Opening Wedge Osteotomy for Distal Radius Malunion: Dorsal or Palmar Approach?

Esin Rothenfluh, MD[1] Andreas Schweizer, MD[1] Ladislav Nagy, MD[1]

[1] Balgrist University Hospital, University of Zürich, Zürich, Switzerland

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Address for correspondence Ladislav Nagy, MD, Balgrist University Hospital, Forchstrasse 340, 8008 Zürich, Switzerland (e-mail: Ladislav.Nagy@balgrist.ch).

Abstract

Background There are various technical variations to consider when performing a corrective osteotomy of a distal radius malunion. We chose two of the more commonly reported techniques and compared the results of volar (palmar) osteotomy and fixation with dorsal osteotomy and fixation.

Method Within a continuous cohort of patients who had undergone corrective osteotomy for a malunited Colles fracture, two groups could be identified retrospectively. In 8 patients a dorsal approach was used. A structural trapezoidal graft, subtending the amount of correction, was inserted into the osteotomy gap and stabilization was performed with a thin round-hole mini-fragment plate. In 14 patients a palmar approach and a palmar fixed-angle plate was used for correction of the malunion and for angular stable rigid fixation of the two fragments. The osteotomy gap was loosely filled with nonstructural cancellous bone chips.

A retrospective comparison of the two groups was performed to see whether the outcome was affected by the use of either operative technique.The demographics, the preoperative amount of deformity, range of motion, pain, and force were comparable for both groups. All osteotomies healed without loss of correction.

After a minimal follow-up of one year, radiographic appearance, objective functional parameters were assessed and subjective data (Disabilities of the Arm, Shoulder, and Hand [DASH] score and special pain and function questionnaire) obtained.

Results These data did not show statistical difference for the two groups except for the amount of final wrist flexion. This parameter was significantly better in patients who had palmar approaches and fixed-angle plates.

Conclusion Corrective osteotomies of distal radius malunions can be done in either way. It might result in some better flexion, if performed volarly.

Keywords

- distal radius
- malunion
- corrective osteotomy
- palmar approach
- dorsal approach

Most fractures of the distal radius, if treated properly, heal without relevant deformity. However, malunions can occur,[1–4] most notably if fractures have been left untreated or if well-meant but inappropriate conservative treatment has been applied. Not every malunion is symptomatic or needs further treatment; nonetheless, the kinematics of the wrist can be changed,[1,5–7] midcarpal instability can be caused[8] and the range of motion and grip strength reduced,[1] eventually resulting in unsatisfactory outcome. Loss of radial length should be the most important predictor for that.[9]

Corrective osteotomy of the distal radius with significant malalignment after a fracture is an option to restore the functional anatomy of the wrist, but can be a difficult procedure anyway. Operative treatment is therefore mainly based on patients' symptoms,[10] and once indicated, early intervention is advised.[11,12] The surgical procedures consist of either opening or closing wedge osteotomy, bone grafting if necessary, fixation by a fixed-angled plate or a standard T-plate and ulnar side procedures if appropriate. Therefore various techniques have been described.[13–17]

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The standard treatment method[10,13,18] is based on using an appropriately sized and shaped iliac crest autologous bone graft, which is inserted from dorsal into the osteotomy gap and which, by virtue of its shape, leads to the correction of the malunion. The resulting position is subsequently stabilized with wires, screws, or a plate. Advances in locking-screw plating technique through a palmar approach led the senior author () to use the fixed-angle volar plate itself for reduction and fixation of the osteotomy. This way, the distal/transverse bar of the T-plate is fixed to the presumptive distal fragment at its anatomically correct position alowing for indirect reduction after osteotomy. Compared with dorsal plating, this method has the advantage of avoiding problems with the extensor tendons.[19–22] The following retrospective comparative cohort analysis was undertaken to find out whether the different techniques applied had an effect on the outcome.

Materials and Methods

All osteotomies of the distal radius performed in our institution from April 6, 1999, through April 08, 2009, were collected ($N = 65$). Indications for osteotomy were significant pain and level of discomfort with limitations in activities of daily living including restricted motion and reduced grip strength. Patients with other indications for corrective osteotomy or required additional procedures, for example on the ulna, (24) were excluded. Of the remaining ($n_1 = 41$), only patients with a "Colles-type" deformity (malunion in extension and shortening) treated with an opening wedge osteotomy and a follow-up later than one year afterward were included ($n_2 = 24$). From these one patient was not available for the study and another one declined to participate (8%). Thus, final evaluation was based upon 22 patients: 14 patients after corrective osteotomy through a palmar approach, using a fixed-angle plate in conjunction with a cancellous bone graft, and 8 patients after osteotomy from dorsal and correction relying upon the shape of a structural corticocancellous graft inserted from dorsal. There were 10 women and 12 men; the average age was 45.14 years (11–84 years).

Operative Procedure

Dorsal Group (Group 1)

In 8 patients a dorsal incision was used. The distal radius was approached between the third and fourth extensor compartment, and the planned osteotomy level was detemined. Then, Schanz screws were introduced proximally and distally to the osteotomy level, strictly in the lateral plane, subtending the planned flexion correction angle between them. Then an incomplete osteotomy parallel to the radiocarpal joint was performed with the saw just proximal to the distal radioulnar joint, usually leaving a thin bony hinge at the ulnopalmar edge of the radius. At this point, by aligning the Schanz screws parallel to each other, the planned anatomical volar tilt could be restored. This position was temporarily stabilized by an external fixator, which was applied between the Schanz screws. With the correct palmar tilt now ensured, a laminar spreader was introduced into the osteotomy gap from the radial side and opened until the radial inclination was also adjusted to normal. The resulting trapezoidal osteotomy gap then was filled with a compression-resistant corticocancellous graft from the iliac crest. Its dimension and shape were sculpted according to the preoperative plan and usually needed only adjustment in size (not the angles), and its fit actually served as confirmation of the correct reduction. Of course this was also checked fluoroscopically, especially with respect to length. If approved, the construct was stabilized with a thin 2.7 mm or a 3.5 small fragment plate.

Concomitant pathologies included a scapholunate dissociation, which was reconstructed during the same surgical procedure, in one patient and a ununited styloid process in another patient, which had to be extirpated simultaneously. In a patient with a caput ulnae syndrome on the basis of an ulnar positive variance of 6 mm and a triangular fibrocartilage complex (TFCC) rupture, a Sauvé-Kapandji procedure was necessary.

Palmar Group (Group 2)

In 14 patients a standard Henry approach.[23] was used. A dedicated locking screw plate (Synthes® 2.4 mm LCP-T-plate) was attached to the presumptive distal fragment in the anatomically correct position, thereby letting the proximal part of the plate stand off from the radius shaft by the intended angle of correction in both projections (►**Fig. 1**). The angle formed by the plate shaft with the radial diaphysis corresponds to the malalignment of the articular surface of the radius. After removing the plate a complete transverse metaphyseal osteotomy of the radius was performed just proximally to the sigmoid notch. Both fragments were then mobilized; in particular, the dorsal periosteum was cut transversally through the osteotomy gap under direct vision. Then the plate was reattached to the distal fragment exactly in its previous position, which is determined when using the prepared screw holes and an LCP plate. By then

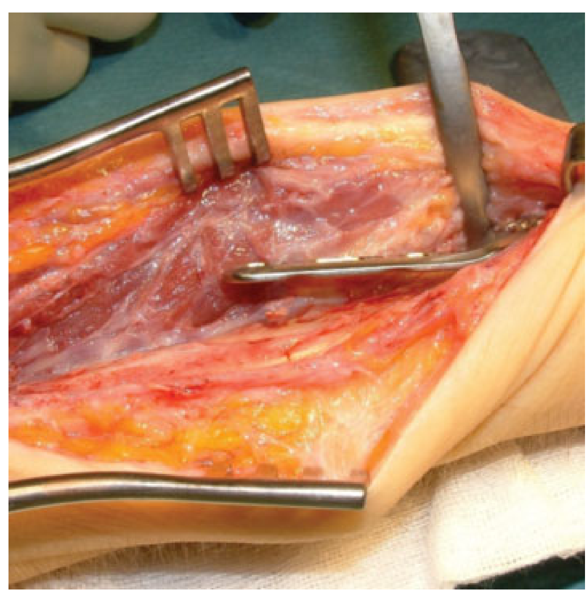

Fig. 1 After fitting the plate on the distal part of the radius, the part of the plate sticking out proximally shows the required reduction angle.

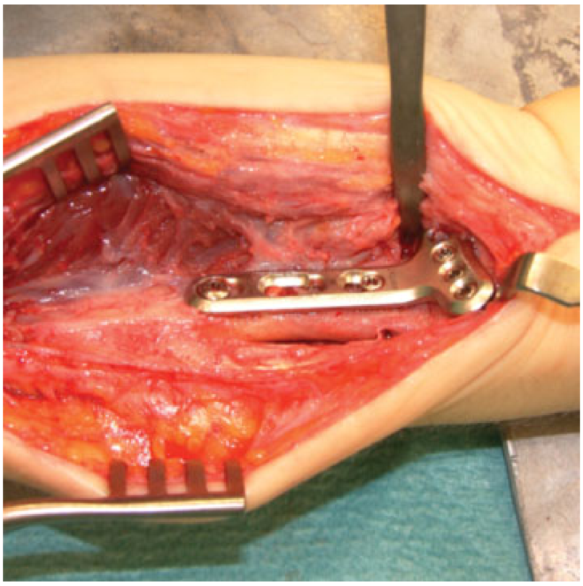

Fig. 2 After filling the osteotomy gap with nonstructural bone and fixing the volar fixed-angled plate on the distal radius.

aligning the proximal body of the plate with the radius shaft, by indirect reduction, the angular malunion was corrected. The plate was then provisionally attached proximally either with a clamp or with a screw through the oblong hole, and the correction is checked under image intensifier especially with regard to the length. Then by sliding the plate upon the shaft, ulnar variance was set as planned to the same amount as contralateral and screws were placed in the remaining plate holes. Finally, the resulting osteotomy gap was filled with cancellous bone chips, preferably from the iliac crest (►**Fig. 2**). The TFCC had to be reconstructed in two patients simultaneously and sutured in one patient. Two lesions were detected by arthroscopy during the same surgery session and one by preoperative magnetic resonance imaging (MRI). One carpal tunnel release had to be performed additionally.

Desired angles for correction were determined corresponding to the opposite side. If the opposite side was anatomically pathological, the aim for surgical correction in the sagittal plane was +10° palmar tilt and +25° for radial inclination. The height of the bone graft was determined to restore ulnar variance corresponding to the opposite side.

Postoperative Care

There was no meaningful variability in terms of postoperative care between groups 1 and 2, and both had the same postoperative treatment: The wrist was completely immobilized in a light splint for two weeks, followed by cautious motion exercises out of the removable splint until the bone consolidation had occurred. Complete removal of the splint and hand strengthening were delayed until radiographs showed solid union of the osteotomy site.

Postoperative Evaluation

Range of motion was measured with a hand-held goniometer and the grip strength with a Jamar hand grip dynamometer preoperatively and in the follow-up examinations. The average grip strength of 3 attempts was used and will be presented as a force-ratio with respect to preoperative and postoperative measurement. Because only three preoperative values for grip strength were available in group 1 and nine in group 2, collected data for force ratios were restricted to these.

Preoperative radiographs and the radiographs from the final follow-up visit were reviewed.

The final radiographic alignment was compared with the preoperative one, and the change in alignment was evaluated for each patient. Radiographic measurements were made with the software Cerner Provision PACS (Picture Archiving and Communication System), Release 5.0. Dorsal tilt was measured on a lateral radiograph of the wrist as the angle between a tangent line to the distal radial articular surface and the horizontal line. Radial inclination was measured on a posteroanterior radiograph of the wrist as an angle between a line orthogonal to the radial diaphysis and a second line connecting the radial and ulnar margins of the distal radius articular surface. Ulnar variance was measured as the distance between two lines that were orthogonal to the radial diaphysis. One was drawn at the level of the ulnar margin of the distal articular surface of the radius, and the other one at the distal limit of the ulnar head.At final follow-up, apart from the DASH questionnaire, the patient was asked to self-assess the degree of pain at rest and under loading conditions, quantified by Visual Analog Scale (VAS) from 0 to 10. The patient was also asked to judge his subjective "wrist-value" on a scale from 0 to 100%, where 100% meant full function and was equivalent to a healthy wrist. The DASH-score[24–26] was calculated based on a 30-item, self report questionnaire to measure physical function and symptoms. No preoperative DASH-scores were collected.

Statistics

All variables were statistically compared before surgery and at the last follow-up visit. For all parametric data the Shapiro-Wilk test was used for verifying that all data arise from a Gaussian distribution. The results of normally distributed continuous data are presented as mean values ± standard deviation. Comparison of both series of measurements was done by Student's *t* test. Nonparametric testing using the Mann-Whitney test was necessary for evaluation of rest and loading pain, value of wrist and DASH score. *P*-values less than 0.05 were considered significant. All *p*-values are reported as two-tailed.

Results

Preoperative

Preoperative wrist motion was $54° \pm 21°$ (group 1) and $55° \pm 24°$ (group 2) for flexion, $67° \pm 23°$ (group 1) and $69° \pm 22°$ (group 2) for extension, $78° \pm 16°$ (group 1, $N = 7$) and $71° \pm 22°$ (group 2, $N = 13$) for supination, $79° \pm 12°$ (group 1, $N = 7$) and $64° \pm 24°$ (group 2, $N = 13$) for pronation, $22° \pm 7°$ (group 1, $N = 6$) and $23° \pm 9°$ (group 2, $N = 13$) for radial deviation, $32° \pm 5°$ (group 1, $N = 6$) and

Fig. 3a–b X-ray at final follow-up of a patient who had a dorsal approach, showing bony healing of the osteotomy. **(a)** Anteroposterior view. **(b)** Lateral view.

Fig. 4a–b X-ray at final follow-up of a patient who had a palmar approach, also showing bony healing of the osteotomy. **(a)** Anteroposterior view. **(b)** Lateral view.

29° ± 11° (group 2, $N = 13$) for ulnar deviation. Pain at rest was 4.54 ± 3.01 (group 1) and 4.88 ± 3.00 (group 2) on the VAS, pain with loading 6.5 ± 3.30 (group 1) and 6.73 ± 2.76 (group 2), grip strength 0.44 ± 0.15 (group 1, $N = 3$) and 0,74 ± 0.16 (group 2, $N = 11$). Preoperative radiographs showed a dorsal tilt of 22° ± 6° in group 1 and 15° ± 8° in group 2. The ulnar variance was 4.03 ± 4.46 mm (group 1) and 1.89 ± 2.96 mm (group 2), the radial inclination was 20° ± 3° (group 1) and 16° ± 7° (group 2).

Postoperative

Radiographs showed bony trabeculae crossing the osteotomy within 3 months in all cases (►**Figs. 3a–b**, **4a–b**).

Values for motion and grip strength are provided in ►**Table 1**. Pain upon loading was quantified at 3.61 ± 3.53 on VAS (group 1) and at 3.08 ± 2.87 (group 2). Pain at rest was 1.54 ± 2.97 (group 1) and 1.29 ± 2.03 (group 2), the wrist value was 85.0% ± 20.74% (group 1) and 70.83% ± 24.20 (group 2).

The DASH- Score showed a scoring of 20.24 ± 32.14 in group 1 and 17.32 ± 22.45 in group 2.

X-ray images at follow-up showed a dorsal tilt of 12° ± 5°, an ulnar variance of 2.24 ± 3.01 mm and a radial inclination of 29° ± 4° in group 1. In group 2 dorsal tilt was 7° ± 5°, ulnar variance −0.23 ± 2.27 mm, and radial tilt 26° ± 6°. This was unchanged compared with immediate postoperative in all cases.

In group 1, five of eight patients (63%) and in group 2 five of 14 patients (36%) underwent hardware removal. In group 1 this was basically reasoned by irritation of the extensor tendons by the implant. Symptoms including pain, impaired tendon function, and irritation led the surgeon to assume that the plate was impinging the tendon and made it necessary to remove it. In group 2 hardware removal was necessary because of unspecific pain or plate prominence.

In one patient of group 2 a secondary dislocation of the distal fragment was observed 21 days after surgery, so that a revision surgery was necessary, providing a satisfactory result afterwards.

Statistical Comparison

Preoperatively no parameters available were significantly different between the two groups. Postoperatively there was a greater degree of flexion ($p = 0.012$) in group 2 (►**Table 1**). All other parameters were comparable including motion, grip strength, pain in rest/under loading, DASH score, and radiographic data ($p > 0.05$).

Discussion

Maintenance of adequate wrist function after fracture of the distal radius has been shown to depend on accurate restoration of the anatomical shape of the bone and the joints.[7,27–33] Angular deformity and shortening of the distal radius lead to

Table 1 Ranges of motion at last follow-up visit for both groups

	Group 1 (dorsal); $n = 8$		Group 2 (palmar); $n = 14$	
	Preoperative	Postoperative	Preoperative	Postoperative
Flexion	54 ± 21°	43 ± 22°	55 ± 24°	**71 ± 13°**
Extension	67 ± 23°	59 ± 18°	69 ± 22°	65 ± 14°
Pronation	79 ± 12°	70 ± 14°	64 ± 24°	75 ± 13°
Supination	78 ± 16°	76 ± 21°	71 ± 22°	82 ± 9°
Ulnar deviation	32 ± 5°	34 ± 12°	29 ± 11°	36 ± 6°
Radial deviation	22° ± 7°	19 ± 12°	23° ± 9°	19 ± 10°
Grip strength	0.44 ± 0.15	0.71 ± 0.25	0,74 ± 0.16	0.92 ± 0.15

The significantly greater flexion in group 2 is indicated in bold. Data are presented as mean values ± standard deviation.

altered load bearing by articular surfaces and, if excessive, it results in a preosteoarthritic condition.[15,34,35] Overload of the radiocarpal and midcarpal joints contributes to synovitis and osteoarthritis, resulting in pain and loss of mobility.[8,36,37] Ulnocarpal impingement can arise from radial shortening and radio-ulnar length discrepancy.[2,10] Several authors have reported on the sequelae after Colles' fractures, and their data about complication types, and frequency did not differ significantly from each other.[27,28,31,38,39]

We have investigated a mostly homogeneous group of patients in terms of indication and preoperative conditions. The measurements of radiologic postoperative outcomes for both cohorts were analyzed statistically, and in this analysis no relevant difference in the amount of correction of the volar tilt, radial tilt, and ulna variance could be marked out. Selection bias of the patients therefore is expected to be largely absent.

Based on this, our data suggest that the radiographic results of osteotomy without the use of a structural bone graft, using merely a palmar locking plate for reduction and retention, are comparable to those achieved with dorsal osteotomy and the interposition of an exactly shaped compression resistant cortico-cancellous bone graft for reduction. In both groups good results were achieved, confirming the value of distal radius osteotomy in the treatment of malunited fractures of the distal radius.

Additionally to these aspects, we were able to demonstrate that a palmar approach has a favorable effect on outcome of wrist flexion. The improved flexion may result from less scarring due to the palmar approach and avoiding irritation of the extensor tendons by the implant. We assume that the grip strength would possibly have reflected better global function or less pain after a palmar approach, if the number of patients had been higher. This presumption, however, is not reflected by the self-assessed functional and pain scores. We could explicitly reveal a statistical difference between the two groups for wrist flexion. Although we could not reveal any statistical relevance for the rest of the parameters, it has to be stated that sample sizes were too small to make any general conclusions at all.

Extensor tendon irritation, attrition, and even rupture are higher for dorsal plate placement and require more secondary procedures for hardware removal. We pointed out a 63% hardware removal rate for the dorsal plate versus a 36% removal rate for the volar plate, thus one is essentially double the other.

This coincides with results of Keller et al,[40] who reported on a series of 49 patients who underwent dorsal plating of the distal radius fractures. At a mean follow- up of 32 months, 37 of the 49 patients had undergone plate removal and one patient suffered a rupture of the extensor indicis proprius. Nevertheless all patients had an average DASH score of 14.4 as well as good motion and grip strength. However, the mechanical advantages for treating acute fractures of the distal radius offered by locking plates[41–43] are attractive for corrective osteotomies as well.

In this report only a limited number of patients could be examined who fulfilled our inclusion criteria and were available for follow-up. Second, no preoperative DASH-scores were available, and there was a lack of data referring to some other preoperative values. Therefore, our study could only incompletely assess the postoperative improvement between the two groups. However, pre- to postoperative change could be completely determined for the most relevant parameters such as flexion and extension of the wrist, which indicated a favorable outcome for the palmar approach.

Two procedures exist for correction of the distal radius after dorsally malunited extra-articular fractures. Given the subtle differences found here, considerably greater cohorts than we could offer and longer-term studies may be needed to clearly delineate these and maybe other differences. Although they may be statistically significant, they may not have clinical relevance, however. Thus, both techniques can effectively be used for correction of distal radius malunion. The palmar approach with insertion of a cancellous graft is likely a little bit easier to perform and entails a lower extensor tendon irritation and hardware removal.

References

1 Jenkins NH, Mintowt-Czyz WJ. Mal-union and dysfunction in Colles' fracture. J Hand Surg [Br] 1988;13(3):291–293
2 Pechlaner S, Sailer R. Korrekturosteotomie nach peripheren Radiusfrakturen. Methode und Ergebnisse [in German]. Unfallchirurgie 1989;15(5):230–235
3 Prommersberger KJ, Froehner SC, Schmitt RR, Lanz UB. Rotational deformity in malunited fractures of the distal radius. J Hand Surg Am 2004;29(1):110–115
4 Zyluk A, Niedźwiedź Z. Ocena wyników leczenia wadliwie wygojonych złamań dalszego końca kości promieniowej przez osteotomie korekcyjna. [in Polish]. Chir Narzadow Ruchu Ortop Pol 2008;73(1):41–48
5 Hirahara H, Neale PG, Lin YT, Cooney WP, An KN. Kinematic and torque-related effects of dorsally angulated distal radius fractures and the distal radial ulnar joint. J Hand Surg Am 2003;28(4):614–621
6 Pogue DJ, Viegas SF, Patterson RM, et al. Effects of distal radius fracture malunion on wrist joint mechanics. J Hand Surg Am 1990;15(5):721–727
7 Prommersberger KJ, Lanz UB. Biomechanik der fehlverheilten distalen Radiusfraktur. Eine Literaturübersicht [in German]. Handchir Mikrochir Plast Chir 1999;31(4):221–226
8 Taleisnik J, Watson HK. Midcarpal instability caused by malunited fractures of the distal radius. J Hand Surg Am 1984;9(3):350–357
9 Aro HT, Koivunen T. Minor axial shortening of the radius affects outcome of Colles' fracture treatment. J Hand Surg Am 1991;16(3):392–398
10 Fernandez DL. Correction of post-traumatic wrist deformity in adults by osteotomy, bone-grafting, and internal fixation. J Bone Joint Surg Am 1982;64(8):1164–1178
11 Sharpe F, Stevanovic M. Extra-articular distal radial fracture malunion. Hand Clin 2005;21(3):469–487
12 Wilhelm K. Indikation und Ergebnisse von Radiuskorrekturoperationen [in German]. Handchir Mikrochir Plast Chir 1985;17(4):225–229
13 Amadio PC, Botte MJ. Treatment of malunion of the distal radius. Hand Clin 1987;3(4):541–561
14 Athwal GS, Ellis RE, Small CF, Pichora DR. Computer-assisted distal radius osteotomy. J Hand Surg Am 2003;28(6):951–958
15 Bushnell BD, Bynum DK. Malunion of the distal radius. J Am Acad Orthop Surg 2007;15(1):27–40
16 Ring D, Roberge C, Morgan T, Jupiter JB. Osteotomy for malunited fractures of the distal radius: a comparison of structual and nonstructual autogenous bone grafts. J Hand Surg [AM] 2002; 27A:216–222

17 Viegas SF. A new modification of corrective osteotomy for treatment of distal radius malunion. Tech Hand Up Extrem Surg 2006;10(4):224–230
18 Roesgen M, Hierholzer G. Corrective osteotomy of the distal radius after fracture to restore the function of wrist joint, forearm, and hand. Arch Orthop Trauma Surg 1988;107(5):301–308
19 Chiang PP, Roach S, Baratz ME. Failure of a retinacular flap to prevent dorsal wrist pain after titanium Pi plate fixation of distal radius fractures. J Hand Surg Am 2002;27(4):724–728
20 Georgoulis A, Lais E, Bernard M, Hertel P. Die volare Plattenosteosynthese bei der typischen und atypischen distalen Radiusfraktur [in German]. Aktuelle Traumatol 1992;22(1):9–14
21 Kambouroglou GK, Axelrod TS. Complications of the AO/ASIF titanium distal radius plate system (Pi plate) in internal fixation of the distal radius: a brief report. J Hand Surg Am 1998;23 (4):737–741
22 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-A(10):1956–1960
23 Henry MH, Griggs SM, Levaro F, Clifton J, Masson MV. Volar approach to dorsal displaced fractures of the distal radius. Tech Hand Up Extrem Surg 2001;5(1):31–41
24 Germann G, Wind G, Harth A. r DASHFragebogen—Ein neues Instrument zur Beurteilung von Behandlungsergebnissen an der oberen Extremität [in German]. Handchir Mikrochir Plast Chir 1999;31(3):149–152
25 Gummesson C, Atroshi I, Ekdahl C. The disabilities of the arm, shoulder and hand (DASH) outcome questionnaire: longitudinal construct validity and measuring self-rated health change after surgery. BMC Musculoskelet Disord 2003;4:11
26 Jester A, Harth A, Wind G, Germann G, Sauerbier M. Disabilities of the arm, shoulder and hand (DASH) questionnaire: Determining functional activity profiles in patients with upper extremity disorders. J Hand Surg [Br] 2005;30(1):23–28
27 Cooney WP III, Dobyns JH, Linscheid RL. Complications of Colles' fractures. J Bone Joint Surg Am 1980;62(4):613–619
28 Gartland JJ Jr, Werley CW. Evaluation of healed Colles' fractures. J Bone Joint Surg Am 1951;33-A(4):895–907
29 Jenkins NH, Jones DG, Johnson SR, Mintowt-Czyz WJ. External fixation of Colles' fractures. An anatomical study. J Bone Joint Surg Br 1987;69(2):207–211
30 Jupiter JB. Fractures of the distal end of the radius. J Bone Joint Surg Am 1991;73(3):461–469
31 Lidstrom A. Fractures of the distal end of the radius. A clinical and statistical study of end results. Acta Orthop Scand Suppl 1959;41:1–118
32 Porter M, Stockley I. Fractures of the distal radius. Intermediate and end results in relation to radiologic parameters. Clin Orthop Relat Res 1987;(220):241–252
33 Stewart HD, Innes AR, Burke FD. Factors affecting the outcome of Colles' fracture: an anatomical and functional study. Injury 1985;16(5):289–295
34 Fernandez DL. Reconstructive procedures for malunion and traumatic arthritis. Orthop Clin North Am 1993;24(2):341–363
35 Lozano-Calderón SA, Brouwer KM, Doornberg JN, Goslings JC, Kloen P, Jupiter JB. Long-term outcomes of corrective osteotomy for the treatment of distal radius malunion. J Hand Surg Eur Vol 2010;35(5):370–380
36 Park MJ, Cooney WP III, Hahn ME, Looi KP, An KN. The effects of dorsally angulated distal radius fractures on carpal kinematics. J Hand Surg Am 2002;27(2):223–232
37 Verhaegen F, Degreef I, De Smet L. Evaluation of corrective osteotomy of the malunited distal radius on midcarpal and radiocarpal malalignment. J Hand Surg Am 2010;35(1):57–61
38 Frykman G. Fracture of the distal radius including sequelae—shoulder-hand-finger syndrome, disturbance in the distal radio-ulnar joint and impairment of nerve function. A clinical and experimental study. Acta Orthop Scand 1967;(Suppl 108):108, 3
39 Lippmann RK. Laxity of the radio- ulnar joint following Colles' fracture. Arch Surg 1937;35(4):772–786
40 Keller M, Steiger R. Osteosynthetische Versorgung distaler Radiusextensionsfrakturen bei Frauen über 60 Jahren mit der dorsalen Radiusplatte (piPlatte) [in German]. Handchir Mikrochir Plast Chir 2006;38(2):82–89
41 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
42 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
43 Prommersberger KJ, Lanz UB. Corrective osteotomy of the distal radius through volar approach. Tech Hand Up Extrem Surg 2004; 8(2):70–77