Original article

Dorsally and volarly angulated extra-articular malunions of the distal radius treated with volar corrective osteotomy and volar locking plate fixation. A case series of 19 patients with a long-term follow-up

Agostino Di Maro[1], Matteo Meroni[2], Placido Stissi[1], Michele Francesco Surace[1], Mario Cherubino[3], Alessandro Fagetti[3]

[1]Division of Orthopaedics and Traumatology, Department of Biotechnology and Life Sciences (DBSV), University of Insubria, Varese, Italy; [2]Orthopaedic and Traumatology Department, Regional Hospital of Locarno, Switzerland; [3]Microsurgery and Hand Surgery Unit, ASST Sette Laghi, Varese, Italy

Abstract. *Background and aim:* To date, different technique of corrective osteotomy for the treatment of distal radius extra-articular malunions are described. With this study, we present a case series of corrective osteotomy using volar plate fixation to treat volar and dorsal extra-articular malunions aiming to evaluate the effectiveness of corrective osteotomies through volar plate stabilization in these two types of extra-articular malunions. *Methods:* Between August 2008 and May 2017 all patients diagnosed with extra-articular malunion were included in the study. An extended volar Orbay approach and two types of dedicated volar locking plate (Medartis AG, Switzerland and Acumed, Hillsboro,OR) were used. Clinical and radiological parameters were evaluated. The DASH and PRWE scores and the VAS scale questionnaires were administered. The results were analyzed through statistical evaluations. *Results:* A retrospective analysis of 19 patients diagnosed with extra-articular malunion was carried out. Nine had a volar type deformity (group A), while the other 10 had a dorsal type deformity (group B). The active range of motion (aROM), radiographic parameters, grip strength and pinches in both groups were statistically improved, except for radial deviation in both groups, ulnar deviation in group A, and radial inclination in group B. The grip strength and pinches values were slightly better in group A. DASH, PRWE scores and VAS scale showed a significant improvement. *Conclusion:* Corrective osteotomy through volar fixation is an effective technique to treat both extra-articular dorsally and volarly angulated malunions. Statistically significant benefits are present in both types of deformities, with better outcomes in the group of volar deformities. (www.actabiomedica.it)

Key words: Extra-articular fracture, Distal radius malunion, Volar and dorsal deformity, Corrective osteotomy, Volar locking plate

Introduction

Fractures of the distal radius represents a common injury, constituting about 8-17% of all fractures of the extremities (1). A frequent complication of distal radius fractures is the malunion: it appears with a recurrence of about 23% of distal radius fractures poorly healed after conservative treatment, and about 11% of cases treated after surgery. They can be classified as intra-articular, extra-articular, combined patterns, dorsally and volarly displaced (2,3).

Regarding the surgical treatment of extra-articular malunions, in the past the surgeons preferred a corrective dorsal osteotomy and fixation with dorsal plate in malunions with dorsal or volar deformities (4,5,6). Later, they were more in favour of using a corrective osteotomy and perform a stabilisation with volar locking plate (7,8).

Regarding the use of bone graft, its real advantage of the graft has been questioned (9,10).

The aim of this study is to evaluate, at long-term follow-up, the outcomes of corrective osteotomy using a volar locking plate fixation in both dorsal and volar extra-articular malunions. Further purpose is to investigate whether better clinical-radiographic results of corrective volar osteotomy were obtained in volar or dorsal malunions. Moreover, we want to evaluate whether the bone grafting significantly contributed to the improvement of results in these two types of deformities.

Materials and methods

Between August 2008 and May 2017, all patients with extra-articular malunions of distal radius (type 23-A according to the AO/OTA classification) were included in the study. All the patients were treated with a volar corrective osteotomy and volar locking plate at Microsurgery and Hand Surgery Department of the ASST Settelaghi (Varese, Italy) by an experienced hand surgeon (A.F.) (11).

Inclusion criteria were patients with extra-articular malunited fractures treated conservatively at the time of trauma, who could participate fully in the study and with at least 1 years of follow-up. Among the inclusion criteria, the patients involved in the trial did not have to suffer from other types of injuries or fractures to the upper extremities, neither from neuromuscular diseases.

Surgical indications were functional impairment during normal daily activities, wrist pain and anatomical deformities, radiographic parameters of malunited fractures (12,13). Exclusion criteria were patients with partial intra-articular fracture (AO type B), complete intra-articular fractures (AO type C), and those who initially treated the fractures with surgery.

An extended volar Orbay approach (14) and two types of dedicated volar locking plate (Medartis AG, Switzerland and Acumed, Hillsboro, OR) were used in our cases. The Acumed plates were used in our hospital from 2006 to 2013, while the Medartis plates were used from 2014 to 2017. Depending on the surgeon's preference, a distraction-type or a hinge-type osteotomy was performed (15,16). In case of distraction-type osteotomy, an autogenous corticocancellous iliac crest (ACIC) bone graft was always applied to fill the gap. In hinge-type osteotomy, a dorsal cortical contact was kept in cases of volar deformity (Fig.1), while a volar cortical contact was retained in dorsal deformity, so always performing an open wedge osteotomy without use of bone graft (17).

In case of volar malunion, two K-wires were used, one proximal and one distal to the osteotomy site, to determine the correction angle. Moreover, they were also used as joysticks to correct the misalignment angle. The goal was to make the K-wires parallel to each other. A lamina spreader was used to achieve the correct alignment of the distal radius on sagittal and coronal planes.

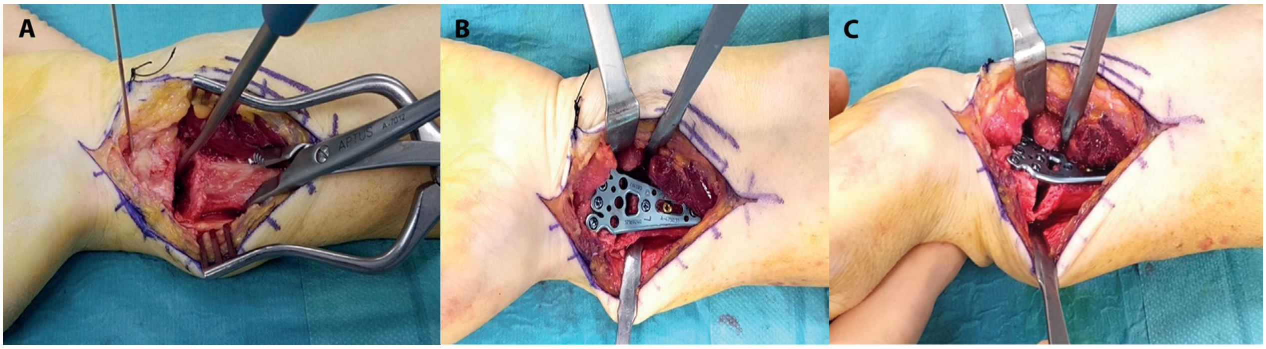

Fig. 1. (A-C) Images of intraoperative correction of a dorsal malunion and its fixation with a volar locking plate.

Regarding the surgical technique for dorsal deformities, the distal part of the plate was temporarily fixed to the distal radius and the obtained angle between the proximal part of the plate and the shaft of the radius indicated the misalignment to be corrected. An osteotomy with an oscillating saw was performed parallel to articular surface of the distal radius.

A correction check with the plate temporarily fixed to the radius by an image intensifier was performed in all cases. Finally, a definitive volar fixation of the plate was carried out (18).

In addition, three patients had DRUJ instability at the level of the ulna head, which was confirmed intraoperatively. Therefore, an open lateral approach according to Nakamura, centered on the ulnar styloid, was performed and the injured TFCC was repaired with an anchor suture fixed at the foveal insertion (19,20).

A short cast was used in all patients for a period of 2 to 4 weeks, depending on the surgeon's preference. Then all patients underwent a variable rehabilitation protocol.

The clinical parameters evaluated were preoperative and postoperative range of motion (flexion, extension, ulnar and radial deviation, supination, and pronation). Preoperative and postoperative grip strength tests were measured by Jamar hand dynamometer set to position 2, with elbow at 90° of flexion and forearm in neutral position, while preoperative and postoperative key and pulp pinches were measured with a pinch gauge (21). Assessment of range of motion (ROM) and strength values between the injured and uninjured side were performed. Each patient underwent the Disability of the Arm, Shoulder and Hand (DASH) score, Patient-Rated Wrist Evaluation (PRWE) score at 2-months follow-up and at the last outpatient clinic. Moreover, patients indicated own preoperative and postoperative pain using the Visual Analogue Scale (VAS).

Patients were evaluated before and after surgery with X-rays of the injured wrist in 2 projections (AP and true lateral view), considering the following parameters: volar tilt, radial inclination and ulnar variance.

At one month, at three months, at 6 months, at one year after surgery, and about every 3 months thereafter, clinical and radiographic evaluations were carried out to assess the general status of the patient and the presence of possible complications such as device failure, delayed union, nonunion, infections.

Bone healing was defined radiographically as the presence of bone neoformation at the osteotomy site and clinically as the absence of wrist pain at rest and functional use. If this was not present after 8 weeks, a delayed union was diagnosed (22,23).

Patients were divided into 2 groups: one grouped malunions with volar deformity (Group A), the other included malunions with dorsal deformity (Group B). Finally, we analyzed the use or non-use of ACIC bone graft within the same group.

Statistical analysis

All data were statistically analyzed by two authors (A.D.M. and M.M.) and were compared within the same group and between the two groups before and after corrective osteotomy. Negative values of volar tilt pointed to a dorsal deformity on the sagittal plane, while negative values of ulnar variance pointed out that the distal ulna was shorter than distal radius.

The Paired Student t test was used to assess clinical and radiographic variables in the study, while the Mann-Whitney U test was used for nonparametric variables as VAS, DASH and PRWE score. P-values < 0.05 were considered statistically significant and were reported as two-tailed.

Results

Nineteen patients, out of 26 patients, surgically treated for extra-articular malunion of the distal radius, were included in our study. The average follow-up of the study was 63.4 months (range, 22-119 months) and the mean time to surgery was 31.2 weeks (range, 4-172 weeks). All fractures were initially treated conservatively with a long cast above the elbow for 4 weeks.

Eight patients were men (42.1%), 11 were female (57.9 %), and the mean age at the time of the diagnosed malunion was 50 years (range, 16-72 years). Eleven patients (57.9%) had damaged their dominant hand.

Six patients (31.6%) performed heavy labour before the fracture, while the remaining 13 patients (68.4%) had a desk job.

Twelve injuries were classified as "mature" malunions (63.2%) and 7 patients presented a "nascent" malunion (36.8%), according to the Ring's definition (9). Table 1 summarizes the main data of each patient.

Ten malunions (52.6%) had a dorsal deformity and the remaining 9 malunions (47.4%) had a volar deformity. Among these, 6 dorsally angulated (60%) and 4 volarly angulated malunions (44.4%) were treated with a hinge-type osteotomy and then with ACIC bone graft.

The clinical and radiographic preoperative and postoperative mean values, the preoperative and postoperative mean values of VAS and finally the mean values of DASH and PRWE score at 2-months follow-up and at the last clinical examination are reported in Table 2, with the range of each value in parentheses.

In the **volar deformity group**, patients reported reduced pain through VAS testing (*p-value = 0.017). The final DASH and PRWE score significantly decreased compared to 2 months postoperatively. Significant increase in ROM were reported, except for the radial deviation (*p-value = 0.095) and ulnar deviation (*p-value = 0.129). Nevertheless, the latter two both increased in mean postoperative values and a significant improvement comparing them with uninjured contralateral values was carried out. Except for flexion and extension, postoperative pronation and supination also showed a significant improvement compared to ROM values of the contralateral wrist (^p-value = 0.356 and ^p-value = 0.082, respectively). Postoperative grip strength, key and pulp pinches increased significantly, and they were not statistically less in comparison of the contralateral side values. The radiographic parameters showed a statistically significant difference improvement, with an average volar tilt of

Table 1. Demographics.

Patient	Age	Gender	Side/ Dominant	Time to surgery (weeks)	Nascent or mature malunion	Volar or dorsal deformity	Bone Graft	Follow-up (months)	Occupation
1	54	F	R/R	4	Nascent	Dorsal	No	45	Heavy labour
2	66	F	R/R	4	Nascent	Volar	Yes	65	Desk Office
3	51	M	L/R	6	Nascent	Dorsal	No	38	Heavy labour
4	28	F	L/R	48	Mature	Dorsal	Yes	54	Desk Office
5	53	M	L/R	4	Nascent	Volar	No	22	Heavy labour
6	16	M	L/R	156	Mature	Dorsal	Yes	66	Desk Office
7	63	F	R/R	4	Nascent	Dorsal	No	45	Desk Office
8	34	M	R/R	20	Mature	Volar	Yes	48	Heavy labour
9	67	F	R/R	30	Mature	Dorsal	Yes	45	Desk Office
10	37	M	R/R	172	Mature	Volar	Yes	51	Desk Office
11	70	F	R/R	8	Mature	Dorsal	Yes	49	Desk Office
12	45	F	R/L	40	Mature	Volar	Yes	59	Heavy labour
13	72	F	L/R	4	Nascent	Dorsal	Yes	58	Desk Office
14	55	M	L/R	10	Mature	Volar	No	72	Desk Office
15	50	F	R/L	8	Mature	Volar	No	89	Heavy labour
16	29	F	L/L	8	Mature	Volar	No	88	Desk Office
17	46	M	R/R	12	Mature	Volar	No	98	Desk Office
18	43	F	L/L	48	Mature	Dorsal	Yes	94	Desk Office
19	72	M	R/R	6	Nascent	Dorsal	No	119	Desk Office
Average	**50**	-	-	**31,2**	-	-	-	**63,4**	-

Table 2. Preoperative and Postoperative Mean Results of Clinical-Radiographic Data, and VAS, DASH and PRWE Score Questionnaires. The Range of Each Result Is Shown in Parentheses. Values obtained with a statistically significant value are marked in bold.

CLINICAL DATA (°)	**Volar deformity Group A**	**Dorsal deformity Group B**	**§ p-value**
Flexion	Mean (range)		
Preop.	31.6 (0 - 44)	34.1 (21 - 50)	0.65
Postop.	59.3 (10 - 75)	64.9 (53 - 78)	0.435
***p-value**	**0.039**	**< 0.001**	
Contralateral flexion	75.2 (60 - 90)	76.7 (64 - 90)	
^p-values	0.048	0.004	
Extension	Mean (range)		
Preop.	40.7 (31 - 50)	39 (20 - 50)	0.636
Postop.	59.2 (45 - 80)	57.9 (42 - 70)	0.785
***p-value**	**< 0.001**	**< 0.001**	
Contralateral extension	72.4 (60 - 90)	65.6 (49 - 80)	
^p-values	0.019	**0.096**	
Supination	Mean (range)		
Preop.	56.1 (35 - 76)	41.7 (30 - 59)	**0.015**
Postop.	85.3 (74 - 90)	83.3 (77 - 90)	0.442
***p-value**	**< 0.001**	**< 0.001**	
Contralateral supination	89.2 (87 - 90)	88.8 (84 - 90)	
^p-values	**0.082**	0.005	
Pronation	Mean (range)		
Preop.	38.9 (23 - 55)	36.6 (23 - 50)	0.598
Postop.	86.7 (79 - 90)	85.1 (78 - 90)	0.516
***p-value**	**< 0.001**	**< 0.001**	
Contralateral pronation	88.4 (82 - 90)	88.6 (84 - 90)	
^p-values	**0.356**	**0.075**	
Radial deviation	Mean (range)		
Preop.	7.7 (2 - 16)	9 (2 - 23)	0.616
Postop.	12.6 (5 - 24)	15.5 (5 - 35)	0.375
***p-value**	0.095	0.055	
Contralateral radial deviation	17 (5 - 30)	19.8 (11 - 40)	
^p-values	**0.221**	**0.282**	
Ulnar deviation	Mean (range)		
Preop.	23 (13 - 38)	19.6 (5 - 30)	0.443
Postop.	31.8 (20 - 50)	30.3 (10 - 45)	0.791
***p-value**	0,129	**0.027**	
Contralateral ulnar deviation	38.8 (24 - 50)	37.5 (25 - 51)	
^p-values	**0.219**	**0.122**	

CLINICAL DATA (Kg)	**Volar deformity Group A**	**Dorsal deformity Group B**	**§ p-value**
Grip strength	Mean (range)		
Preop.	9.7 (1 - 18)	7.3 (2 - 12)	0.214
Postop.	22.6 (2 - 35)	14.2 (8 - 20)	0.052

Table 2 (*Contined*)

CLINICAL DATA (Kg)	Volar deformity Group A	Dorsal deformity Group B	§ p-value
*p-values	**0.022**	**0.015**	
Contralateral grip strength	28 (19 - 42)	19.3 (14 - 25)	
^p-values	**0.163**	0.008	
Key pinch	Mean (range)		
Preop.	3.1 (2 - 4)	2.6 (1 - 5)	0.257
Postop.	6.2 (4 - 9)	4.5 (1.5 - 7)	**0.048**
*p-values	**< 0.001**	**0.006**	
Contralateral key pinch	7.6 (4 - 11)	5.6 (3.5 - 8)	
^p-values	**0.188**	**0.16**	
Pulp pinch	Mean (range)		
Preop.	4.6 (3 - 7)	3.6 (2 - 5)	0.076
Postop.	8.2 (4 - 11)	5.9 (4 - 8)	**0.049**
*p-values	**0.006**	**< 0.001**	
Contralateral lateral pinch	9.5 (6 - 13)	7.2 (6 - 10)	
^p-values	**0.578**	**0.118**	
VAS	Mean (range)		
Preop.	3.3 (1 - 6)	2.2 (1 - 4)	0.112
Postop.	1.3 (0 - 4)	0.4 (0 - 2)	0.112
*p-values	**0.017**	**0.001**	
DASH score	Mean (range)		
at 2-month follow-up	53.4 (22.5 - 71.2)	58.3 (29.9 - 76.5)	0.667
last follow-up	20,7 (0 - 49.1)	18,4 (3.3 - 38.3)	0.741
*p-values	**0.02**	**0.009**	
PRWE score	Mean (range)		
at 2-month follow-up	54.6 (35 - 77)	57 (39 - 71)	0.542
last follow-up	10.6 (2 - 20)	10.6 (2 - 19)	0.968
*p-values	**< 0.001**	**< 0.001**	

Radiographic parameters	Volar deformity Group A	Dorsal deformity Group B	§ p-value
Volar tilt (°)	Mean (range)		
Preop.	15.6 (7 - 23)	-15.3 (-23 ; -3)	**< 0.001**
Postop.	11.6 (8 - 18)	9.7 (3 - 17)	0.246
*p-values	**0.042**	**< 0.001**	
Radial inclination (°)	Mean (range)		
Preop.	15.7 (7 - 24)	13.7 (2 - 19)	0.582
Postop.	20.8 (14 - 26)	17.4 (11 - 23)	0.086
*p-values	**0.03**	0.265	
Ulnar variance (mm)	Mean (range)		
Preop.	2.9 (-4.6 ; +5.6)	2.1 (-3.7 ; +6)	0.699
Postop.	0.2 (-3 ; +1.5)	0.4 (-2.4 ; +2.3)	0.837
*p-values	**0.038**	**0.019**	

11.6°, a radial inclination of 20.8° and an ulnar variance of 0.2 mm (Fig. 2).

In the **dorsal deformity group**, patients referred an overall significant satisfaction, as reported by average VAS, DASH and PRWE scores. As in the Group A, there was an improvement in the postoperative radial deviation, but this was not statistically significant, whereas the ulnar deviation showed a significant difference (*p-value = 0.027). Postoperative flexion, extension and pronation were also significantly close to the contralateral side values, while this statistical significance was not present for the supination (^p-value = 0.005). Apart from the grip strength compared to the contralateral side, post-operative grip strength, key and pulp pinches values had significantly recovered. Finally, a proximity of the three radiographic parameters to normal values was obtained, although the radial inclination did not show a statistically significant difference (*p value = 0.265) (Fig. 3).

Regarding the **comparison of the two groups**, there was a significant improvement in key and pulp pinches in favour of the group A, while there were no other statistically significant differences in the remaining evaluated parameters. Finally, regarding the bone graft factor, we found no significant influence, within the same group examined, in its use in comparison to cases that did not use bone graft.

We encountered three complications: two complications in group A and one in group B. In the first group, an elderly patient with cardiovascular disease presented a deep vein thrombosis of the operated upper arm in the postoperative period. He was treated for 6 months with oral anticoagulant therapy and thrombolytic drugs. At the end of this treatment, the patient presented no further general problems or limitations regarding the function of the operated wrist. The second complication of group A concerned a patient who developed signs and symptoms of Complex Regional

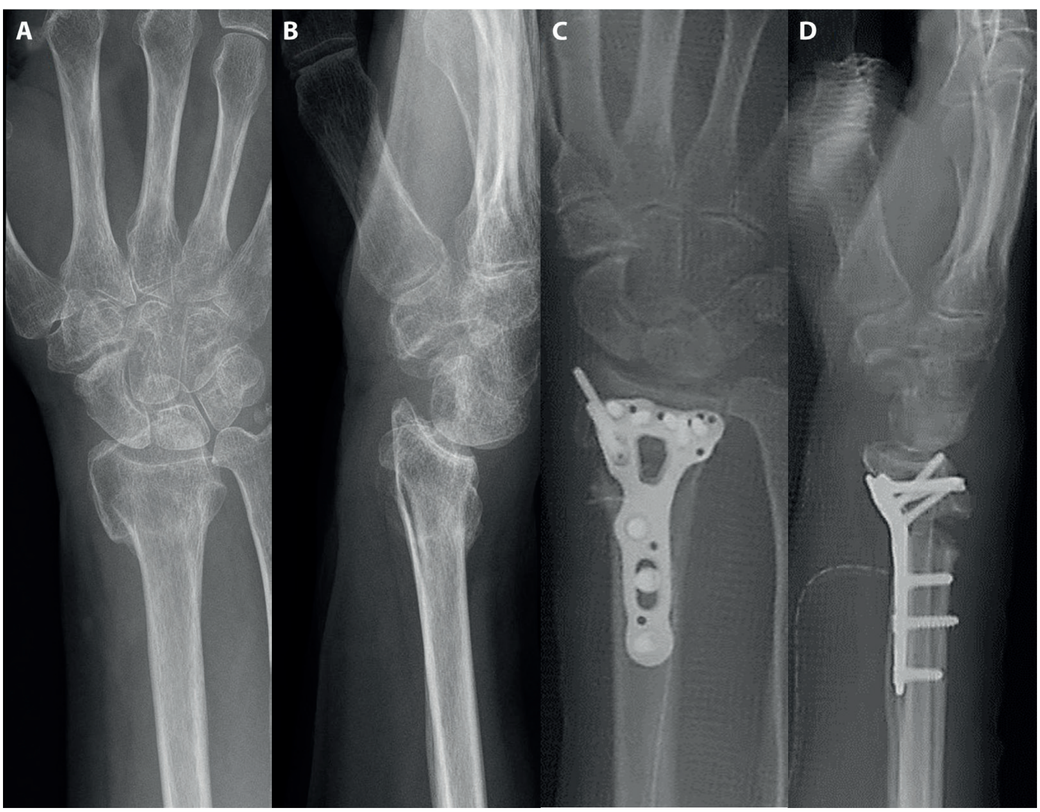

Fig. 2. (A-B) Preoperative and (C-D) postoperative case of volar malunion, corrected through a hinge-type osteotomy and fixed with a volar locking plate.

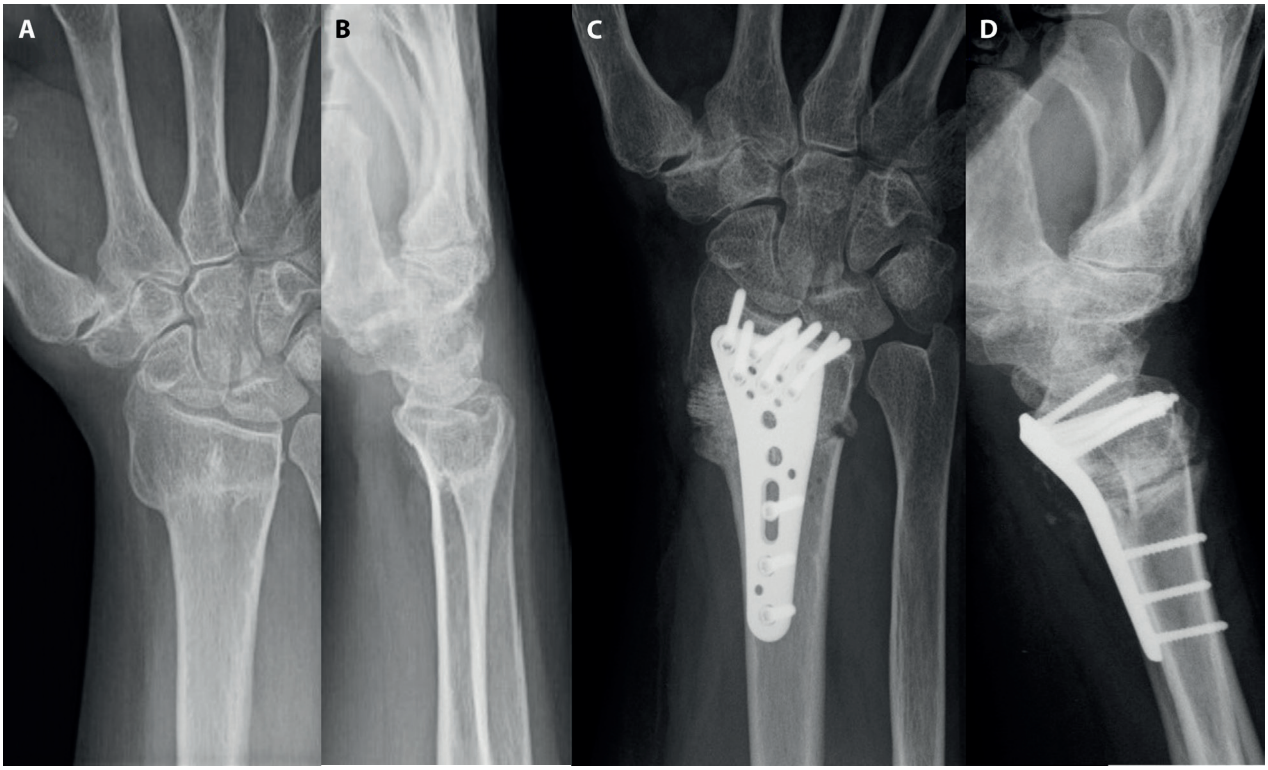

Fig. 3. (A-D) Preoperative and (C-D) postoperative radiographic images of a dorsal malunion.

Pain Syndrome type 1 (CRPS-I), treated with analgesic, anti-edema drugs and physiotherapy. The disease was resolved in 8 months, with good ROM of the wrist and patient satisfaction. The only complication in the group B was in a patient with clinical symptoms of carpal tunnel syndrome 10 months after surgery. A decompression of the carpal tunnel and removal of the volar plate were performed 12 months after the corrective osteotomy. The patient was very satisfied with the entire surgical procedure. No patient reported complications as tendons ruptures, implant failure, delayed union and non-union. All patients returned to their previous work activities without any kind of limitation.

Discussion

Untreated malunions can lead to complications such as complex regional pain syndrome (CRPS), carpal tunnel syndrome, other types of neuropathies and lastly wrist arthritis (1,17).

Surgical indications are suitable for patients who complain of pain and reduced function in the wrist, such that they are unable to carry out their pre-injury daily activities. Radiographic criteria of unacceptable healing of distal radius fracture and aesthetic discomfort of the wrist reported by the patient are further parameters of surgical evaluation (1,2,4). These principles were used as surgical indications in our study. In recent years, corrective osteotomy and plating fixation using the volar approach has proved to be the preferred technique compared to the dorsal approach (24-26).

The reasons lie in the production of the new volar fixed-angle plates, an easier reproducibility of the volar corrective osteotomy through a volar approach and a lower rate of associated complications, with good clinical, radiographic and patient satisfaction outcomes (27-29).

Several authors compared clinical-radiographic results and complications between volar and dorsal corrective osteotomy for the treatment of extra-articular dorsally-angulated malunions. In general, the results showed restoration of radiographic values with both surgical techniques, but in some studies, there were better clinical results and fewer complications with volar corrective osteotomy (30-32). Several studies in the literature have also shown the effectiveness of treating extra-articular malunions through volar procedures (33,34).

Our study shows, in a long-term follow-up, the effectiveness of corrective osteotomy using a palmar plate both in extra-articular volar and dorsal malunions, with statistically significant clinical and radiographic results, except for the radiographic parameter of the radial inclination in the group with dorsal deformities. This is probably due to the difficulty of correcting the radial inclination starting from poorer preoperative values than in the group with volar deformities. A second hypothesis could arise from the fact that in some cases a distraction-type osteotomy should be used rather than the hinge-type osteotomy to restore this radiographic parameter. This could derive from the assumption that, with the distraction technique, one can probably gain more length of the distal radius (since there is no hinge constraint), while with the hinge-type technique, it is possible to gain till a certain length of the distal radius, because of the constraint caused by the hinge itself (otherwise there is the risk of fracture of the hinge point). The ulnar deviation improved significantly only in the group B-dorsal deformities. Evaluating the clinical results between the two cohorts, it is pointed out that extension values in the group B are closer to the values of the contralateral side, although the postoperative mean values of both groups are overlapping (mean extension in the volar group = 59.2°, range 45-80; mean extension in the dorsal group = 57.9°, range 42-70). A similar situation occurs in supination, but in favour of the group A. Such results could originate from a non-homogeneity of the sample evaluated, representing a possible further limit of our study. Regarding the grip strength, it is noted that the postoperative results are higher in group A than in group B (22.6 kg with range of 2-35, and 14.2 kg with range of 8-20, respectively), although there is no statistically significant difference between the two outcomes (§p-value = 0.052). Moreover, grip strength values of the group A are significantly closer to the values on the contralateral side.

We obtained a statistically significant improvement in key and pulp pinches in both group A and group B (Table 2). Regarding the use of graft, the choice of its application, depending on the type of osteotomy used and associated with the low number of patients, may have influenced the non-statistically significant data of comparison between its use and non-use. Nevertheless, using either the distraction-type or the hinge-type osteotomy, we found no cases of delayed union and non-union (10,15,16).

Our study has other limitations as possible sources of bias: the low number of cases, the retrospective nature of the results, the use of two volar plates from two different companies, no control group (dorsal corrective osteotomy and dorsal plating in the two types of deformities analyzed), no homogeneity of the sample examined, absence of a standard rehabilitation protocol (some patients used pulsed electromagnetic fields to accelerate bone healing at the osteotomy site), presence of both nascent and mature malunions, recognizing from previous studies that their treatment results differ from each other (6,35).

In conclusion, the corrective osteotomy with volar locking plate is an effective clinical-radiographic treatment both in dorsal and volar extra-articular malunions and easily reproducible as shown in literature; it improves the wrist function, with a good patient satisfaction and the return to the previous working and daily life activities. No major complications were founded.

The grip strength of the operated wrist compared to the contralateral is significantly closer in the group with volar deformities. In addition, the key pinch and pulp pinches in the group with volar deformities are significantly higher than in the group with dorsal malunion. All radiographic parameters were significantly improved except for the radial inclination in the dorsal deformity group. Further studies are needed with a larger group of cases, a control group and more sophisticated preoperative planning techniques to obtain more accurate results.

Conflicts of Interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article.

References

1. Lodha SJ, Wysocki RW, Cohen MS. Malunions of the distal radius. Hand surgery update V. Am Soc Surg Hand, Rosemont. 2011:125-37.
2. Evans BT, Jupiter JB. Best Approaches in Distal Radius Fracture Malunions. Curr Rev Musculoskelet Med. 2019; 12(2):198-203. doi:10.1007/s12178-019-09540-y
3. Prommersberger KJ, Lanz UB. Corrective osteotomy of the distal radius through volar approach. Tech Hand Up Extrem Surg. 2004;8(2):70-77. doi:10.1097/01.bth.0000126572.28568.88
4. Prommersberger KJ, Pillukat T, Mühldorfer M, van Schoonhoven J. Malunion of the distal radius. Arch Orthop Trauma Surg. 2012 May;132(5):693-702. doi: 10.1007/s00402-012-1466-y. PMID: 22294090.
5. Fernandez DL. Radial osteotomy and Bowers arthroplasty for malunited fractures of the distal end of the radius. J Bone Joint Surg Am. 1988;70(10):1538-1551.
6. Jupiter JB, Ring D. A comparison of early and late reconstruction of malunited fractures of the distal end of the radius. J Bone Joint Surg Am. 1996;78(5):739-748. doi:10.2106/00004623-199605000-00014
7. Osada D, Kamei S, Takai M, Tomizawa K, Tamai K. Malunited fractures of the distal radius treated with corrective osteotomy using volar locking plate and a corticocancellous bone graft following immediate mobilisation. Hand Surg. 2007;12(3):183-190. doi:10.1142/S0218810407003560
8. Henry M. Immediate mobilisation following corrective osteotomy of distal radius malunions with cancellous graft and volar fixed angle plates. J Hand Surg Eur Vol. 2007;32(1):88-92. doi:10.1016/j.jhsb.2006.09.002
9. Ring D. Treatment of the neglected distal radius fracture. Clin Orthop Relat Res. 2005;(431):85-92. doi:10.1097/01.blo.0000152442.66083.ff
10. Tiren D, Vos DI. Correction osteotomy of distal radius malunion stabilised with dorsal locking plates without grafting. Strategies Trauma Limb Reconstr. 2014;9(1):53-58. doi:10.1007/s11751-014-0190-2
11. Tang JB, Giddins G. Why and how to report surgeons' levels of expertise. J Hand Surg Eur Vol. 2016;41(4):365-366. doi:10.1177/1753193416641590
12. Graham TJ. Surgical Correction of Malunited Fractures of the Distal Radius. J Am Acad Orthop Surg. 1997;5(5):270-281. doi:10.5435/00124635-199709000-00005
13. Nana AD, Joshi A, Lichtman DM. Plating of the distal radius. J Am Acad Orthop Surg. 2005;13(3):159-171. doi:10.5435/00124635-200505000-00003
14. Orbay JL, Fernandez DL. Volar fixation for dorsally displaced fractures of the distal radius: a preliminary report. J Hand Surg Am. 2002;27(2):205-215. doi:10.1053/jhsu.2002.32081
15. Ozer K, Chung KC. The use of bone grafts and substitutes in the treatment of distal radius fractures. Hand Clin. 2012;28(2):217-223. doi:10.1016/j.hcl.2012.02.004
16. Haghverdian JC, Hsu JY, Harness NG. Complications of Corrective Osteotomies for Extra-Articular Distal Radius Malunion. J Hand Surg Am. 2019;44(11):987.e1-987.e9. doi:10.1016/j.jhsa.2018.12.013
17. Krimmer H, Schandl R, Wolters R. Corrective osteotomy after malunited distal radius fractures. Arch Orthop Trauma Surg. 2020;140(5):675-680. doi:10.1007/s00402-020-03370-1
18. Katt B, Seigerman D, Lutsky K, Beredjiklian P. Distal Radius Malunion. J Hand Surg Am. 2020;45(5):433-442. doi:10.1016/j.jhsa.2020.02.008
19. Nakamura T, Sato K, Okazaki M, Toyama Y, Ikegami H. Repair of foveal detachment of the triangular fibrocartilage complex: open and arthroscopic transosseous techniques. Hand Clin. 2011;27(3):281-290. doi:10.1016/j.hcl.2011.05.002
20. Luchetti R, Atzei A, Cozzolino R, Fairplay T, Badur N. Comparison between open and arthroscopic-assisted foveal triangular fibrocartilage complex repair for post-traumatic distal radio-ulnar joint instability. J Hand Surg Eur. Vol. 2014;39(8):845-855. doi:10.1177/1753193413501977
21. Smaby N, Johanson ME, Baker B, Kenney DE, Murray WM, Hentz VR. Identification of key pinch forces required to complete functional tasks. J Rehabil Res Dev. 2004;41(2):215-224. doi:10.1682/jrrd.2004.02.0215
22. Buza JA 3rd, Einhorn T. Bone healing in 2016. Clin Cases Miner Bone Metab. 2016;13(2):101-105. doi:10.11138/ccmbm/2016.13.2.101
23. Bhandari M, Guyatt GH, Swiontkowski MF, Tornetta P 3rd, 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. doi:10.1097/00005131-200209000-00004
24. Mahmoud M, El Shafie S, Kamal M. Correction of dorsally-malunited extra-articular distal radial fractures using volar locked plates without bone grafting. J Bone Joint Surg Br. 2012;94(8):1090-1096. doi:10.1302/0301-620X.94B8.28646
25. Opel S, Konan S, Sorene E. Corrective distal radius osteotomy following fracture malunion using a fixed-angle volar locking plate [published correction appears in J Hand Surg Eur Vol. 2014 Jun;39(5):561] [published correction appears in J Hand Surg Eur Vol. 2014 Jun;39(5):561]. J Hand Surg Eur Vol. 2014;39(4):431-435. doi:10.1177/1753193413497636
26. Valerio Pace, Pasquale Sessa, Matteo Guzzini, et al. Clinical, functional and radiological outcomes of the use of fixed angle volar locking plates in corrective distal radius osteotomy for fracture malunion. Acta Biomed. 2021;92(3):e2021180. Published 2021 Jul 1. doi:10.23750/abm.v92i3.11265
27. Tarallo L, Mugnai R, Zambianchi F, Adani R, Catani F. Volar plate fixation for the treatment of distal radius fractures: analysis of adverse events. J Orthop Trauma. 2013;27(12):740-745.doi:10.1097/BOT.0b013e3182913fc5
28. Rozental TD, Beredjiklian PK, Bozentka DJ. Functional outcome and complications following two types of

dorsal plating for unstable fractures of the distal part of the radius. J Bone Joint Surg Am. 2003;85(10):1956-1960. doi:10.2106/00004623-200310000-00014
29. Malone KJ, Magnell TD, Freeman DC, Boyer MI, Placzek JD. Surgical correction of dorsally angulated distal radius malunions with fixed angle volar plating: a case series. J Hand Surg Am. 2006;31(3):366-372. doi:10.1016/j.jhsa.2005.10.017
30. Rothenfluh E, Schweizer A, Nagy L. Opening wedge osteotomy for distal radius malunion: dorsal or palmar approach? . J Wrist Surg. 2013;2(1):49-54. doi:10.1055/s-0032-1326725
31. Oka K, Kataoka T, Tanaka H, Okada K, Yoshikawa H, Murase T. A comparison of corrective osteotomies using dorsal and volar fixation for malunited distal radius fractures. Int Orthop. 2018;42(12):2873-2879. doi:10.1007/s00264-018-3972-1
32. Schurko BM, Lechtig A, Chen NC, et al. Outcomes and Complications Following Volar and Dorsal Osteotomy for Symptomatic Distal Radius Malunions: A Comparative Study. J Hand Surg Am. 2020;45(2):158.e1-158.e8. doi:10.1016/j.jhsa.2019.05.015
33. Tarallo L, Mugnai R, Adani R, Catani F. Malunited extra-articular distal radius fractures: corrective osteotomies using volar locking plate. J Orthop Traumatol. 2014;15(4):285-290. doi:10.1007/s10195-014-0307-x
34. Sato K, Nakamura T, Iwamoto T, Toyama Y, Ikegami H, Takayama S. Corrective osteotomy for volarly malunited distal radius fracture. J Hand Surg Am. 2009;34(1):27-33.e1. doi:10.1016/j.jhsa.2008.09.018
35. Krzyżańska L, Straburzyńska-Lupa A, Rąglewska P, Romanowski L. Beneficial Effects of Pulsed Electromagnetic Field during Cast Immobilization in Patients with Distal Radius Fracture. Biomed Res Int. 2020;2020:6849352. Published 2020 Feb 25. doi:10.1155/2020/6849352

Correspondence:
Received: 13 February 2022
Accepted: 3 April 2022
Agostino Di Maro, MD
Division of Orthopaedics and Traumatology,
Department of Biotechnology and Life Sciences (DBSV),
University of Insubria, Via J. H. Dunant 3, Varese, Italy
Telephone: +41782372126
E-mail: agostino.dimaro88@gmail.com