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ORIGINAL ARTICLE

Nascent Malunion of Distal Radius Fractures Treated with Fixed Angled Volar Plates without Using Bone Grafts

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Abstract

Purpose Malunion of the distal radius is a common complication. Using bone grafts is common to restore the bone to an acceptable level. This study aimed to verify if it is necessary to use bone grafts in nascent malunion of distal radius fractures treated with fixed angled volar plates and which radiographic parameters are essential to obtain satisfactory outcomes.

Methods This single-centered prospective study included 11 patients who underwent corrective osteotomy of the radius for malunion. Patients with a metaphyseal, extraarticular osteotomy stabilized by a volar fixed angle plate within 3 months after the fracture are included. Patients underwent a standard radiological evaluation at postoperative 1 month, 3 months, 6 months, 1 year, and annually thereafter. Radial inclination, radial height, ulnar variance, and palmar tilt were measured. Wrist ranges of motion are measured throughout follow-up with a goniometer. Grip strength is measured using a Jamar Hand Dynamometer. The function is evaluated via the Gartland–Werley (GW) score and the Disabilities of the Arm, Shoulder, and Hand (DASH) score.

Results The mean age of 11 patients, 9 (81.82%) males, included in the study was 41.45 ± 14.89 years. The mean post-fracture admission time is 39.3 ± 15.1 days. Radial inclination, radial length, and ulnar variance improved significantly after surgery ($p = 0.0023$, 0.0002, 0.0037). Radial inclination values are within normal limits for all patients at admission. The radial length was in the normal range for 72.73%, the ulnar variance was in the normal range for 72.73%, and palmar tilt was in the normal range for 100% of the patients. Extension 54.55%, flexion 72.73%, radial deviation 81.82%, ulnar deviation 63.64%, pronation 90.91%, and supination 72.73% were achieved after surgery. GW average was 3.09 ± 3.24 DASH score average was 12.24 ± 13.48. The mean grip strength was 29.27 ± 7.21 on the operated side, while it was 34.91 ± 5.32, on the healthy side, with a significant difference ($p = 0.0108$).

Conclusion It is possible to get good results without using bone grafts in corrective osteotomy of distal radius malunions.

Keywords Corrective osteotomy · Distal radius fracture · Nascent malunion · Volar fixation

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Introduction

Malunion of the distal radius is a common complication, especially in unstable patterns treated conservatively with a cast. Malunion of the distal radius is reported in approximately 35% of conservatively treated fractures and up to 10% of surgically treated fractures [1]. Haase et al. attempted to define unacceptable healing for distal radius fractures [2]. Radial inclination < 10°, radial height < 10 mm, ulnar variance > 2 mm, palmar tilt > 20° or dorsal tilt > 20°, and intra-articular step or gap > 2 mm are considered unacceptable radiographic criteria. Malunion comes with pain, decreased range of motion, and loss of grip strength, resulting in difficulty performing daily activities [3]. Decreased radial inclination leads to alterations as transferring the load dorsoulnarly, reduced DRUJ space; as a result, DRUJ pain and decreased forearm rotation [4]. Increased dorsal tilt causes an increase in the force over the distal ulna and dorsal force concentration over the distal radius and osteoarthritis as well [4]. The changes in alignment can lead to adaptive dorsal intercalated segment instability (DISI); less commonly, carpal instability non-dissociative is also described [5].

Malunions to a limited degree in lower-demand elderly patients may be adequately treated by conservative methods [6]. If surgical treatment is necessary, osteotomy of the distal radius is commonly performed with a single operation, leaving the ulna untouched in our clinic. Some available articles shorten the ulna in single or multiple stages [7, 8].

The primary aims of the study are to question the necessity of bone grafts in nascent malunion of distal radius fractures treated with fixed angled volar plates, to determine the radiographic parameters that are essential to obtain satisfactory outcomes, and also to reveal the tricks of achieving good function in AO type C fracture malunion, where anatomical reduction is not completely possible.

Materials and Methods

Patients

Between April 2019 and December 2021, 19 patients with symptomatic malunion of the distal radius underwent corrective osteotomy. Only 11 adult patients who had volar plate fixation without bone grafting following a metaphyseal extraarticular distal radius osteotomy within 3 months after the fracture was included. Those in the pediatric age group ($n = 4$), intra-articular osteotomies ($n = 1$), bone graft usage ($n = 2$), and lost in follow-up ($n = 1$) were excluded. Patients with scaphoid fracture and DRUJ subluxation were also treated correctly, which did not appear to affect outcomes and were included in the study. Concomitant injuries were inevitable since most cases occurred either as a result of a high-energy injury, such as falling from a height, or with low-energy but comminuted fractures due to osteoporosis. This is a single-center prospective study approved by the ethics committee with the approval number E1-20–691.

Ten of the 11 cases were followed by plaster casts in other clinics and were admitted with malunion. The other patient had an external fixator applied to the wrist due to an additional critical trauma in another clinic. So, unfortunately, none of the patients are under our follow-ups from the moment of fracture.

Demographics, side, dominance for side, job, whether the patient changed job, smoking status, type of initial trauma, type of initial treatment, additional injuries, presence of RSD, time till our treatment (days), follow-up period after our surgery (months) and union time (days) were recorded.

Surgical Procedure

Surgery was performed under regional anesthesia and tourniquet control through a 6 cm volar incision overlying the flexor carpi radialis (FCR) tendon. The FCR sheath was incised along its radial border to avoid the palmar cutaneous branch of the median nerve and then through the floor of the sheath. The deep approach was between the FCR, which was retracted radially toward the radial artery, and the flexor pollicis longus (FPL), retracted ulnarly. The pronator quadratus was incised along its radial and distal borders and retracted in an ulnar direction, exposing the entire distal radius. The prior fracture site and apex of the deformity were easily identified by direct inspection, with landmarks confirmed radiographically. The brachioradialis was released from the distal radius, and the wrist and digital extensor tendons were elevated from the dorsal surface of the radius from the radial side with a curved periosteal elevator before osteotomy. An osteotomy was performed with a thin osteotome, following the traces of the old fracture lines. After correcting, the sharp edges on the proximal and dorsal border of the distal fragment adjacent to the extensor tendons were trimmed. The complete anatomical reduction did not occur in any case due to the partial disappearance of the fracture lines and the severity of the prior comminution. The osteotomy line was distracted using a spatula, the radius length was adjusted with traction, and the osteotomy line was fixed with a temporary oblique Kirschner wire over the radial styloid and radius shaft. The volar fixed angle plate was attached to the distal fragment and checked radiographically for plate alignment. The combined unit of the plate and the distal fragment

were then oriented relative to the radial shaft to correct the original deformity's length, tilt, and inclination. The plate was first fixed to the distal fragment and then to the shaft with screws. The cavity volume formed by the osteotomy was left empty in all cases.

The DRUJ stability was manually tested. The pronator quadratus was closed over the plate and osteotomy gap, followed by skin closure and dressing with a volar splint holding the wrist in slight extension. The temporary K-wire was removed but, in some cases, left in place for 2 weeks. When adding the K-wire to the construct, the primary goal was to preserve the surgical reduction while starting early motion in cases with poor distal screw fixation. There was no reduction loss in any of the patients. If the K wires were not placed, these fractures might have collapsed.

Postoperative Rehabilitation

Postoperatively, a short arm volar splint was applied to the patients, and active finger exercises were started immediately. After 2 weeks, the sutures and the splint were removed, and physical therapy was started under the guidance of a physiotherapist. Anti-edema therapy, tendon gliding, and ROM exercises continued during weeks 2–6.

Radiologic Evaluation

The radiologic evaluation was based on the posteroanterior and lateral wrist X-rays taken at the time of injury and postoperatively. Patients underwent a standard radiological evaluation on the postoperative 1st day, postoperative 1st, 3rd and 6th months, 1st year, and annually thereafter. X-rays were taken preoperatively, on the postoperative 1st day (early postoperative), and at the last follow-up (late postoperative) were evaluated. The measurements were made, as described in the article by Blakeney [9]; dorsal/palmar tilt, radial height, radial inclination, and ulnar variance were measured.On the AP view, radial inclination, radial height, and ulnar variance were measured, while dorsal/palmar tilt was estimated on the lateral view. The radial inclination is the angle between the perpendicular to the neutral axis of the radial shaft and a line drawn from the radial styloid to the distal margin of the sigmoid notch. Radial height is the distance between two lines drawn perpendicular to the long axis of the radius from the apex of the radial styloid and the level of the ulnar aspect of the articular surface. Tilt is the measured angle between the perpendicular to the neutral axis of the radial shaft and a line drawn between the radius's volar and dorsal articular margins. Positive values indicate volar tilt, and negative values indicate dorsal tilt. Ulnar variance is the longitudinal distance, measured in millimeters, between the distal margin of the ulnar head and the subchondral line of the distal radial articular surface where the lunate fossa meets the sigmoid notch on a neutral forearm rotation. Positive values indicate the ulna to be more distal than the radius, and negative values indicate the ulna to be more proximal than the radius. Jupiter's criteria were used for the radiologic variables. Unacceptance criteria are radial inclination $< 100°$, volar tilt $> 20°$ or dorsal tilt $> 20°$, radial height < 10 mm, ulnar variance $> +2$, intraarticular step or gap > 2 mm [10, 11].

Dorsal and volar gaps were measured to see any relation regarding the size of the defect afterward. The longest diameters of the gap on the AP and lateral wrist X-rays were measured.

At the follow-up visits, the timing of the union was recorded according to the x-ray, and if the union is delayed, tomography was taken for confirmation.

Functional Evaluation

Preoperative range of motion data was found from the physical examination notes, given as total flexion–extension arc angle. Postoperative wrist range of motion is measured throughout the follow-up with a goniometer. Cut-off values for the range of motion are accepted as follows; extension 68°, flexion 68°, radial deviation 20°, ulnar deviation 26°, pronation 70°, supination 85° [12, 13].

Grip strength is evaluated by comparing the injured side with the uninjured. The patient was seated with the elbow at 90° of flexion. The grip strength of both hands was measured using a Jamar Hand Dynamometer. The mean of three measurements is used.

Patients were evaluated by a senior author and a resident for the Gartland–Werley (GW) score and the Disabilities of the Arm, Shoulder, and Hand (DASH) score.

Statistical Analysis

StataMP13 (StataCorp. Stata Statistical Software: Release 13) was used for descriptive and inferential analyses. Shapiro–Wilk test was used to assess normality. Chi-square and Fisher's exact tests were used for categorical variables. For comparisons between independent groups, *T*-Test for the parametric and the Mann–Whitney *U* test for the non-parametric data were used. Wilcoxon for 2 groups and Friedman for 3 groups were used for dependent group comparisons. A P-value less than 0.05 was accepted as significant. For the correlation analysis, the Pearson test was used if both variables were parametric; if any of the variables was non-parametric, the Spearman test was used. According to the study of Chan et al. rho > 0.7 is accepted as solid relation [14].

Results

The mean age of 11 patients, 9 (81.82%) males, included in the study was 41.45 ± 14.89 years. The dominant side was operated on in 2 (18.18%)) patients. The mean post-fracture admission time is 39.3 ± 15.1 days. According to the AO classification, 1 patient (9.09%) was accepted as 23.A3, 1 patient (9.09%) 23.C1 8 patients (72.73%) 23.C2, and 1 patient (9.09%) 23.C3. Mean follow-up time was 22.1 ± 4.4 months (min 14- max 30). At admission, 8 patients had an ulnar styloid fracture, 1 patient had an additional acetabular fracture, 1 patient had an additional scaphoid fracture, and 1 patient had additional DRUJ subluxation. While K wire was left in place in 6 patients (54.55%), it was removed in 5 patients (45.45%).

Radial inclination, radial length, and ulnar variance improved significantly after surgery ($p = 0.0023$, 0.0002, 0.0037) (Table 1). Radiologic parameters were significantly better in the postoperative x-rays, and there was no difference between the early and postoperative periods; showing no loss in reduction. At the time of admission, 11/11 (100%) radial inclination, 4/11 (36.36%) radial height, 7/11 (63.64%) ulnar variance, and 6/11 (54.55%) palmar tilt was in the acceptable range. Postoperatively 11/11 (100%) radial inclination and palmar tilt, 8/11 (72.73%) radial height, and ulnar variance were achieved.

The mean dorsal gap is 5.86 ± 3.61 mm and the mean volar gap is 2.14 ± 0.98 mm. As the size of the dorsal defect increased the time to union was prolonged (rho = 0.7268 for dorsal gap). In the follow-up of all the patients, bone healing was achieved without additional interventions. The mean time for the union is 69.00 ± 52.04 days. In 2 patients with a delayed union, additional CTs were taken to confirm the union. One patient with delayed union did not stop smoking, did not perform exercises, and returned to work early. Four of the 11 patients were heavy smokers and did not stop smoking after surgery. All working patients were able to continue their pre-operative jobs.

When the patients' range of motion was compared with reference values, extension 54.55%, flexion 72.73%, radial deviation 81.82%, ulnar deviation 63.64%, pronation 90.91% and supination 72.73% were achieved after surgery (Table 2). GW average was 3.09 ± 3.24 and the mean DASH score was 12.24 ± 13.48. Postoperative mean grip strength was 29.27 ± 7.21 on the operated side, while it was 34.91 ± 5.32, on the healthy side, with a significant difference ($p = 0.0108$). The ratio of the operated side to the control side is 0.84 ± 0.14 on average.

The comparison of patients with and without K-wire showed no significant functional change other than the radial deviation being significantly higher in the pinned group ($p = 0.0338$). Preoperative radiographic findings of reflex sympathetic dystrophy (RSD) were observed in 4 patients (36.36%). The presence of RSD preoperatively did not affect the functional outcomes. Correlation

Table 2 Wrist range of motion values and the percent in the normal range is given

	Angle mean (Std)	Normal range *N* (%)
Extension	65.45 (11.50)	6 (54.55)
Flexion	71.82 (9.82)	8 (72.73)
Radial deviation	20.82 (4.51)	9 (81.82)
Ulnar deviation	28.55 (7.97)	7 (63.64)
Pronation	72.27 (6.47)	10 (90.91)
Supination	80.91 (8.61)	8 (72.73)

Table 1 Radial inclination, radial height, ulnar variance, and palmar tilt data is given for the preoperative, early postoperative and late postoperative period

	Preoperative	Early postoperative	Late postoperative	*P*	Final difference
Radial inclination (°)	18.27 (3.82) 11 (100%)	24.09 (2.15) 11 (100%)	24.00 (2.07) 11 (100%)	**0.0023**[a]	5.73 (4.24)
Radial height (mm)	8.45 (3.55) 4 (36.36%)	11.75 (2.88) 8 (72.73%)	11.64 (2.87) 8 (72.73%)	**0.0002**[b]	3.18 (2.91)
Ulnar variance (mm)	2.64 (2.19) 6 (54.55%)	1.23 (1.25) 9 (81.82%)	1.32 (1.55) 8 (72.73%)	**0.0037**[c]	–1.32 (1.95)
Palmar tilt (°)	− 4.73 (24.01) 6 (54.55%)	2.27 (4.54) 11 (100%)	1.91 (5.10) 11 (100%)	0.9294	6.64 (21.93)

Values are given in the form of mean (std) on top line, and number of patients in acceptable range (%) on the bottom line of each cell

P values are the comparisons of 3 measurements: preoperative, early and late postoperative periods. Friedman test is used. For the significant ones, intermeasurement analysis is performed using the Wilcoxon test

$P < 0.05$ is accepted as significant and given in bold

[a]There is no difference between early and late postoperative periods for RI ($p = 0.0843$). Preoperative RI is significantly lower than both early and postoperative RI ($p = 0.0066$, 0.0066)

[b]There is no difference between early and late postoperative periods for RU ($p = 0.0840$). Preoperative RU is significantly lower than both early and postoperative RU ($p = 0.0038$, 0.0068)

[c]There is no difference between early and late postoperative periods for UV ($p = 0.5650$). Preoperative UV is significantly higher than both early and postoperative UV ($p = 0.0066$, 0.0288)

Table 3 Details of the 11 patients

NO	Sex Age	Side (Dom)	AO 23	Job (change)	Smoking (pack/d)	Trauma	First TX	Preop RSD	Preop ROM	Additional injury	Time till TX (d)	K wire	Follow up (m)	UC pain	Union (d)	Notes
1	M 35	Left (−)	C3	Worker (−)	1	Fall from height (3rd floor)	External fixator	–	50	US Pelvis	44	–	14	-	128	
2	M 32	Left (−)	C2	Worker (−)	1	Fall from height (4 m)	Cast	–	30	US	28	–	18	+	48	Workers' compensation claim
3	M 64	Left (−)	C2	Lorry driver (−)	2	Traffic accident (out of the car)	Cast	+	60	–	58	–	19	–	50	
4	M 55	Left (−)	C2	Civil servant (−)	1	Fall (same height)	Cast	–	35	–	35	+	19	–	204	Heavy smoker, noncompliant
5	F 59	Left (−)	C2	Retired (−)	–	Fall (same height)	Cast	–	60	US	24	–	25	–	58	Parkinsonism
6	M 18	Right (+)	C1	Electrical technician (−)	–	Traffic accident (out of the car)	Cast	–	70	US	26	–	24	–	40	Tendon irritation, plate removed
7	M 26	Right (+)	C2	Accountant (−)	–	Fall from height (from tree)	Cast	–	45	US Scaphoid	18	+	24	–	35	
8	M 30	Left (−)	A3	Private security (−)	–	Fall (same height)	Cast	+	70	US	53	+	26	–	74	
9	M 53	Left (−)	C2	Civil servant (−)	–	Traffic accident (motorcycle)	Cast	–	70	US	65	+	30	–	44	
10	M 46	Left (−)	C2	Academic (−)	–	Fall (same height)	Cast	+	70	US	45	+	22	–	40	
11	F 38	Left (−)	C2	Real estate agent (−)	–	Fall (same height)	Cast	+	30	US DRUJ dislocation	36	+	22	–	38	

M male, *F* female, *US* ulnar styloid, *DRUJ* distal radioulnar joint, *RSD* reflex sympathetic dystrophy

In the "job" colon, + and − in the paranthesis showed whether a change is job is needed due injury

Table 4 Details of the 11 patients (continued)

NO	RI (°) Preop Early PO Late PO	RH (mm) Preop Early PO Late PO	UV (mm) Preop Early PO Late PO	PT (°) Preop Early PO Late PO	GAP (mm) Dorsal Volar	EX (°)	FL (°)	RD (°)	UD (°)	PR (°)	SP (°)	GW	DASH	Grip op/nop (%)
1	13.0	**4.5**	**5.5**	− 18.5	12.0 1.5	75	85	20	30	75	85	1	5.8	32/32 %100
	24.0	13.0	2.0	5.5										
	23.5	12.0	2.0	5.5										
2	18.0	11.5	1.0	− 6.5	4.0 1.5	**55**	**50**	**14**	27	70	**65**	6	38.0	20/29 %69.97
	25.7	13.0	1.0	8.0										
	25.5	13.0	1.0	9.0										
3	13.0	**9.0**	0.0	**− 22.0**	5.0 2.0	**65**	80	20	30	70	85	1	5.8	32/32 %100
	22.5	**9.2**	0.0	0.0										
	22.5	**9.0**	0.0	0.0										
4	13.5	**3.5**	**3.0**	**− 31.5**	12.0 4.0	**50**	70	20	30	7	85	7	5.0	29/42 %69.05
	22.0	**8.5**	2.0	− 0.5										
	22.0	**7.5**	2.0	0.0										
5	21.0	**6.0**	**4.0**	**− 30.0**	5.5 2.0	75	75	**15**	**25**	70	85	7	38.5	21/29 %72.41
	23.0	**9.0**	**3.0**	− 3.0										
	23.0	**8.5**	**3.0**	− 6.5										
6	22.0	12.0	− 1.0	19.0	1.5 4.0	80	70	20	**25**	90	90	0	4.0	45/44 %102.27
	27.0	15.5	− 1.0	4.0										
	25.0	14.5	− 1.0	0.0										
7	21.0	15.0	2.0	15.0	4.0 2.0	70	80	30	45	70	85	1	1.0	35/40 %87.50
	21.0	15.0	1.5	0.0										
	21.0	15.0	**3.0**	0.0										
8	23.0	10.0	2.0	**27.5**	4.0 1.5	75	80	20	**25**	75	85	0	10.0	21/33 %63.64
	22.0	11.0	1.0	3.5										
	22.0	10.0	1.0	7.0										
9	**16.0**	**5.0**	**5.5**	**− 37.0**	9.5 2.0	**60**	70	20	30	70	**75**	8	14.0	30/39 %%76.92
	27.0	12.0	**3.0**	− 5.0										
	27.0	11.0	**3.5**	− 4.0										
10	**19.0**	**8.5**	**5.0**	19.5	4.0 1.0	70	**65**	25	35	70	85	0	1.0	29/32 %90.63
	27.5	17.0	0.0	2.5										
	26.5	16.5	− 1.0	1.0										
11	21.5	**8.0**	2.0	12.5	3.0 2.0	**45**	**65**	25	**12**	**65**	**65**	3	11.5	28/32 %87.50
	26.0	11.0	1.0	10.0										
	26.0	11.0	1.0	9.0										

Values that are out of the acceptable range are given in bold

RI radial inclination, *RH* radial height, *UV* ulnar variance, *PT* palmar tilt

EX extension, *FL* flexion, *RD* radial deviation, *UD* ulnar deviation, *PR* pronation, *SP* supination, *GW* Gartland-Werley, *DASH* Disabilities of the Arm, Shoulder, and Hand

analysis between radiologic parameters and functional outcomes showed no relation for DASH score or grip strength. But GW score is correlated with palmar tilt correction (rho = 0.8447, $p = 0.001$) and final ulnar variance (rho = 0.7311, $p = 0.0106$).

Detailed data of 11 patients included in the study are given in Tables 3, 4.

Discussion

Examining the results of this study, surgical correction resulted in a significant improvement in postoperative radial height, and ulnar variance. Statistics show no significant difference in palmar tilt, but this is due to the huge standard deviation preoperatively. The correction in the palmar tilt could be assessed by interpreting the percentage of patients in the acceptable range, which is 100% postoperatively, whereas it was only 54.55% preoperatively. The ulnar variance was still > 2 in the last measurements for 3 patients, but this did not affect the function. This study addresses exactly that dynamic situation. When considered the DRUJ in 3 dimensions, a positive ulnar variance does not matter in the presence of a restored palmar tilt, and impaction does not occur when the ulna is not subluxed dorsally.

Restoration of range of motion was observed in pronation and supination, radial and ulnar deviation, and flexion, and the least was seen in extension. The analysis is made according to the cut-off values. According to Ryu et al. most functional tasks could be accomplished with 70 percent of the maximal range of wrist motion [15]. When 70% is accepted as the minimum of the range, all of our patients are in the accepted range.

The study also showed that the function was regained in terms of grip strength to 84% compared to the non-injured hand. No evidence of osteoarthritis was found in this short-term follow-up. GW score showed a correlation with palmar tilt correction and final ulnar variance. As a result, the radiologic parameters that affect the results are the ulnar variance and palmar tilt, which is perhaps this study's most important achievement.

A common complaint of patients with malunited distal radius fracture is ulnar sided wrist pain and only 1 of our patients had ulnar corner pain, patient#2, the one with the workers' compensation claim. The absence of this complaint is probably due to the restored palmar tilt.

Our literature review found several data regarding the clinical outcome of displaced distal radius fractures. Reports linking radial shortening with pain, instability, and restricted forearm pronation and supination indicate that radial length is the most important factor affecting functional outcome [16–18]. In our study, the palmar tilt and ulnar variance, not the radial length, was found to be the most important parameter. Rubinovich and Rennie reported that failure to restore normal radius volar tilt had a detrimental effect on functional outcomes, particularly grip strength, as in our study [19]. There is a marked difference in patients younger than 60 years or older with extraarticular fractures of the

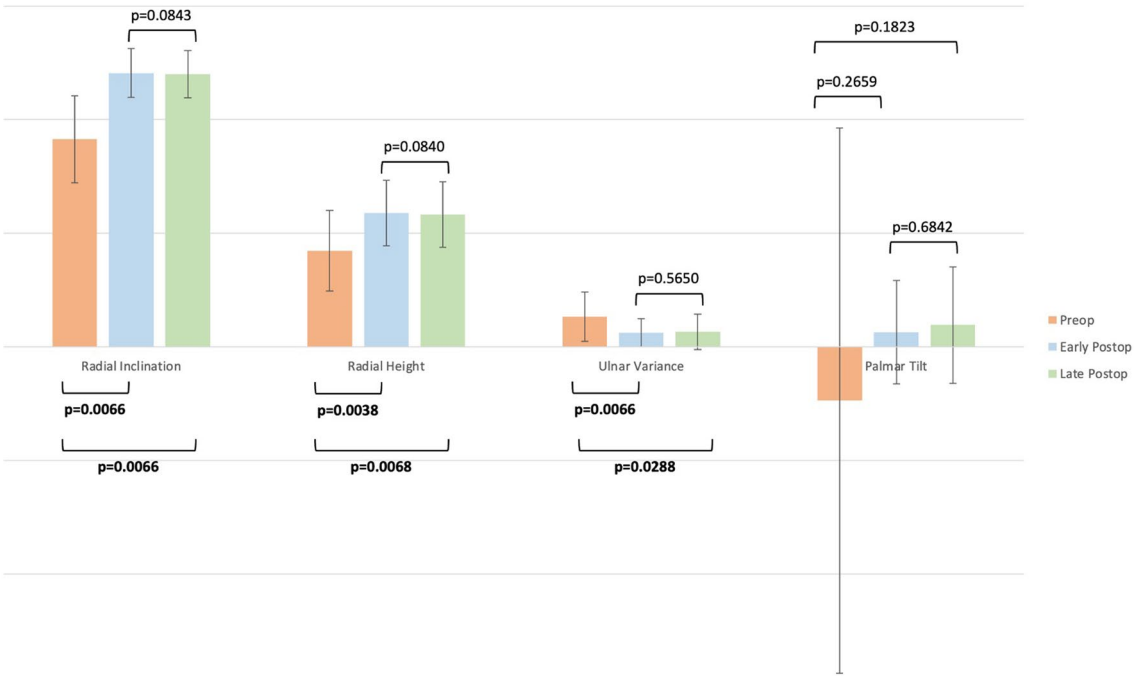

Fig. 1 Radial inclination, radial height, ulnar variance, and palmar tilt data are given for the preoperative, early and late postoperative periods

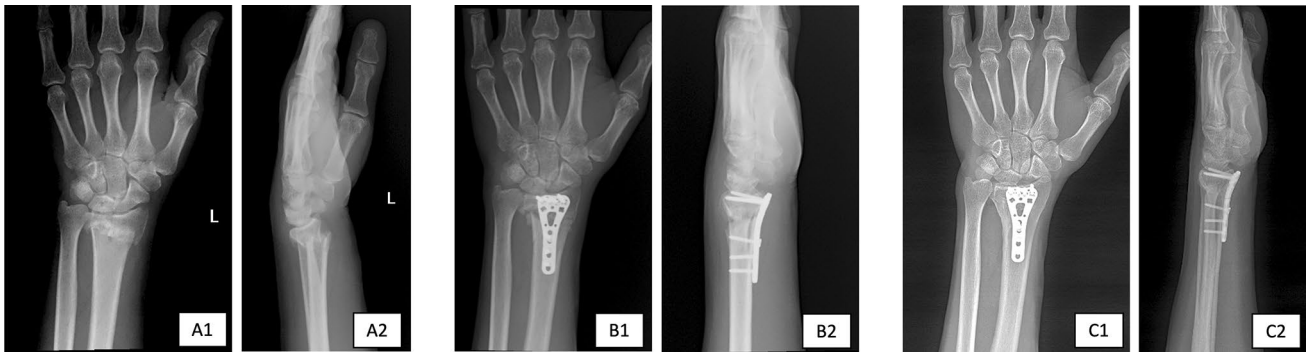

Fig. 2 Radiologic images of the patient #4, the heavy smoker and noncompliant patient. **A** Preoperative AP (1) and lateral (2) images. **B** Postoperative 14-month AP (1) and lateral (2) images, showing non-union. **C** Postoperative 19-month AP (1) and lateral (2) images, showing delayed union

distal radius [20]. In the younger patients, there was a solid link between poor outcomes and a malalignment of the distal radius. In elderly patients, there is no statistically significant relationship between radial length, radial tilt, or dorsal tilt and pain and disability. Our experience shows that the focal point of the treatment of nascent malunion of distal radius fractures with volar-locked plates is to reduce the fractures to restore particularly volar tilt and ulnar variance, as shown by the results of recovery of ROM and activity scores (Fig. 1).

According to the literature, after the decision to intervene in the malunion of the distal radius, surgery should be performed as soon as possible, provided that there is no trophic change, acceptable bone quality, and adequate wrist function [10]. Our study also obtained good results in 4 patients who did not have trophic findings but underwent corrective osteotomy despite radiographic RSD findings. This result shows us that radiographic signs alone are not crucial for surgical decision making in patients presenting with RSD. Certainly, in the literature, there are patients with malunion who first admitted to the physiotherapy program and operated months later due to lack of movement, grip strength, and diagnosis of RSD [21]. What we advocate here is to show that when these patients come to our clinics, it is better for the patient to start early surgery and following early therapy program without wasting time. We have seen that the results of those who are operated early on are also good.

It is known that early correction in distal radius malunion has better clinical results than late correction [22]. We believe achieving success with early corrective osteotomy without using structural or nonstructural bone grafts is possible. The results of structural and nonstructural grafts were previously shown to be similar radiographically and functionally [23]. This study obtained bone union and satisfactory functional results in all osteotomies without using bone grafts. This result encouraged us to believe that corrective osteotomy of the distal radius can be performed without bone grafting.

Three patients with low-performance scores were also examined to reveal the reasons that may adversely affect the results of such a risky surgery. Patient no. 2 came with a wrist fracture 4 weeks after the work accident, applied for a workers' compensation claim, and was constantly trying to get bad results. In the follow-up of the elderly patient no. 5, severe parkinsonism symptoms appeared, adversely affecting the results. Patient no. 9 was a heavy smoker, did not apply any given exercises, and returned to his manual work immediately after surgery. Therefore, his bone healed much later than the other patients (Fig. 2). It is essential to mention that three patients with relatively poor results stated that they would like to have wrist surgery again if they had broken their wrists. The surgery performed and the results obtained are satisfactory enough for the patients.

We think using a K-wire biting 2 cortices of the osteotomy contributes to mechanical stability. For this reason, we supported the skeleton with a K wire to prevent collapse while starting early physical therapy in cases with a risk for healing. This is the first time such a hybrid fixation has been studied in the literature, but it is also an issue that needs to be studied. The results showed no effect, but this issue should be evaluated with a larger patient number.

Eight patients had AO 23C2 type fractures, and the need for an intraarticular osteotomy is inquirable. The bone was fused entirely when these patients applied to us with AO type C2 simple intra-articular fractures. On CT, none of the patients had a displacement greater than 2 mm, and we think intra-articular osteotomies in such cases would increase surgical morbidity. One patient with > 2 mm displacement in our case series was excluded due to the performed intraarticular osteotomy.

The study lacks the preoperative GW, DASH, and grip strength data. These patients underwent surgery as soon as we removed their casts. Also, from the patient's point of view, preoperative orthopedic scoring of the patients and asking to squeeze the arm of a dynamometer was not found

to be ethical since it may cause psychological trauma in a patient recovered with a malunion. The healthy side data are only for grip strength. Other than the normal range among the population, comparing the radiologic parameters with the healthy side would provide individual norms. This study was conducted with a relatively small number of patients by ignoring some radiographic parameters (e.g., radial height) those other surgeons considered as a culprit in unsatisfactory results. Also, it is preferred to have a homogenous group rather than a large one. In addition, this study differs from others without using bone grafts by revealing which of the radiological criteria directly affected the result in challenging cases where anatomical reconstruction is not completely possible. Since healing was achieved without using bone grafts in this study, there is a need for a prospective randomized controlled study with a bone graft group to increase the level of evidence.

Conclusion

It is possible to get good results without using bone grafts in corrective osteotomy of distal radius malunions. In the surgical technique, short-term K-wire fixation and the volar plate may improve radial deviation in some patients. A corrective osteotomy before trophic findings appear in RSD can improve the patient's hand function. Cooperative patients are essential for successful results in this technically demanding surgery.

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Declarations

Conflict of interest All authors have no potential conflicts of interest, including financial interests, activities, relationships, and affiliations, to disclose.

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Informed consent Informed consent was obtained from all individual participants included in the study.

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