, 101 patients were evaluated in the study (Table I). The ORIF group (n = 41) was treated using a pre-contoured plate (Acumed, Hillsboro, Oregon) (Fig. 1), the IMN group (n = 28) was treated with IMN (Acumed, Hillsboro, Oregon) (Fig. 2), and the HYBRID group (n = 32) was treated using plate fixation for the radius and IMN for the ulna (Acumed, Hillsboro, Oregon) (Fig. 3).

Surgery was performed first on the bone with the least comminution to facilitate the reduction and restoration of length in the ORIF and IMN groups. Since intramedullary nail insertion into the relatively straight ulna could be easily achieved following rigid fixation of the radius with a plate, open reduction of the radius was performed first in

Table I. — Demographics and general medical information of patients who underwent plate osteosynthesis (ORIF group), intramedullary nailing (IMN group), and hybrid fixation (HYBRID group) for the treatment of diaphyseal fractures in both forearm bones

Variable	ORIF	IMN	HYBRID	P Value
Patients (n)	41	28	32	
Injury mechanism (n)				
Motor vehicle accident	18	14	15	>0.05
Industrial accident	7	5	6	>0.05
Sport injury	10	5	6	>0.05
Injury from falling down	6	4	5	>0.05
Fracture type (n)				
AO/ASIF classification				
Type A3	20	13	16	>0.05
Type B3	21	15	16	>0.05
Soft tissue coverage				
Closed	29	20	24	>0.05
Open	12	8	8	>0.05
I	4	3	3	>0.05
II	5	3	3	>0.05
IIIA	3	2	2	>0.05
Gender (M/F)	27/14	18/10	21/11	>0.05
Age (years)	40.3 (10)	43.1 (11)	42.5 (10)	>0.05

Values are mean (±SD).

Figure 1. — A 26-year-old male patient with fractures in both bones of the left forearm. **A** Anteroposterior initial plain radiography. Patient underwent surgery with plate osteosynthesis. **B** Anteroposterior postoperative plain radiograph at final follow-up.

Figure 2. — A 33-year-old male patient with fractures in both bones of the left forearm. **A** Anteroposterior initial plain radiography. Patient underwent surgery with intramedullary nailing. **B** Anteroposterior postoperative plain radiograph at final follow-up.

Figure 3. — A 25-year-old male patient with fractures in both bones of the left forearm. **A** Anteroposterior initial plain radiography. Patient underwent surgery with plate osteosynthesis for the radius and intramedullary nailing for the ulna. **B** Anteroposterior postoperative plain radiograph at final follow-up.

the HYBRID group. Hybrid fixation performed by respectively applying a plate onto the radius and a nail into the relatively straight ulna was employed to attain accurate restoration of the radial bow. In the present study, plate osteosynthesis was considered as the first treatment option for both-forearm-bone fractures. Patients in poor medical condition who required admission to the intensive care unit, patients with poly trauma coupled with head, chest, abdominal, and pelvis injury, and patients with poor skin condition at the incision site were treated with either IMN or hybrid fixation.

All open fractures were treated with debridement, irrigation, and fixation on the date of admission, whereas all other fractures were stabilized within 7 days after the injury by a single surgeon.

For the ORIF group, a Henry approach was used to expose the radius and a subcutaneous approach was used to expose the ulna between the flexor carpi ulnaris and the extensor carpi ulnaris.

For the IMN group, preoperative radiographs were used to create a template for the canal size. When insertion of a radial nail was performed, an entry hole was created at the distal end of the radius, just ulnar to the Lister's tubercle, and approximately 5 mm proximal to the articular surface. A handheld reamer was inserted to ream the canal and aid in the reduction of the fracture without the use of a guidewire. In this series, all fractures were successfully reduced using a closed technique. With the aid of fluoroscopic guidance, the tip of the selected nail was gently guided past the fracture site and up to the end of the proximal metaphysis. Further, through ensuring tight engagement, even possibly up to the radius and ulna metaphyseal portion, the aim was to increase rotational stability. The nail position was assessed fluoroscopically in orthogonal planes to ensure that it had successfully crossed the fracture site and maintained a good reduction.

For the HYBRID group, ORIF for the radius was performed first using a Henry approach to achieve anatomical restoration of the radial bow with plating. Once the reduction, alignment, and provisional fixation of the radius were complete, an intramedullary nail was inserted in the relatively straight ulna. IMN of the ulna was performed in a closed setting via fluoroscopy.

For the ORIF group, when good compression and rigid fixation were achieved, a compression dressing was applied for the first few days, and gentle active exercises of the elbow, wrist, and hand were started immediately. If the fractures were comminuted, a sugar tong splint was placed at the time of the surgery. After two weeks, the splint was removed, and the patient was referred for physical therapy and rehabilitation to work on the ROM of the elbow, forearm, and wrist using active and gentle active-assisted exercises. From two to six weeks, light weight lifting training was performed. All lifting and twisting restrictions were removed at six weeks.

For the IMN group, a well-molded long-arm cast was applied right after surgery. The cast was split longitudinally to accommodate postoperative swelling. At the first postoperative office visit (two weeks), a hinged elbow brace was applied,

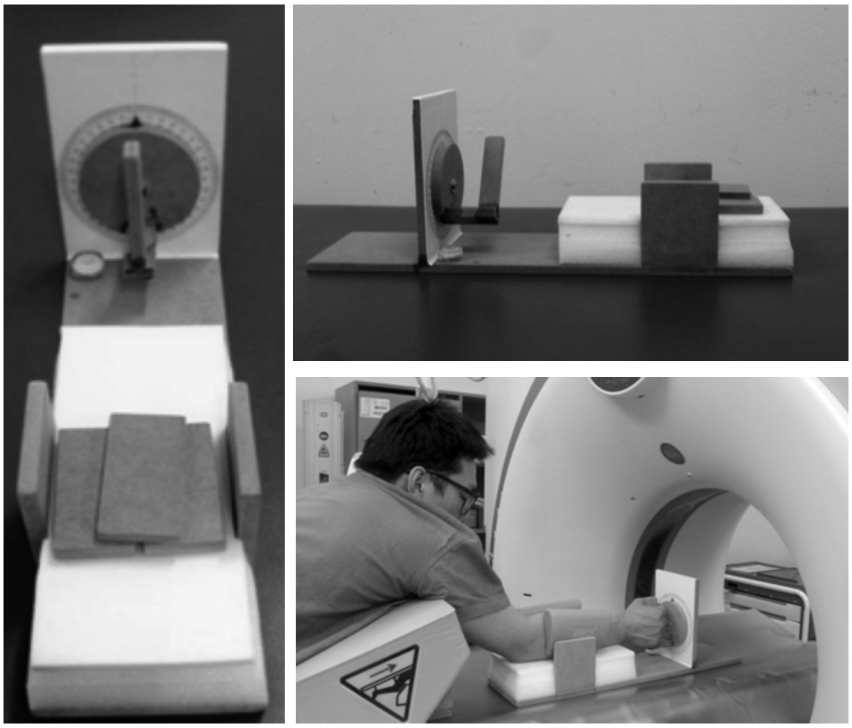


***Figure 4.* —** In order to measure the range of motion of the forearm, we produced our own version. The middle scale can be measured from neutral, 0 degrees to pronation 90 degrees and supination 90 degrees, with a minimum unit of 1 degree.

with the wrist held in a neutral position. Active ROM exercises of the elbow were initiated by the physiotherapist. At six weeks postoperatively, the elbow brace was removed, and active forearm supination and pronation exercises were allowed. The rehabilitation protocol for the HYBRID group was identical to that for the ORIF group.

The follow-up period was a minimum of 24 months (range, 24-67 months ; average, 34 months) for all patients. The results were assessed based on the time to union, functional recovery (ROM and functional outcomes : the Grace and Eversmann rating system *(4)* and the Disabilities of the Arm, Shoulder and Hand questionnaire [DASH] *(7)*), restoration of the ulna and the radial bow, operating time, complications, and patient satisfaction.

Fracture union was judged to have occurred when bridging callus or obliteration of the fracture line was evident in anteroposterior, lateral, and oblique radiographs of the forearm. Nonunion was defined as the lack of radiographic union at six months. Plain radiographs were taken every two weeks postoperatively for six weeks and then every four weeks during the follow-up period.

Functional outcomes were assessed using the Grace and Eversmann rating system, which is based on fracture union and forearm rotation. The result was rated as “excellent” when the fracture had united, and at least 90% of the normal forearm rotation was achieved ; as “good” when the fracture had united, and 80-89% of the normal rotation was achieved ; as “acceptable” when the fracture had united, and 60-79% of the normal forearm rotation was present ; and as “unacceptable” when nonunion or <60% of normal forearm rotation occurred. The patient-rated outcome was assessed using DASH, with a score of 0 points indicating a perfectly functioning upper extremity and a score of 100 points indicating complete impairment. The range of pronation and supination were evaluated according to the neutral-0 method with the elbow flexed 90° and compared with the range of motion of the contralateral side using a forearm goniometer (Fig. 4). To reduce measurement errors, we produced our own version and measurement of ROM were obtained twice by each of the authors and the average values were calculated. Intra-observer reliability was recorded using the Winer criteria (degree of bias and mean squared error) *(29)*. Reliability was classified according to the intra-class correlation coefficient as absent to poor (0 to 0.24), low (0.25 to 0.49), fair to moderate (0.50 to 0.69), good (0.70 to 0.89), or excellent (0.90 to 1.0). An intra-observer reliability of 0.92 was achieved. When the measurements of the pronation-supination of the opposite forearm were unavailable, it was assumed that the normal arc was 90° of pronation and 90° of supination.

To estimate the restoration of the ulnar and the radial bow, the anteroposterior forearm radiograph taken at the last follow-up was used to measure the maximum magnitude and location of the ulna and the radial bow (Fig. 5) *(21)*. These parameters were measured using the picture archiving and communication software Maroview version 5.4 (Marotech, Seoul, Korea) *(3,21)*. The magnitude of the ulna and the radial bow was recorded as the length. The locations of the ulna and radial bows were recorded as percentages of the total ulna and radial lengths. The restoration of the bow was also assessed as the ratio of the maximum magnitude of the bow on the injured side compared to that on the contralateral side ("the contralateral ratio"). To reduce measurement errors, radiological measurements were also obtained twice by each of the authors and the average values were calculated. An intra-observer reliability of 0.94 was achieved.

Patient satisfaction was assessed using a 4-point scale : insufficient (score = 1), satisfactory (score = 2), good (score = 3), or very good (score = 4). Functional recovery, complications, and patient satisfaction were measured three times at four months after the surgery by taking into account the mean bony union time. The parameters were re-measured at 12 months after the surgery and the values were compared at the last follow-up *(8)*.

Statistical analyses were performed using SPSS version 20.0 (SPSS Inc., Chicago, IL, USA). Differences in continuous variables among the groups for operating time, time to union, functional recovery, restoration of the bow, and patient satisfaction were examined using analysis of variance or Wilcoxon signed-rank tests. Fisher's exact test was used to examine the differences in the functional outcomes (Grace and Eversmann rating system). The Kaplan-Meier product-limit method was used to construct survivorship curves to determine the median time to radiographic healing for the 101 fractures treated with different surgical methods. The data are presented as the mean ± standard deviation. A value of $p< 0.05$ was considered statistically significant.

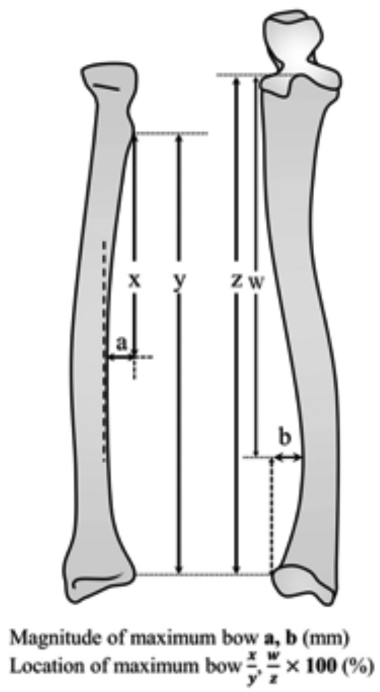


Figure 5. — The modified Schemitsch and Richards method for quantifying the maximum radial and ulnar bow as well as its location relative to the length of the entire radius and ulna.

RESULTS

All patients in the ORIF and HYBRID groups achieved fracture union, and one nonunion occurred in the IMN group (the union rate was 100% in the ORIF and HYBRID groups and 97% in the IMN group). The time to union in the ORIF group (10 ± 3 weeks) was significantly shorter than that in the IMN group (14 ± 5 weeks) and was similar to that in the HYBRID group (11 ± 2 weeks) (Fig. 6). The patients in the ORIF (A3, 10 ± 2 ; B3, 11 ± 4, p = 0.562) and HYBRID (A3, 11 ± 1 ; B3, 11 ± 9, p = 0.623) groups had similar union times regardless of the fracture type (A3 or B3). However, in the IMN group, B3 fractures had a significantly higher

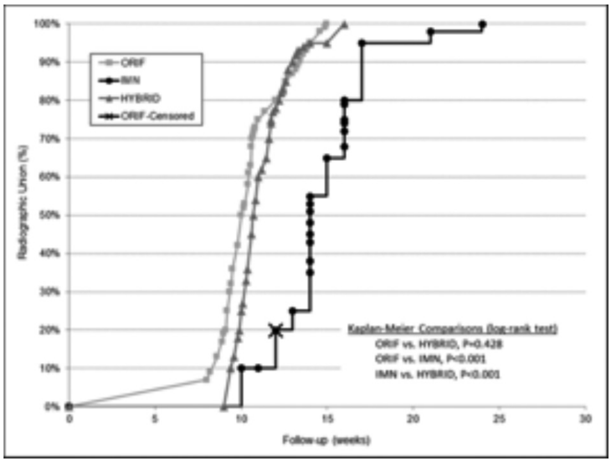


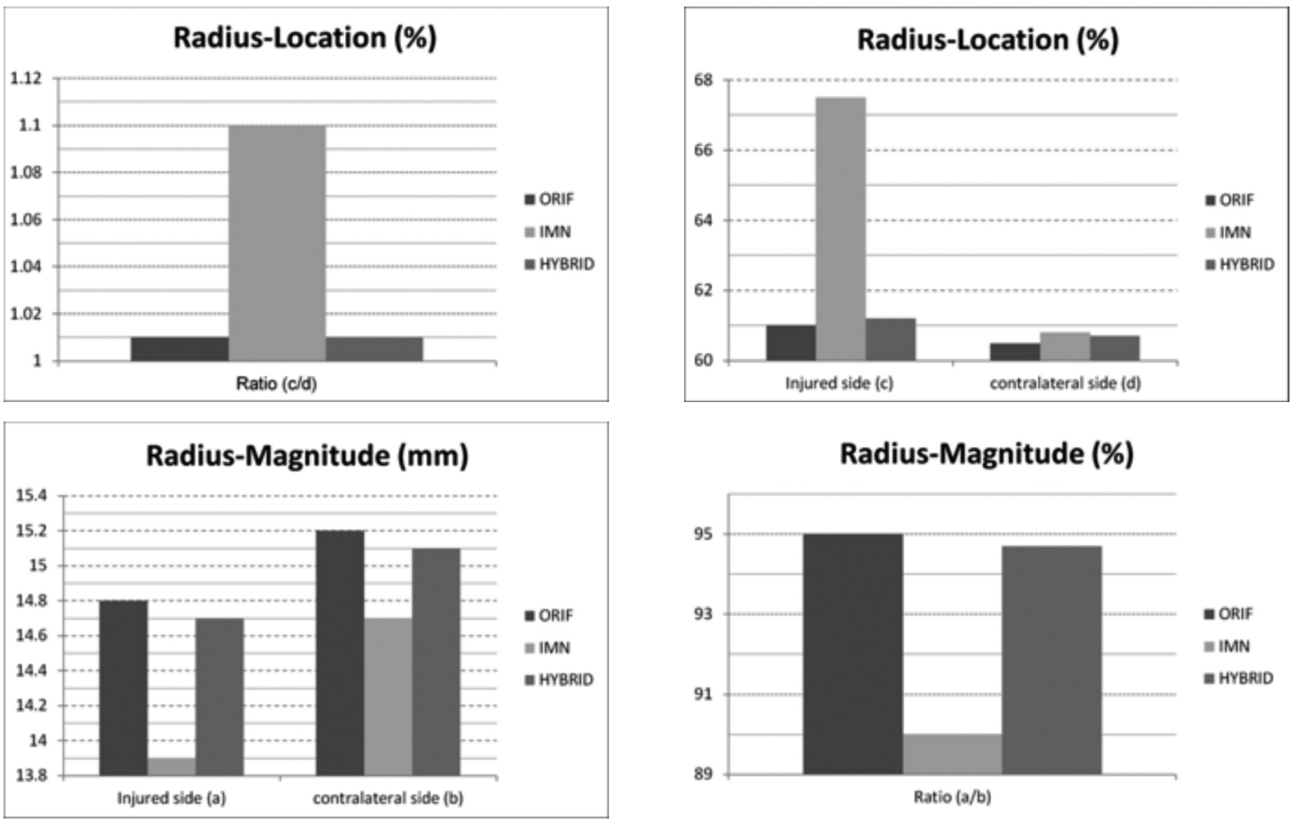
Figure 6. — Kaplan-Meier curve illustrating the estimated time to union after surgical treatment according to the three surgical methods employed. The median time to healing was 10, 11, and 14 weeks for the ORIF, IMN, and HYBRID groups, respectively.

time to union relative to A3 fractures (A3, 13 ± 3 ; B3, 17 ± 5, p = 0.038). No intergroup differences were observed in the maximum magnitude of the radial bow on the injured side. However, the ORIF and HYBRID groups had better contralateral ratios than the IMN group. Similarly, the location of the maximum bow on the injured side, as well as the ratio of this parameter between the injured and contralateral sides, was significantly better in the ORIF and HYBRID groups relative to the IMN group (Table II) (Fig. 7). The maximum magnitude and location of the ulnar bow on the injured side and the contralateral ratio were not significantly different in the three groups.

The mean pronation and supination measured after four months and at the final follow-up showed significant intergroup differences. Interestingly, the mean pronation and supination measured at four months, 12 months and 24 months showed no significant differences in the ORIF and HYBRID groups. The IMN group showed increasing mean pronation and supination at each follow-up as well as intergroup differences, unlike the ORIF

A

B



C

D

Figure 7. — The maximum location (A and B) and magnitude (C and D) of the radial bow according to the three surgical methods used.

Tab II. — Comparison of various surgical factor in three group patients

Variable	ORIF	IMN	Hybrid	P Value
Time to union (weeks)				
Average time	10 ± 3[b]	14 ± 5	11 ± 2[b]	<0.05*
Fracture type				
Type A3	10 ± 2[b]	13 ± 3	11 ± 1[b]	<0.05*
Type B3	11 ±4[b]	17 ±5	11 ± 9[b]	<0.05*
Restoration of the bow				
Radius				
Magnitude				
Injured side (a, mm)	14.8 ± 2.5	13.9 ± 2.9	14.7 ± 2.4	>0.05
Contralateral side (b, mm)	15.2 ± 1.2	14.7 ± 1.5	15.1 ± 1.4	>0.05
Ratio (a/b, %)	95.0 ± 4.7[b]	90.0 ± 3.5	94.7 ± 4.4[b]	<0.05*
Location (%)				
Injured side (c, %)	61.1 ± 7.6[b]	67.5 ± 6.4	61.2 ± 6.6[b]	<0.05*
Contralateral side (d, %)	60.5 ± 5.6	60.8 ± 4.2	60.7 ± 4.4	>0.05
Ratio (c/d, %)	1.0 ± 1.4[b]	1.1 ± 3.6	1.0 ± 1.5[b]	<0.05
Operating time (min)	74 ± 8[b]	59 ± 10	68 ±8[a]	<0.05*

[a] *P*<0.05 compared with ORIF group. [b] P<0.05 compared with IMN group. * Statistically significant.

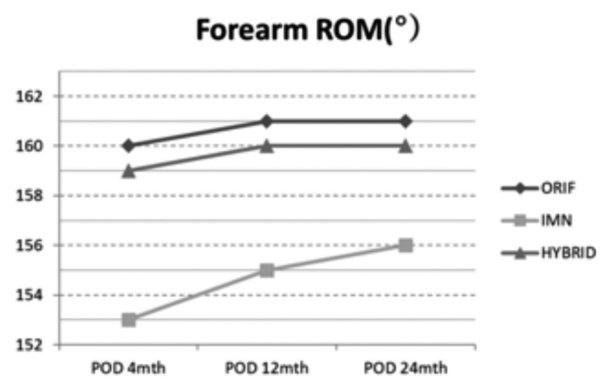


Figure 8. — The mean forearm range of motion measured at postoperative four months, 12 months, and 24 months according to the three surgical methods used.

and HYBRID groups (Fig. 8). Regardless of the time of assessment, no intergroup differences were observed in the functional outcomes assessed using the Grace and Eversmann rating system and DASH scores. ORIF group patients showed a significantly lower level of satisfaction relative to the patients in the IMN and HYBRID groups. The differences in satisfaction were significant in women (Table III).

Some complications occurred, but they were rare in the three groups (IMN group prevalence, 9%). One nonunion (no callus formation for 6 months on plain radiographs, IIIA open fracture of the ulna) and two delayed unions occurred in the IMN group. In the patient with nonunion, complete radiographic consolidation was achieved 16 weeks following removal of the nail and application of a plate supplemented with an autologous iliac crest bone graft. In the two cases of delayed union, complete union was achieved at 21 and 24 weeks without additional treatment. Nonunion and delayed union did not occur in the ORIF and HYBRID groups.

No refracture occurred in the IMN and HYBRID groups. However, in the ORIF group, one patient experienced a refracture after implant removal (22 months after initial surgery and seven weeks after implant removal). Thus, ORIF was performed again for this patient.

Table III. — Comparison of patient factor in three group patients

Variable	Four-month follow-up				Last follow-up			
	ORIF	IMN	Hybrid	P Value	ORIF	IMN	Hybrid	P Value
Functional recovery								
Pronation/supination (°)	160 ± 9^{b}	153 ± 7	159 ± 1^{b}	<0.05*	161 ± 5^{b}	156 ± 6	160 ±2^{b}	<0.05*
Grace and Eversmann rating system								
Excellent (n, %)	33 (80.6)	22 (78.6)	25 (79.1)	>0.05	35 (85.3)	23 (82.1)	27 (84.4)	>0.05
Good (n, %)	4 (9.7)	3 (10.7)	4 (12.5)	>0.05	4 (9.7)	3 (10.7)	3 (9.4)	>0.05
Acceptable (n, %)	4 (9.7)	3 (10.7)	3 (9.4)	>0.05	2 (4.9)	2 (7.1)	2 (6.2)	>0.05
DASH	13 ± 2	15 ± 4	14 ± 3	>0.05	15 ± 3	18 ± 3	16 ± 4	>0.05
Patient satisfaction								
Average	2.8	3.3	3.2	>0.05	2.8	3.3	3.2	>0.05
Sex								
Male	3.2	3.1	3.1	>0.05	3.2	3	3.1	>0.05
Female	1.9	3.6^{a}	3.4^{a}	<0.05*	1.7	3.8^{a}	3.6^{a}	<0.05*

^{a}P<0.05 compared with ORIF group. ^{b} P<0.05 compared with IMN group. * Statistically significan.t

In the ORIF group, one patient with an open fracture had a superficial infection, which resolved after the administration of oral antibiotics. No cases of deep infection, radio-ulnar synostosis between the forearm bones, compartment syndrome, failure of fixation, or breakage of a device occurred in the three groups.

DISCUSSION

The treatment of choice for both-forearm-bone fractures is plate osteosynthesis. Although plate osteosynthesis is currently the gold standard for the treatment of both-forearm-bone fractures, it has some disadvantages. As an alternative, IMN can be performed for the stabilization of both-forearm-bone fractures. However, it is difficult to accurately preserve the radial bow and reduce anatomical relationships in comminuted fractures using IMN. However, IMN has not been widely adopted for the fixation of both-forearm-bone fractures because of its limited indications *(11)*, namely poor soft tissue integrity such as burns, segmental fractures, multiple injuries, severe osteoporosis, and select type I and II open fractures. Other disadvantages of IMN include a reportedly high rate of nonunion, inability to restore accurate bowing of the forearm bone and insufficient rotational stability *(10,20)*.

Current concerns regarding the use of IMN in the forearm include the difficulty of preserving the radial bow. The forearm anatomy directly affects the biomechanics of the ulna (relatively straight) and radius (a gentle lateral bow). Sage described the lateral and dorsal bowing of the radius as 9.3° and 6.4°, respectively *(19)*. Restoration of the radial bow is an important step in reconstruction of the forearm after a diaphyseal fracture, because radial bowing is crucial to pronation-supination and enables the radius to rotate around the fixed ulna. Many authors argue that the recovery of forearm rotation and grip strength is associated with restoration of the radial bow to near normal *(9,15,21,25)*. Overcorrection, undercorrection, and a change in the location of the maximum radial bow have all been associated with loss of forearm rotation and grip strength *(21)*. When both bones of the forearm were angulated 10°, a loss of forearm rotation of 16% occurred *(25)* and this was associated with a restriction in pronation and supination of up to 20° *(9)*. With 20° of angulation, there was a statistically significant and functionally important loss of at least 30% of normal forearm rotation *(9)*.

Another treatment option for both-forearm-bone fractures is hybrid fixation. Theoretically, hybrid fixation should minimize some of the disadvantages of plate fixation and incorporate some of the advantages of IMN. However, there has been little research reported on hybrid fixation for the treatment of both-forearm-bone fractures. We sought to compare the three different operative methods for both-forearm-bone fractures based on the radiographic and functional outcomes.

In the present study, differences in time to union were observed according to the operative method employed. However, there was a non-significant trend toward higher rates of union in the ORIF group, with an index union rate of 100% in the ORIF group (n = 41), 97% for the IMN group (n = 28), and 100% for the HYBRID group (n = 32). There is a theoretical concern that the use of hybrid fixation may facilitate fracture healing with absolute stability in radius and relative stability in ulna. However, our study shows that the union rate and time to union were not significantly different from those of the ORIF group. These results were attributed to the gentle curvature applied to the radius during hybrid fixation, which resulted in a firm and accurate anatomical fixation. The use of the plate to the radius and application of the intramedullary nail to the relatively straight ulna yielded superior the time to union and incidence of nonunion, compared to the application of dual IMN, similar to the results with plate osteosynthesis.

We speculated that a more anatomically accurate reduction was possible with plate osteosynthesis due to the direct contact. In contrast to plate osteosynthesis, anatomical reduction was not only difficult to achieve with IMN, changes in the bony shape were caused by callus formation due to indirect healing. For this reason, we concluded that hybrid fixation, in which the radial bow is restored with anatomical accuracy using a plate and the straighter ulna is fixed with IMN, would be a good alternative option for surgically stabilizing fractures in both forearm bones. With regard to the radius, there was a significant difference in the location of the maximum bow between plate osteosynthesis (ORIF and HYBRID groups) and IMN (IMN group). Thus, the maximum bow for patients treated with plate osteosynthesis was closer to the uninjured value. There were also significant differences in the maximum magnitude of the radial bow ratio (injured side to contralateral side ratio) between plate osteosynthesis (ORIF and HYBRID groups) and IMN (IMN group). The maximum magnitude of the radial bow ratio for patients treated with plate osteosynthesis was also closer to the uninjured value. Thus, the magnitude and location of the maximal radial bow was nearly completely restored in the ORIF and HYBRID groups because a gentle lateral bowed radius was anatomically fixed with the plate. IMN showed similar results to plate osteosynthesis for the restoration of the ulnar bow because the ulna has a relatively straight morphology. The significant differences in the restoration of the bow affected the final forearm ROM and clinical outcomes in our study. We think that our data show the importance of anatomical reduction by plate osteosynthesis for the restoration of the radial bow, and suggest that the restoration of the normal radial bow affects the final clinical outcome.

Pronation and supination of the forearm measured at four months showed significant differences in the ORIF group (160°), IMN group (153°), and HYBRID group (159°). These differences persisted at the final assessment : ORIF group 161°, IMN group 156°, and HYBRID group 160°. The results were attributed to the effects of the different rehabilitation protocols employed according to the respective operative techniques and to differences in the restoration of the radial bow. That is, the forearm ROM in the ORIF and HYBRID groups during the early follow-up period (postoperative four months) was significantly different from that in the IMN group, due to the early active and passive movements in the two groups. The difference in the ROM persisted in the final follow-up for the patients in the IMN group, who started physical therapy relatively late and experienced a gradual increase in their ROM.

Although there are statistically significant differences on the final forearm range of motion, the difference was only 7 °at postoperative 4 month follow-up and the difference was only 5° at final follow-up. Although radial bowing restorations had a significant effect on the ROM of the forearm, the difference in ROM angle was relatively minimal, and the difference in ROM angle was further reduced by postoperative rehabilitation. The clinical outcome differences between ORIF, IMN, and the HYBRID fixation groups were considered to be small if the radial bow is corrected more than a certain amount.

The recovery times and patterns were different in the three groups in accordance with the surgical technique and rehabilitation protocols. The IMN group showed a higher level of patient satisfaction despite the longer time to bone union. In particular, women in the ORIF group showed progressively lower levels of satisfaction at each follow-up while women in the IMN and HYBRID groups showed progressively higher levels of satisfaction at each follow-up. The patients were highly interested in the external wound in addition to functional recovery. This tendency was more notable in female patients and was considered to be due to the cosmetic effect of the skin incision.

Our study is limited firstly by its retrospective nature, and the fact that it represents a review of the experience of only one surgeon. However, such analyses are characterized by gradual data collection and a uniform surgical technique, which is regarded as an advantage.

Second, this was a nonrandomized study, thus selection bias has to be considered in the group assignments. Selection of the surgical method was based on clinical criteria and physician discretion rather than objective criteria. However, statistical analysis did not reveal any differences in the fracture patterns, injury mechanism, number of open fractures, gender, and age in the three groups. Therefore, the effects of selection bias seem to be insignificant.

Third, this study is based on selective indication in both-forearm-bone fractures. For example, since the cases that required precise length preservation, such as comminuted diaphyseal fractures, Monteggia fractures, and Galeazzi fractures, were not included in this study, the results of the study cannot be generalized to all cases of both-forearm-bone fractures.

CONCLUSION

The treatment of choice for both forearm bone fracture is plate osteosynthesis. IMN and HYBRID fixation can be applied to cases of both-forearm-bone fractures in adults as an alternative option. Among them, HYBRID fixation tended to follow the advantage of each group when compared with plate osteosynthesis group and IMN group. With an appropriate selection of indications taking into account the patient's medical condition, soft tissue condition, fracture pattern and patient's concern about cosmesis, especially women, HYBRID fixation can show results comparable to plate osteosynthesis.

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