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ORIGINAL ARTICLE

Open reduction through original fracture line and fixation with locking plate is a feasible approach for extra-articular distal radius fracture malunion

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ABSTRACT

Objectives: This study aims to investigate the effectiveness of open reduction through original fracture line and fixation with locking plate in treatment of extra-articular distal radius fracture (DRF) malunion.

Patients and methods: Between January 2015 and December 2018, a total of 69 patients (27 males, 42 females; mean age: 62.0±8.9 years; range, 46 to 70 years) suffering from symptomatic extra-articular DRF malunion were included. All patients were followed for more than six months. Patient's demographics, hand dominance, data including Quick Disabilities of the Arm, Shoulder and Hand (QuickDASH) questionnaire, pain on a Visual Analog Scale (VAS) score, radius height, ulnar variance, wrist range of motion, volar tilt and radial inclination before and after surgery were analyzed.

Results: The median follow-up was 14.13 months, and the median time to fracture healing after the operation was 14.25 weeks. The mean QuickDASH score and VAS score were significantly reduced from 63.4±13.97 and 4.6±1.23 preoperatively to 7.8±4.67 and 1.3±0.76 at the final follow-up, respectively. Radius height, ulnar variance, volar tilt, radial inclination and wrist range of motion (flexion, extension, pronation, supination) were all significantly improved ($p<0.001$). Images showed good radius height, ulnar variance, volar tilt and radial inclination. The range of motion of wrist and forearm were improved substantially. Among 69 patients, two patients received allograft due to osteoporotic bone collapse. No serious complication was developed, except for minor pain in three patients during follow-up.

Conclusion: Open reduction through original fracture line and fixation with locking plate is a feasible and effective treatment for selective DRF malunion.

Keywords: Distal radius fracture; locking plate; malunion; open fracture; osteotomy.

Distal radius fractures (DRFs) are one of the common fragility fracture in orthopedic traumatology[1] and mainly treated in the emergency settings. Malunion is the major cause of residual symptoms and a non-anatomical consolidation of DRFs. The incidence of DRF malunion varies from 23 to 28% in DRF patients treated conservatively and is 11% in patients treated surgically.[2] Impaired wrist function such as loss of strength, nerve involvement or tendon involvement may be caused by the alteration of the articular or extra-articular radial anatomy.[3]

Not all DRFs malunion are symptomatic. Clinical severity presenting functional outcome is not always related to bone deformity.[4] However, DRF malunion may result in considerable disability when symptoms appear. Post-traumatic ulnar impaction syndrome commonly occurs following by DRFs,[5] which is mainly characterized by reduced grip strength and pain. Good prognosis of displaced DRFs can be achieved by non-operative treatment after adequate closed reduction, and the risk of subsequent surgeries due to symptomatic malunion or a secondary displacement is up to 40%,[6] which

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may result in a decreased range of wrist motion, forearm rotation, pain and grip strength on the ulnar side of wrist, particularly where an ulna impaction caused by the shortened radius.[7] It has been reported that osteotomy for radius or ulnar is an effective treatment for DRF malunion.[5,8-11] However, substantial defect may be produced by corrective osteotomy in the radius due to the degree of shortening and angulation.[12] Barbaric et al.[13] reported that the complication rate of osteotomies was nearly 50%, which included tendons rupture or irritation, nonunions and delayed healing at the osteotomy site as the same to ulnar osteotomies. In addition, In Rivlin et al.'s[14] study, six patients with extensor pollicis rupture who underwent osteotomy and volar plate fixation for DRF malunion showed an average time of 10 weeks to tendon rupture after surgery. Various factors may result in a high rate of complication for patients with DRF malunion undergoing corrective osteotomies. The osteotomies are technically demanding, including surgery of restoring anatomic relationships, operation solely for gaining a functional improvement, operation for eliminating pain, and approaches combined two or more above.[7] Corrective osteotomy should be performed upon the symptomatic malunion.[7] Therefore, it is essential and urgently needed to find an alternative approach to treat DRF malunion without osteotomy.

In the present study, we hypothesized that the distal radius extra-articular malunion fracture could be reduced, when the nascent callus was ablated or resected through the fracture line and the adhered soft tissue were released, and a volar locking plate could maintain the reduction.[15] Open reduction through original fracture line and fixation with locking plate could achieve restoring anatomic relationships, a functional improvement and pain relief. We, therefore, aimed to investigate the effectiveness of open reduction through original fracture line and fixation with locking plate in treatment of extra-articular DRF malunion.

PATIENTS AND METHODS

This retrospective cohort study was conducted at Tianjin Hospital, Department of Orthopedic between January 2015 and December 2018. A total of 69 patients (27 males, 42 females; mean age: 62.0±8.9 years; range, 46 to 70 years) suffering from DRFs were recruited. Patients were selected according to the following criteria: *(i)* patients aged above 18 years old; *(ii)* duration longer than 12 weeks from injury; and *(iii)* a vaguely visible fracture line on plain film with an intact articular surface. Indications for surgery were as follows: *(i)* a radius height less than 10 mm; *(ii)* volar tilt disappearing; radial inclination <10°; *(iii)* distal radioulnar joint dislocation; *(iv)* ulnar variance >2+; and *(v)* a duration of follow-up for more than six months. Those having a duration less than 12 weeks from injury, having an invisible fracture line on the plain film, and having comminuted articular surface were excluded.

Surgical techniques

Before surgery, imaging of extra-articular distal radius fracture, including X-ray films (Figure 1a, b) and computed tomography (CT) images (Figure 1c, d) were obtained. Intraoperative fluoroscopy was used during the surgical procedures. A classical Henrry approach was adopted to expose the distal radius (Figure 2a) through a 6-cm dorsal curvilinear incision to expose the pronator muscles (Figure 2b). After cutting off at the stop point of the radius, the volar side of the distal radius was exposed. The formation of callus and fracture malunion at the broken end of the fracture can be seen in Figure 2c. After the pronator quadratus muscle was disconnected from the radius, the callus on the fracture surface was ablated by the Electrohome® blade (Figure 2d). The soft tissue was detached from the volar, lateral and medial of proximal fracture line at least 3 cm. After the distal fracture was pulled distally upward until separation, the volar cortex was exposed (Figure 2e). The radius shaft was rotated inwardly, and the dorsal soft tissue could be detached (Figure 2f). The fracture was reduced according to the volar fracture line as the anatomical mark (Figure 2g). The Kirschner wires were temporarily applied to fix the fracture. The reduction of radius, volar tilt, and radius inclination were checked under the C-arm fluoroscopy. Volar plate fixation was performed after radius length and palm inclination returned to normal. Osteosynthesis was maintained by a volar anatomical locking plate, not beyond the "watershed" area. After the pronator quadratus was repaired, the wound was closed.

Rehabilitation and follow-up

Patient rehabilitation was initiated to flex and extend their fingers on the second day postoperatively. Wrist flexion and extension and forearm rotation started at two and four weeks postoperatively, respectively. Postoperative immobilization was not necessary in all patients. The progression of bone healing was assessed monthly on the plain film.

FIGURE 1. Preoperative imaging of extra-articular distal radius fracture. **(a, b)** Preoperative X-ray films; **(c, d)** Preoperative computed tomography imaging.

Data collection

Patient's baseline characteristics, such as sex, age, injured side reasons of trauma, time to surgery were collected. The variables including Quick Disabilities of the Arm, Shoulder and Hand (QuickDASH) questionnaire, pain on a Visual Analog Scale (VAS) score, radius height, ulnar variance, volar tilt degree and radial inclination degree, wrist range of motion (flexion, extension, pronation and supination degree), were also collected and compared between pre-operation and the final follow-up.

Statistical analysis

Statistical analysis was performed using the SPSS version 17.0 software (SPSS Inc., Chicago, IL, USA). Continuous variables were expressed in mean ± standard deviation (SD) or median (25^{th}-75^{th} percentiles). Categorical variables were expressed in number and frequency. The paired Student t-test was performed to compare pre- and postoperative variables. A p value of <0.05 was considered statistically significant.

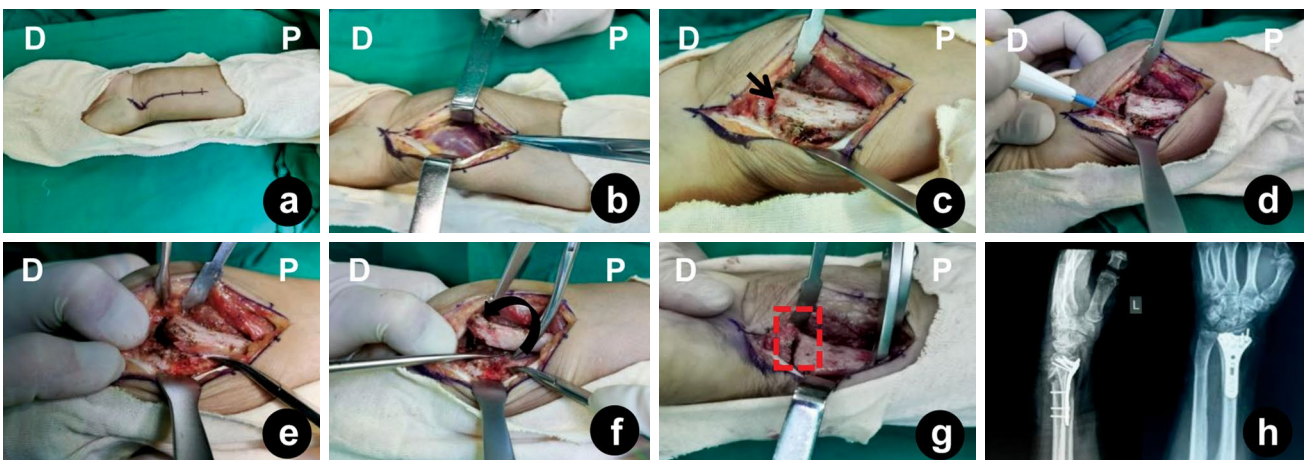

FIGURE 2. The reducing process and Intraoperative imaging. **(a)** Surgical incision; **(b)** Dorsal approach and the exposure pronator quadratus muscle. **(c)** The arrow showed the callus filled in the original fracture line. **(d)** The callus was ablated by Electrohome® blade. **(e)** The distal fracture was sticked up dorsally and retracted distally. **(f)** Rotating the radius shaft inwardly (curved arrow), the callus covering the dorsal fracture line was detached from the proximal and distal cortex. **(g)** The fracture was reduced referring to the fracture line using the medial cortex as the "keystone" (red dotted box). **(h)** Intraoperative images showed good volar reduction and fixation of the fracture.

RESULTS

A total of 27 left and 42 right radiuses of 69 patients were included. The patients had an accompanying ulnar styloid fracture in 59.42% (41/69). The mean duration from injury to surgery was 16.2±3.3 (range, 12 to 24) weeks. The detailed demographic and surgical data are shown in Table I.

The mean operation time was 70.1±5.2 (range, 64.9 to 75.1) min. No patients were lost-to-follow-up and the median follow-up was 14.13 (range, 6 to 20) months. All fractures were healed with a median duration of 14.25 (range, 12 to 18) weeks. Secondary fracture displacement or hardware failure were not observed. Carpal ligament, carpal tunnel syndrome, triangular fibrocartilage complex injuries, infection and implants complications were not noted. Two patients received allograft, due to dorsal bone defect.

Clinical and radiographic findings in patients with distal radius malunion were analyzed (Table II). The median scores were 63.4 (range, 42 to 93) for QuickDASH and 4.6 (range, 3 to 7) for VAS preoperatively, which were decreased to 7.8 (range, 0 to 16) and 1.3 (range, 0 to 2) at the final follow-up. All motion measurements

TABLE I
Baseline demographic and surgical data of patients (n=69)

	n	%	Mean±SD
Age (year)			62.0±8.9
Sex			
Female	42	60.87	
Male	27	39.13	
Injured side			
Left	27	39.13	
Right	42	60.87	
Ulnar styloid fracture	41	59.42	
Reasons of trauma			
Bicycle fall	27	39.13	
E-bike fall	3	4.35	
Pedestrian fall	39	56.52	
Time to surgery (weeks)			16.2±3.3
Surgery duration (min)			70.1±5.2

SD: Standard deviation.

TABLE II
Clinical and radiological data before and after surgery

	Baseline	Final follow-up		
	Mean±SD	Mean±SD	*p*	95% CI
Quick DASH	63.4±13.97	7.8±4.67	<0.001	49.07 – 62.14
Visual Analog Scale	4.6±1.23	1.3±0.76	<0.001	2.67 – 3.93
Radius height (mm)	4.6±1.06	10.6±1.88	<0.001	-6.84 – -5.06
Ulnar variance (mm)	4.9±0.78	1.1±0.56	<0.001	3.30 – 4.26
Volar tilt (degree)	-10.2 ±-5.27	8.3±2.65	<0.001	-21.00 – -15.95
Radial inclination (degree)	9.8±2.56	19.2 ±3.33	<0.001	-10.5 – -8.29
Flexion (degree)	20±7.51	52±6.34	<0.001	-36.33 – -27.58
Extension (degree)	30±11.52	70±9.28	<0.001	-44.97 – -33.73
Pronation (degree)	40±9.76	80±10.44	<0.001	-46.75 – -34.12
Supination (degree)	40±9.76	70±9.78	<0.001	-36.76 – -23.98

SD: Standard deviation; CI: Confidence interval; QuickDASH: Quick Disabilities of the Arm, Shoulder and Hand.

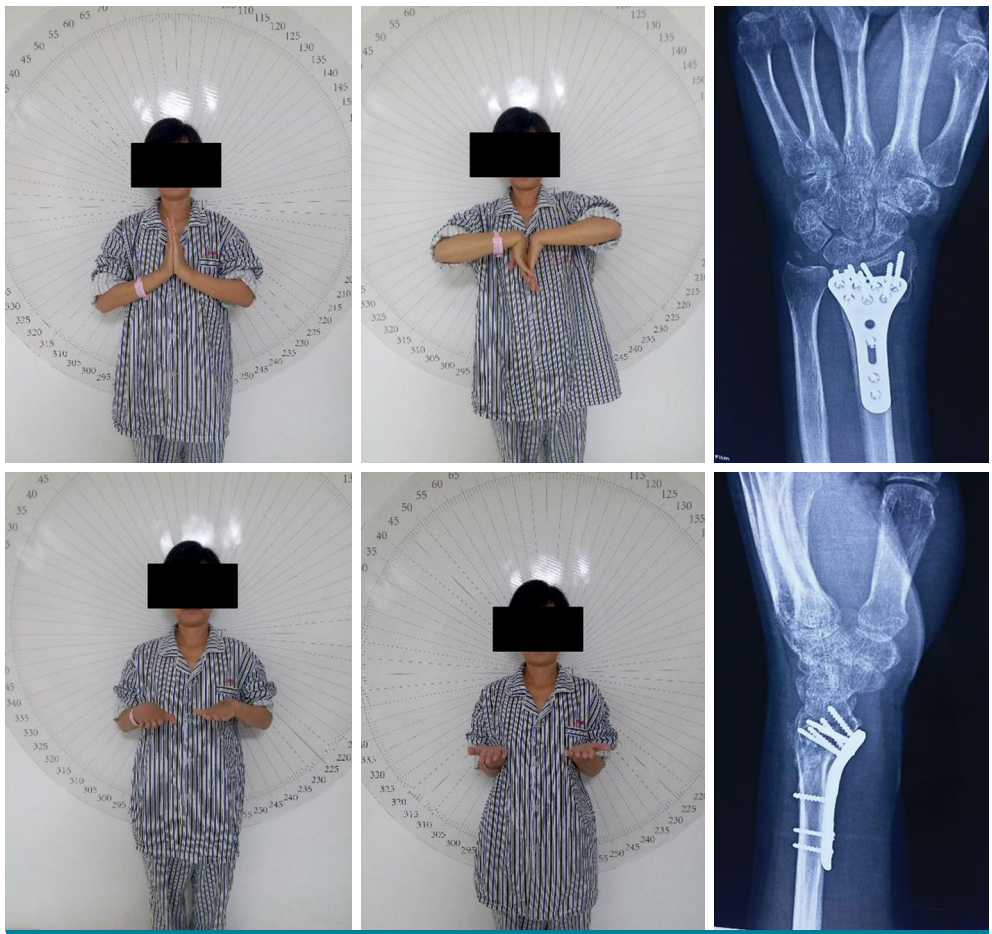

FIGURE 3. Case example of the clinical outcome plain film at 12 months. A 52-year-old female patient was diagnosed with left distal radius fracture and fracture of the ulnar styloid process and showed the distal radius fracture malunion at 16 weeks after closed reduction and plaster fixation.

including radius height, ulnar variance, volar tilt, radial inclination and wrist range of motion demonstrated statistically significant improvements postoperatively compared to preoperative values ($p<0.001$ for all, Table II). The mean ranges of wrist motion, such as flexion, extension, pronation and supination were all significantly increased ($p<0.001$ for all).

A 52-year-old female case diagnosed with a left DRF and fracture of the ulnar styloid process showed DRF malunion at 16 weeks after closed reduction and plaster fixation with the improved wrist function and imaging performance at the final follow-up (Figure 3).

DISCUSSION

Malunion of DRFs represents a common clinical entity and the most common complication of DFR in patients received non-operative treatment. Surgical correction is challenging due to unpredictable clinical outcomes. In this study, we adopted open reduction through original fracture line and locking plate internal fixation to treat DRFs malunion with a visible fracture line on plain film. The visible fracture line indicated that the fracture was not consolidated union and the bony callus was not mineralized, which might be broken again. Deformity or uncorrected distal radius articular step-offs has been shown to cause post-traumatic arthritis and poor functional outcomes. Specifically, a decreased range of motion, persistent pain and weakened grip strength can be caused by DFR malunions.[7] Recently, corrective osteotomy for radius is an effective and classical treatment for DRF malunions.[8,10] Earlier, an opening wedge corrective osteotomy was widely used, which was via a dorsal approach followed by dorsal buttress plate fixation.[16] Open wedge osteotomy for radius could be performed with oscillating saw and osteotomes, and fixed with plate through a volar approach for

Colles type fracture and a dorsal approach for Smith type fracture or a combined approach,[10,17,18] in which bone grafting for defect is required. In some cases with minimal radial angulation, whose symptoms result from positive ulnar variance, ulnar shortening osteotomy (USO) has become the standard procedure for DRF malunion.[13]

Haghverdian et al.[12] reported that the complication rate of distal radius osteotomies was nearly 50%, including nonunion, delayed healing at the osteotomy site, tendon tear of extensor carpi longus radialis and delayed extensor pollicis longus tendon ruptures with the use of an osteotome. Through dorsal and volar approaches, both tendon rupture and tendon irritation were observed. Compared to patients who underwent osteotomy hinged on the volar cortex, patients receiving distraction-type osteotomy had more complications. Our surgical procedure is similar to the process of reducing the new fracture using the volar fracture line as the anatomical mark, and corrective osteotomy for radius or ulnar is avoided. Corrective osteotomy for radius develops a substantial bone defect which should be filled with structural bone graft from autogenous corticocancellous iliac crest, allogeneic bone or bone substitute. When a volar locked plate is used to maintain volar cortical contact, bone grafting is unnecessary.[19] Our surgical procedures guaranteed the contact of cortex to the greatest extent and reduced the development of bone defect at the utmost extent to avoid bone grafting. In the current study, only two osteoporosis patients having severe bone collapse consented to receive allograft.

Tendon complications could occur after the operation of DRF. A systematic review reported that the incidence of tendon complications varied from 1.7% (rupture) to 3.8% (irritation) in volar locking plate fixation for DRFs.[20] However, Haghverdian et al.[12] reported an incidence of all tendon-related complications in corrective osteotomy for DFR malunion as 20%, and osteotome from a volar to a dorsal direction might result in one carpi radialis longus tendon laceration. Rivlin et al.[14] reported that the dorsal callus, prominent osteotomy resection edges, and osteophytes might contribute to attritional rupture of the extensor pollicis longus tendon after a corrective osteotomy through a volar approach in the absence of screw prominence and technical flaws. Malposition of the plate could resulted result in rupture of the flexor tendon.[21] In this study, no tendon complications were observed in any of the patients during follow-up.

Functional outcomes were also appreciated in this study. In the Luo et al.'s[10] study, patients undergoing corrective osteotomy showed a 10-week duration from injury to corrective osteotomy and reported seven consecutive, and significant improvements in the QuickDASH (38.7-11.6), pain scores (7.1-0.9), range of motion of wrist. A total of 37 patients were followed for three to 10 years after dorsal osteotomy fixated with a Henry approach volar plate, and the patients' function and ability to perform activities were highly restored, and even if the function was not fully restored in some cases, no complications were reported.[22] In our patients, the range of motion of wrist was acceptable and the imaging performance greatly improved, suggesting that our simple surgical procedure may be as effective as osteotomy to regain the length and alignment of wrist. Another early rehabilitation program also contributed to the recovery of wrist function.

The timing of surgery for DRFs still remains debatable. A high number of scholars advocate that surgery after fracture should be carried out as soon as possible, as long as the patients meet the standards. Compared to late reconstruction in DFR malunions, Jupiter and Ring[23] concluded that early reconstruction was technically easier and effectively reduced the overall period of disability, if radiographic characteristics were predictive of persistent functional limitation. Pillukat et al.[24] compared early correction at an average of eight weeks in 14 patients and late correction at an average of 52 weeks after the injury in 20 patients, and they found that all osteotomies healed uneventfully and early corrections significantly reduced bone grafting. In our opinion, for DRF malunions with a duration of injury beyond 12 weeks, fracture reduction being performed with the palmar cortex as the anatomic landmark through the original fracture line should be taken timely as long as the fracture line can be seen on the X-ray film, which indicate the callus is nascent and unmineralized, and stripped easily. The soft tissue contractures are mild, which may not affect the reduction seriously after a careful release.

Nonetheless, there are some limitations to this study. First, although we attempted our best to recruit the eligible subjects as more as possible, this cohort study has a relatively small sample size, which may limit the potential complications during surgery. Second, the lack of a control group may be a disadvantage that we were unable to directly compare the efficacy in patients with/out

osteotomy in this study. Third, we only applied this technique to extra-articular DRF malunions, and the current study can be considered as a preliminary temptation. Whether this technique is applicable for intra-articular DRF malunion, and we would confirm it in the subsequent practice. Further indications should be included in prospective studies with a larger sample size.

In conclusion, open reduction through original fracture line and fixation with a locking plate is a feasible and effective treatment for selective extra-articular DFR malunions with few complications, and good functional recovery and imaging performance.

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Ethics Committee Approval: The study protocol was approved by the Ethics Committee of Tianjin Hospital (date: 20220307, No: 2022EIC007). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Patient Consent for Publication: A written informed consent was obtained from each patient.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Provided input into the concept and design of the study, and provided the materials: G.B., W.W.; Collected and assembled the data: J.L., T.Y., M.L.; Analyzed the data: J.L., T.Y.; Carried out literature review: M.L.; Wrote the article: G.B., M.L.; All authors have critically revised the article, read and approved the final version at the time of submission.

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