

Evidence Based Postoperative Treatment of Distal Radius Fractures following Internal Locking Plate Fixation

Důkazem podložené pooperační léčení zlomenin distálního radia po osteosyntéze úhlově stabilní dlahou

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SUMMARY

Originally, the treatment method of choice for distal radial fractures (DRF) has been a non-operative approach with six to eight weeks of plaster casting. The introduction of volar locking plate systems at the beginning of the 21st century has pushed trends towards open reduction and internal fixation (ORIF). While the introduction of fixed angle locking plates together with the increasing knowledge on wrist function and related variable outcomes has led to consensus that operative fixation in instable DRF is the treatment method of choice, there is no agreement on a postoperative care of these injuries. The authors will discuss the available evidence for current concepts of postoperative treatment of DRFs following fixed angle fixation under socioeconomical, biomechanical and burden of disease aspects. Further, relevant randomized controlled trials are evaluated with regard to applied postoperative treatment regimes and related risks for complications.

KEY WORDS: distal radius fracture, postoperative treatment, evidence based aftercare, early mobilization, internal fixation, volar locking plate, complications.

INTRODUCTION

Fractures of the distal radius (DRF) are commonly defined as fractures within three centimeters of the radiocarpal joint of the radius, where the lower end of the radius interfaces with the carpal bones (21). A recent prospective study on the national incidence of osteoporosis-associated fractures in a population of more than 200,000 inhabitants revealed DRFs as the most frequent fracture type with an annual incidence of 197/100,000. Remarkably, 75% of these fractures underwent operative treatment, which indicates a general trend towards open reduction and internal fixation (ORIF) in inadequately reduced DRFs (1, 42, 72).

Originally within the domain of conservative therapy, modern fracture treatment has led to concepts of ORIF that circumvent the multiple disadvantages of long-term immobilization. Only within the 21st century implants that follow a fixed angle concept have become available, particularly for the distal radius (14, 63). These proceedings in osteosynthesis systems have brought great progress in achievable levels of stability and have led to consensus that ORIF in instable displaced DRFs is the treatment method of choice (9, 64). Nevertheless, there has been no agreement on a postoperative care in the context of these injuries (6, 9, 25, 59).

This review summarizes available literature for evidenced based treatment regimes for the postoperative rehabilitation of DRFs in adults. Current postoperative strategies are analyzed for outcomes as well as related complication rates and reported with regard to socioeconomical, biomechanical and burden of disease aspects. Further, relevant randomized controlled trials were evaluated concerning the optimal period of immobilization and appropriate methods of rehabilitation with corresponding risks for complications.

BIOMECHANICAL ASPECTS OF WRIST IM-/ MOBILIZATION

Although the evolution in fracture treatment with fixed angle locking plate (FALP) systems has generally led to therapy regimens that allow fracture healing during the course of early mobilization, the necessity of additional postoperative casting after internal plate fixations in DRF is still highly controversial (37, 39, 49, 50, 52, 55, 62, 63).

Table 1. Complication rates following fixed angle plate fixation. In order to detect rare complications after fixed angle plate fixation studies that included at least 200 patients were reviewed for their distribution of complications. Most frequent complications seem to be either tendon or nerve related problems. However bone related issues, such as secondary dislocations are rare events according to these reports and may therefore not be circumvented by postoperative splinting.

Author / study type	**Cohort size / patient demographics**	**AO-fracture type**	**Implant type**	**DASH outcome / time point (* Quick-DASH)**	**Total complication rate**
Fowler et al. (18) / prospective	n = 37, mean 57 y (range 16–89y)	A (13%) B (5%) C (81%)	Volar locking plate (Aptus Distal Radius 2.5 plate)	50 / 2 w. 26 / 6 w. 16 / 12 w. 06 / 52 w.	5%
Aftertreatment 2 to 6 w protective orthosis used as needed. At 2. w. aggressive anti-edema, tendon gliding, and range of motion exercises. At 6. w. progressive strengthening and resistance exercises. At 12. w. work-hardening program or discharge from therapy.					
Karantana et al. (27) / prospective	n = 66 / N/A	A3 (41%) C2 (56%) C3 (3%)	Volar locking plate (Distal Volar Radius (DVR) plate)	*41 ± 21 / 6 w. *21 ± 17 / 12 w. *9 ± 12 / 12 mo.	24%
Aftertreatment 2 w. immobilization in either plaster splint or removable Velcro splint with subsequent standard wrist and finger range-of-motion exercises.					
Qu et al. (60) / prospective	n = 19, mean 55.4 y (range 23–71 y)	B2 (15%), B3 (15%), C1 (5%), C2 (36%), C3 (26%)	Volar locking plate (Gear drive plate)	9.3 / 12 mo.	All fractures united uneventfully with no secondary displacement, and no superficial or deep infection.
Aftertreatment 2–4 w. immobilization with splint (not further specified).					
Jakubietz et al. (23) / retrospective	**Volar plate group:** n = 22, mean 67.7 y (range 52–92). **Dorsal plate group:** n= 20, mean 67.6 y (range 52 – 85 y)	C1 (45%), C2 (31%), C3 (26%)	Volar locking plate (Aptus Radius Plate) or dorsal Pi-plate (AO-ASIF Pi-Plate)	**Volar plate group:** 10.5 / 12 mo. **Dorsal plate group:** 14.3 / 12 mo.	**Volar plate group:** 41% **Dorsal plate group:** 55%
Aftertreatment 2 w. cast immobilization followed by another 4 w. immobilization in removable splint accompanied by motion exercises.					
Osti et al. (57) / retrospective	n = 30, mean 52.0 y (SD ±12.0Y)	A3 (40%), C2 (20%), C3 (40%)	Volar locking plates (1.5-mm palmar titanium locking plate, first generation of locking compression plates)	9.9 (SD 10.4) / 4.85 (±0.80) y	25%
Aftertreatment 30.4±9.7 d. mean time of immobilization in a splint cast.					
Sügün et al. (68) / retrospective	n = 46, mean 48.7 y (range 24- 87y)	C (100%)	Volar locking plates (2.3 mm or 2.4 mm)	DASH 10.5 / 12 mo. (palmar group), 14.3 / 12 mo. (dorsal group)	30%
Aftertreatment 2 w. of immobilization in below elbow splint. End of 2. w. physiotherapy for wrist mobilization.					
Kwan et al. (31) / prospective	n = 75, mean 51 y (range 13–82 y)	C (75%)	Volar locking plate (2.4-mm locking plate fixation, Synthes) Switzerland)	11.6±14.6 / 24 mo.	13%
Aftertreatment No immobilization. Immediate initiation of free active mobilization of wrist joint.					
McFadyen et al. (45) / prospective	n = 27, median 61 (range 26–80)	A (100%)	Volar locking plates (Hand Innovations DVR-Anatomic plate / Synthes LCP T-plate 3.5 mm)	DASH 18.26 / 3 mo., DASH 15.89 / 6 mo.	No specific complications within time limits of study.
Aftertreatment 6 w. immobilization in below-elbow cast.					

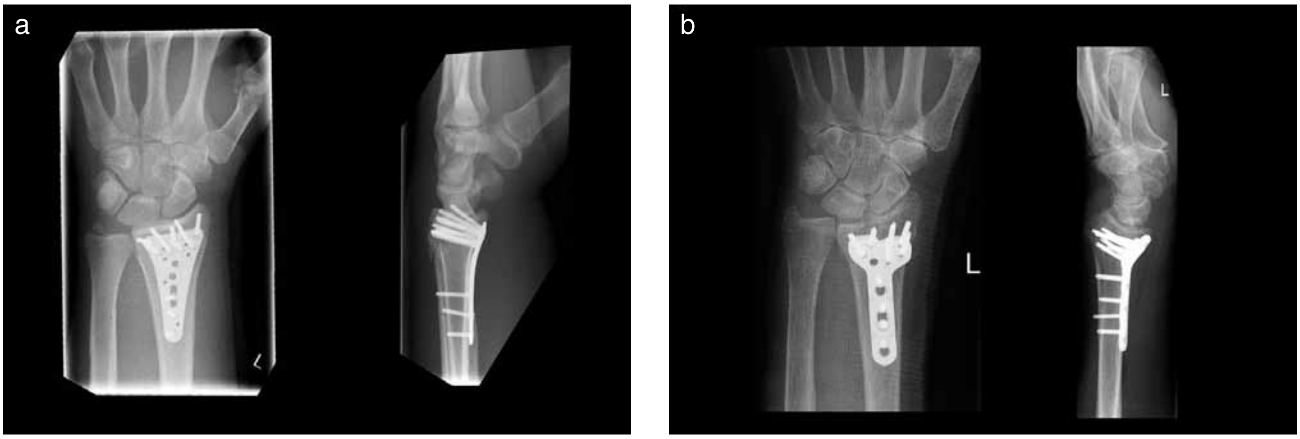

Fig. 1. A.p. and corresponding side views of x-ray images demonstrating AO type C3 DRFs in this bimodal age cohort. a) Postoperative result following volar locking plate fixation in a male patient, 21 years of age who suffered an AO type C3 DRF on the left side as a work related injury. b) Postoperative result following volar locking plate fixation in a female patient with osteoporotic bone structure, 76 years of age who suffered an AO type C3 DRF on the left side after a slip and fall accident. c) Same patient 4 weeks postoperatively showing secondary loss of reduction in the ulnar column, despite continuous immobilization in a circumferential below elbow splint. Patient age above 58 years has been identified as the most significant factor for secondary fracture displacement.

Early mobilization and related risk for fracture displacement

Instable fractures are defined as fracture patterns that show secondary displacement despite reduction into an anatomic alignment (51). In 1989 Lafontaine et al. (33) defined initial dorsal angulation > 20°, dorsal comminution, intra-articular fracture type, associated ulna fracture and patient age > 60 years as five principal factors that indicate fracture instability in radius fractures during the course of cast immobilization. More recent data indicates, that increasing patient age might be the most significant factor for secondary fracture displacement (8, 51, 69), whereas the influence of external splinting devices on the prevention of fracture collapse in unstable reductions has been increasingly questioned (3, 13). Nesbitt et al. (51) observed an increase for the probability of redisplacement of 50% after 4 weeks of an initially acceptable closed reduction in patients above the age of 58 years. Rigid internal fixations system such as FALPs with their ability to provide angular and axial stability minimize the risk for loss of reduction and hence revolutionized operative fracture treatment (15). Forces across the wrist joint reach estimated loads of 100 N for active wrist motion and up to 250 N for active finger motion. Modern locking plate implants for DRF surgery presented yield points that are five times greater than those estimated for active finger motion (54, 56), hence current FALP systems are more than capable of withstanding physiologic loads comparable to that of an intact radius (35, 36, 44, 74). Accordingly, secondary dislocation due to implant failure seems to be an unlikely event in contemporary DRF surgery (54, 56).

Prolonged immobilization and related risk of joint stiffness and overall outcome

On the other hand, prolonged immobilization of the wrist is likely to delay the early phase of rehabilitation (10), whereas the first two months of recovery presented to be significant for the overall patient outcome (41). Further, joint rest is widely recognized as a principal risk factor in the development of posttraumatic motion loss (48). Immobilization of uninjured connective tissue leads to biochemical, biomechanical, and physiologic changes within seven days. These local tissue disarrangements are exacerbated in the presence of trauma or edema, and may create permanent damage if not addressed swiftly and properly (10, 20, 40). The presence of trauma seems to alter the physiological equilibrium between matrix synthesis and tissue remodeling and hence triggers a fibrogenic process with consecutive changes in connective tissue healing, becoming clinically evident as joint capsule contractures (48). In fact regaining the status quo of the physical capability and performance of the previously immobilized wrist is not only frustrating for patients, but frequently illusive, especially in the elderly (10, 20, 40). The potential for rehabilitation of deleterious causes of prolonged rest in musculoskeletal tissues presented to decline with increasing age (5, 4). In contrast, early resumption of motion has shown to maintain physiologic viscoelasticity and homeostasis of connective tissue (10). Further early movement and loading 1–3 weeks after injury appears to promote bone healing significantly at least in long bone fracture sites (29).

Available Evidence suggests that early, controlled motion is vital to circumvent undesirable changes associated with immobilization and in order to maintain normal homeostasis and viscoelasticity of connective tissue (10). Mobilization within a certain time window of 1–3 weeks might be a key for the efficient rehabilitation of DRFs.

SOCIOECONOMICAL AND BURDEN OF DISEASE ASPECTS IN DISTAL RADIUS FRACTURE REHABILITATION

Socioeconomical aspects in DRF rehabilitation

The burden of DRFs together with its endemic incidence is reflected by the socioeconomic aspects of this disease and its treatment related expense. Interestingly DRFs – in contrast to most fracture types – occur with a bimodal distribution of prevalence, disproportionately affecting young adults as well as elderly patients in their professional life, leisure activities and activities of daily living (Fig 1a-b) (53). The peak incidence for male patients occurs at an age of 15–24 years, whereas the incidence for females concentrates at an age of 65–74 years (73). In fact more than 50% of the patients with DRFs are employed at the time when they suffer this fracture type, and they are subsequently unable to work from 67 days up to 20 weeks following the event of injury (26, 71).

The relationship of socioeconomic impact and aftercare treatment modalities in DRFs was markedly demonstrated by a trial of the German Employers' Liability Insurance Association in 2005. In this prospective study, a modified aftercare regimen reduced the days of inability to work by more than 40% (55.37 days vs. 92.38 days) in intraarticular DRFs, which resulted in a reduction of costs of more than 60% per case (992.40 Euros vs. 2602.20 Euros) (38). This data emphasizes the strong influence of aftercare modalities on the overall expenses in these injuries. More structured rehabilitation of DRFs may not only facilitate more rapid return into patients' daily routine, but as well reduce the duration of sick leave and laborer compensation, and is thus of great social and economic interest.

Burden of disease aspects in DRF rehabilitation

Substantial pain and the accompanying limited range of motion in the initial period of wrist fractures are within the nature of most acute injuries. However, whereas this acute phase can be compensated more easily in the lower extremity by the use of walking aids, about one third of patients suffering DRFs complain of an inability to perform basic activities of daily living for as long as 5 weeks following removal of wrist casts (11). Besides this handicap in the early stage of rehabilitation, chronic loss of function has as well been reported for DRFs (28). The undesirable dilemma of an impaired wrist following fracture has been demonstrated by Greendale et al. (19). This group examined more than 1000 elderly women for late effects after a mean time of 6.7 years following DRF events and found that these patients still experience functional disability during common activities such as holding onto hand rails while ascending or descending a stairway (19). With fractures accounting for the majority of trauma in developing nations, evidence based rehabilitation methods are desperately needed to optimize patient outcomes (17).

COMPLICATIONS FOLLOWING FIXED ANGLE LOCKING PLATE FIXATION IN DISTAL RADIUS FRACTURE

Besides the main objective of rapid rehabilitation, aftercare regimens should prevent possible complications during the healing process. To assess common complications following ORIF with FALP implants, available literature was analyzed for the most frequently reported events. Retrospective trials with large patient numbers allow the detection of rare complications and therefore provide a more comprehensive embodiment for this particular purpose. Interestingly, tendon and nerve related issues appear to be the most common type of complication following ORIF, whereas bone related problems are rare (Table 1). Secondary loss of reduction is mostly observed in elderly patients with low bone quality (33, 51), whether this complications can reliably be prevented by immobilization is debatable (Fig 1b-d). Esenwein et al. (16) reported a secondary dislocation rate as low as 1.4% in more than 650 patients that were immobilized for 2 weeks postoperatively. Other studies with more progressive postoperative regimens reported even lower secondary dislocation rates (34). Still, conclusions regarding the influence of immobilization cannot be drawn as the presented trials are without randomization and without control groups. Further, the impact of aftertreatment on the complication rate was outside the scope of these studies. Indeed, with respect to available evidence it is questionable if more conservative strategies with long-term postoperative immobilization relevantly reduce complications encountered after ORIF with FALPs.

CURRENT TRENDS IN OPEN REDUCTION AND INTERNAL FIXATION AFTERCARE

Although adequate fragment reduction and stable fixation are integral components of DRF therapy, postoperative rehabilitation plays a major role in functional restoration (65). Clearly, postoperative rehabilitation is essential to prevent short and long-term impairment of the injured wrist (11, 22). Although there is wide consensus that internal fixation with FALPs requires less immobilization time and hence allows more rapid return to routine activities, the review of various studies on internal fixations suggests that the aftercare regimens substantially differ in their immobilization policies, be-

Table 2. An overview of recent studies with various corresponding postoperative strategies that reported on outcomes following fixed angle plate fixation in DRFs. Only few studies analyzed early outcomes, such as DASH-scores after 6 weeks. Despite comparable implants, aftertreatment regimes include immobilization policies far different from each other, ranging from immediate wrist motion over orthosis used as needed to six weeks of immobilization. Further, postoperative treatment does not seem to correlate with fracture type or patient demographics. Nonetheless direct comparison is impossible, due to variability in follow up periods, frequency of fracture types and differences in patient demographics.

Author	**Cohort size / patient demographics**	**Type of fractures**	**Total complication rate**	**Tendon**	**Nerve**	**C.R.P.S.**	**Sec. dislocation**	**Malunion / delyaed healing**	**Other**
Esenwein et al. (16)	n=665, mean 58 y (range 13 -96)	A (24%) B (6%) C (70%)	11.3%	-	3%	1.4%	1.4%	-	-
Aftertreatment 2 w. immobilization in palmar splint, followed by additional 4 w. immobilization in protective removable splint.									
Soong et al. (66)	n=594, mean 52y (16–92)	A (26%), B (21%), C (53%)	4.0%	-	0.17% (CTS)	-	1.2%	0.34%	1.3% (intra-articular screw), 0.7% (symptomatic hardware), 0.34% (infection)
Aftertreatment Not specified.									
Johnson et al. (24)	n=204, mean 55 y (range 16–94)	A(33%) B/C (67%)	9.7%	3.4%	-	2%	-	-	1.9% re-operation for metalwork problems, 1,5% fracture reductions problems
Aftertreatment 2 w. immobilization in plaster of Paris backslab with subsequent mobilization unless additional injury or concern regarding stability.									
Lattmann et al. (34)	n=245, 62y (range 18–96)	A (42%) B (5%) C (54%)	15%	3.7%	2.0% (CTS), 2.4% (median nerve irritation)	3.7%	0.82%	0.4% (refracture)	0.4% (infection) 0.82% (wrist pain)
Aftertreatment Postoperatively immobilization in dorsal forearm splint. 1. d hand therapy, including active finger mobilization, hand and wrist edema therapy. Depending on fracture pattern and bone quality, immediate active wrist (n = 125, 51%) or after cast removal (n = 120, 49%; mean immobilization time, 12 ± 4 [6–42] d.). 6 w. strengthening exercises and weight bearing were started.									

sides precise postoperative practice patterns are not even mentioned in most reports (Table 2).

Postoperative occupational therapy policies and related outcomes

In general most authors report that patients were referred to formal occupational therapy following surgery. Unfortunately, very few studies exist that compare the influence on outcomes in DRFs of different occupational practice patterns. Among trials that focus on occupational therapy, the majority analyze injuries of the pre-locking plate era. Souer et al. (67) investigated the effect of formal occupational therapy versus independent exercising with instructions on the recovery of DRFs following ORIF and volar plate fixation. Despite a trend towards favoring the independent exercise group, there was no significant difference in DASH scores at any time point. A comparable trial by Krischak et al. (30) concluded that, based on PRWE outcomes, instructions in a home exercise program using a booklet with guidance is a valid alternative to prescribed physical therapy. This data is encouraging, especially for patients who have limited access to physiotherapy due to living in remote residential areas or lack of transportation. Considering that age is a significant predictor for functional outcome after DRF surgery (8), the wide range of age in DRF patients make general recommendations somewhat problematic.

Postoperative immobilization time and related outcomes

Studies focusing on immobilization times in conservative treatment of DRFs suggest that shorter immobilization causes improved short term recovery without increased risk of secondary fracture displacement (7, 43, 47, 70). In contrast the current guideline of the American Academy of Orthopaedic Surgeons (AAOS) suggests that patients do not routinely need to begin early wrist motion following stable fracture fixation (37). Other guidelines stay more vague and just recommend immobilization depending on the method of osteosynthesis and achieved level of stability (61).

One single randomized controlled study was identified that compared wrist mobilization within two weeks vs. six weeks following volar locking plate plate fixation in DRFs (39). The authors concluded that wrist immobilization for six weeks did not lead to decreased wrist motion when compared to initiation of wrist motion within two weeks after surgery. Careful reading of this study revealed some limitations in the significance of this experiment. The authors chose range of motion after three months as a primary endpoint and hence based their sample size calculation on this parameter. Range of motion does not correlate with DASH-score, which is the best validated outcome scoring system for wrist function (2, 32). However, while DASH-score outcomes were selected as a secondary endpoint, the small sample sizes of this study might not allow reliable detection of significant differences in DASH-scores. The study may therefore be considered as underpowered for the secondary endpoint of wrist function as reflected by the DASH-scores. Further, the endpoint was set on wrist motion after three months. Accordingly, the early phase of rehabilitation, known to be most important for rapid return into the daily routine, was not detected by this study design. Additionally, aspects such as cost-utility analysis and return to work, which are major issues regarding the increasing expenses in health care were not considered

The insufficient evidence in rehabilitation of DRFs became as well obvious, when Handoll et al. (21) conducted a review for the *Cochrane* database in 2006. The authors concluded that available evidence from randomized controlled trials is insufficient to establish the relative effectiveness of the various interventions used in the rehabilitation of adults with DRFs.

Current trials on internal fixations present a wide range of immobilization times, splinting systems, time, type, intensity and frequency of physiotherapy (Table 2). Possibly, functional outcomes approximate with time and therefore most studies present similar results after 6 or 12 months, whereas studies analyzing functional impairment after 6 to 12 weeks are scarce (Table 2). For patients in their professional life, the early phase of rehabilitation is especially essential for their return into daily routine. Regarding the high prevalence of this fracture in employed patients, time of convalescence is of major socioeconomic significance (1, 38, 72).

DISCUSSION

According to current literature, the duration of wrist immobilization after DRFs remains a topic of high relevance and dispute. Just recently, investigators published a study protocol on 3 weeks vs. 5 weeks of cast immobilization for the conservative treatment of non-displaced DRFs (2). In contrast to long term immobilization the concept of early mobilization combines rehabilitation and bone healing as two parallel processes that synchronously end with an entirely functional and stable usable limb (12, 43).

Despite numerous reports on ORIF with FALPs as a method of treatment for DRFs, the optimal aftercare has been scarcely considered in recent research. Although there is a wide consensus that internal fixation requires less immobilization time and hence allows return to routine activities sooner, there have been few systematic investigations on the extent of benefit from immobilization after internal fixation (9, 39). Studies focusing on immobilization times in conservative treatment of DRFs suggest that shorter immobilization causes improved short term recovery without increased risk of secondary fracture displacement (7, 43, 47, 70). In contrast, Lozano-Calderón et al. (39) reported that wrist immobilization for six weeks did not lead to decreased wrist motion when compared to early initiation of wrist motion following volar locking plate fixation. Yet there is insufficient evidence to give clear advice whether postoperative splinting is of any benefit after FALP fixation in DRFs, which results in postoperative treatment regimes that are rather based on subjective preferences, as opposed to available evidence. Fear of malunion in the fracture site or loss of anatomic alignment, as well as mistrust in the fixation device and individual intuition might lead to overprotection by some clinicians, with possible consequences for the overall (functional) outcome and related treatment expenses (11, 22, 38). In contrast investigations on implant stability, joint biomechanics and reported complications rates suggest that early mobilization is safe and might in fact be advantageous under socioeconomical aspects (1, 35, 36, 44, 72, 74).

Professional organizations are yet unable to recommend the type, intensity, and duration of postoperative treatment (37, 61), nor are there recommendations supported by studies regarding which patients might best profit from physical therapy (46). Details concerning the postoperative occupational therapy are not mentioned in the majority of trials in the field of DRF surgery (Table 2). Further, current aftercare regimes seem to disregard substantial confounding factors such as patient age and complexity of the fracture pattern (33, 51), which are known to cover a wide range, particularly in the cohort of DRF patients (73) (Fig 1a-b). Possibly, elderly patients with complex osteoporotic bone fractures might benefit from more conservative aftercare regimens (33, 51), while more progressive postoperative mobilization might be favorable for young manual workers. On the other hand, connective tissue appears to be more vulnerable to immobilization in the elderly (5, 4), and whether secondary loss of reduction can be prevented reliably by more conservative aftercare strategies remains unclear (Fig 1b-c). Conversely, novel fixations systems such as FALPs have been reported to allow stable fixation even in low bone quality (58). However, at this time, no studies exist that would clearly support one or the other method of rehabilitation.

Despite proceedings in osteosynthesis that have brought great progress for the treatment of DRFs, the lack of evidence-based postoperative treatment regimes is likely to be a limiting factor for the overall outcome. Future randomized controlled trials will hopefully contribute to more refined conclusions for the evidence-based postoperative rehabilitation of this endemic fracture.

References

1. BÄSSGEN, K., WESTPHAL, T., HAAR, P., KUNDT, G., MITTLMEIER, T., SCHOBER, H.-C.: Population-based prospective study on the incidence of osteoporosis-associated fractures in a German population of 200,413 inhabitants. J. Public Health (Oxf), 35: 255–261, 2013.
2. BENTOHAMI, A., KORTE, N., DE, SOSEF, N., GOSLINGS, J. C., BIJLSMA, T., SCHEP N.: Study protocol: non-displaced distal radial fractures in adult patients: three weeks vs. five weeks of cast immobilization: a randomized trial. BMC Musculoskelet. Disord., 15: 24, 2014.
3. BONG, M. R., EGOL, K. A., LEIBMAN, M., KOVAL, K. J.: A comparison of immediate postreduction splinting constructs for controlling initial displacement of fractures of the distal radius: a prospective randomized study of long-arm versus short-arm splinting. J. Hand Surg. Am., 31: 766–770, 2006.
4. BUCKWALTER, J. A.: Effects of early motion on healing of musculoskeletal tissues. Hand Clin., 12: 13–24, 1996.
5. BUCKWALTER, J. A.: Maintaining and restoring mobility in middle and old age: the importance of the soft tissues. Instr. Course Lect., 46: 459–469, 1997.
6. CAMPBELL, D. A.: Open reduction and internal fixation of intra articular and unstable fractures of the distal radius using the AO distal radius plate. J. Hand Surg. Br., 25: 528–534, 2000.
7. CHRISTENSEN, O. M., CHRISTIANSEN, T. G., KRASHENINNIKOFF, M., HANSEN, F. F.: Length of immobilisation after fractures of the distal radius. Int. Orthop., 19: 26–29, 1995.
8. CHUNG, K. C., KOTSIS, S. V., KIM, H. M.: Predictors of functional outcomes after surgical treatment of distal radius fractures. J. Hand Surg. Am., 32: 76–83, 2007.
9. CHUNG, K. C., SHAUVER, M. J., BIRKMEYER, J. D.: Trends in the United States in the treatment of distal radial fractures in the elderly. J. Bone Jt Surg., 91-A: 1868–1873, 2009.
10. CYR, L. M., ROSS, R. G.: How controlled stress affects healing tissues. J Hand Ther, 11: 125–130, 1998.
11. DEKKERS, M., SØBALLE, K.: Activities and impairments in the early stage of rehabilitation after Colles‘ fracture. Disabil. Rehabil., 26: 662–668, 2004.
12. DIAS, J. J., WRAY, C. C., JONES, J. M., GREGG, P. J.: The value of early mobilisation in the treatment of Colles‘ fractures. J. Bone Jt Surg., 69-B: 463–467, 1987.
13. DIAZ-GARCIA, R. J., CHUNG, K. C.: Common myths and evidence in the management of distal radius fractures. Hand Clin, 28: 127–133, 2012.
14. DROBETZ, H., KUTSCHA-LISSBERG, E.: Osteosynthesis of distal radial fractures with a volar locking screw plate system. Int. Orthop., 27: 1–6, 2003.
15. EGOL, K. A., KUBIAK, E. N., FULKERSON, E., KUMMER, F. J., KOVAL, K. J.: Biomechanics of locked plates and screws. J. Orthop. Trauma, 18: 488–493, 2004.
16. ESENWEIN, P., SONDEREGGER, J., GRUENERT, J., ELLENRIEDER, B., TAWFIK, J., JAKUBIETZ, M.: Complications following palmar plate fixation of distal radius fractures: a review of 665 cases. Arch. Orthop. Trauma Surg., 133: 1155–1162, 2013.
17. FAYAZ, H. C., JUPITER, J. B., PAPE, H. C., SMITH, R. M., GIANNOUDIS, P. V., MORAN, C. G., KRETTEK, C., PROMMERSBERGER, K. J., RASCHKE, M. J., PARVIZI, J.: Challenges and barriers to improving care of the musculoskeletal patient of the future – a debate article and global perspective. Patient Saf. Surg., 5: 23, 2011.
18. FOWLER, J. R., ILYAS, A. M.: Prospective evaluation of distal radius fractures treated with variable-angle volar locking plates. J. Hand Surg. Am., 38: 2198–2203, 2013.
19. GREENDALE, G. A., BARRETT-CONNOR, E., INGLES, S., HAILE, R.: Late physical and functional effects of osteoporotic fracture in women: the Rancho Bernardo Study. J. Am. Geriatr. Soc., 43: 955–961, 1995.
20. GREWAL, R., MACDERMID, J. C., KING, G. J. W., FABER, K. J.: Open reduction internal fixation versus percutaneous pinning with external fixation of distal radius fractures: a prospective, randomized clinical trial. J. Hand Surg. Am., 36: 1899–1906, 2011.
21. HANDOLL, H. H. G., MADHOK, R., HOWE, T. E.: Rehabilitation for distal radial fractures in adults. Cochrane Database Syst. Rev., CD003324, 2006.
22. HEGEMAN, J. H., OSKAM, J., VAN DER PALEN, J., DUIS, H. J. TEN, VIERHOUT, P. A. M.: The distal radial fracture in elderly women and the bone mineral density of the lumbar spine and hip. J. Hand Surg. Br., 29: 473–476, 2004.
23. JAKUBIETZ, M. G., GRUENERT, J. G., JAKUBIETZ, R. G.: Palmar and dorsal fixed-angle plates in AO C-type fractures of the distal radius: is there an advantage of palmar plates in the long term? J. Orthop. Surg. Res., 7: 8, 2012.
24. JOHNSON, N. A., CUTLER, L., DIAS, J. J., ULLAH, A. S., WILDIN, C. J., BHOWAL, B.: Complications after volar locking plate fixation of distal radius fractures. Injury, 45: 528–533, 2014.
25. JUPITER, J. B., MARENT-HUBER, M.: Operative management of distal radial fractures with 2.4-millimeter locking plates. A multicenter prospective case series. J. Bone Jt Surg., 91-A: 55–65, 2009.
26. KAKARLAPUDI, T. K., SANTINI, A., SHAHANE, S. A., DOUGLAS, D.: The cost of treatment of distal radial fractures. Injury, 31: 229–232, 2000.
27. KARANTANA, A., DOWNING, N. D., FORWARD, D. P., HATTON, M., TAYLOR, A. M., SCAMMELL, B. E., MORAN, C. G., DAVIS, T. R. C.: Surgical treatment of distal radial fractures with a volar locking plate versus conventional percutaneous methods: a randomized controlled trial. J. Bone Jt Surg., 95-A: 1737–1744, 2013.
28. KAUKONEN, J. P., KARAHARJU, E. O., PORRAS, M., LÜTHJE, P., JAKOBSSON, A.: Functional recovery after fractures of the distal forearm. Analysis of radiographic and other factors affecting the outcome. Ann Chir Gynaecol, 77: 27–31, 1988.
29. KENWRIGHT, J., RICHARDSON, J. B., GOODSHIP, A. E., EVANS, M., KELLY, D. J., SPRIGGINS, A. J., NEWMAN, J. H., BURROUGH, S. J., HARRIS, J. D., ROWLEY, D. I.: Effect of controlled axial micromovement on healing of tibial fractures. Lancet, 2: 1185–1187, 1986.
30. KRISCHAK, G. D., KRASTEVA, A., SCHNEIDER, F., GULKIN, D., GEBHARD, F., KRAMER, M.: Physiotherapy after volar plating of wrist fractures is effective using a home exercise program. Arch. Phys. Med. Rehabil., 90: 537–544, 2009.
31. KWAN, K., LAU, T. W., LEUNG, F.: Operative treatment of distal radial fractures with locking plate system-a prospective study. Int. Orthop., 35: 389–394, 2011.
32. KWOK, I. H. Y., LEUNG, F., YUEN, G.: Assessing results after distal radius fracture treatment: a comparison of objective and subjective tools. Geriatr. Orthop. Surg. Rehabil., 2: 155–160, 2011.
33. LAFONTAINE, M., HARDY, D., DELINCE, P.: Stability assessment of distal radius fractures. Injury, 20: 208–210, 1989.
34. LATTMANN, T., MEIER, C., DIETRICH, M., FORBERGER, J., PLATZ, A.: Results of volar locking plate osteosynthesis for distal radial fractures. J. Trauma, 70: 1510–1518, 2011.
35. LEUNG, F., ZHU, L., HO, H., LU, W. W., CHOW, S. P.: Palmar plate fixation of AO type C2 fracture of distal radius using a locking compression plate--a biomechanical study in a cadaveric model. J. Hand Surg. Br., 28: 263–266, 2003.
36. LEVIN, S. M., NELSON, C. O., BOTTS, J. D., TEPLITZ, G. A., KWON, Y., SERRA-HSU F.: Biomechanical evaluation of volar locking plates for distal radius fractures. Hand (N Y), 3: 55–60, 2008.
37. LICHTMAN, D. M., BINDRA, R. R., BOYER, M. I., PUTNAM, M. D., RING, D., SLUTSKY, D. J., TARAS, J. S., WATTERS, W. C., GOLDBERG, M. J., KEITH, M., TURKELSON, C. M., WIES, J. L., HARALSON, R. H., BOYER, K. M., HITCHCOCK, K., RAYMOND, L.: American Academy of Orthopaedic Surgeons clinical practice guideline on: the treatment of distal radius fractures. J. Bone Jt Surg., 93-A: 775–778, 2011.
38. LOHSTRÄTER, A., GERMANN, S., BAK, P., SMOLENSKI, U.: Kosteneffektivität und Qualitätssicherung des Rehamanagements der Verwaltungs-BG am Beispiel von Patienten mit distalen Radiusfrakturen. Phys. Rehab. Kur. Med., 4: 15 – A35, 2005.
39. LOZANO-CALDERÓN, S. A., SOUER, S., MUDGAL, C., JUPITER, J. B., RING, D.: Wrist mobilization following volar plate

fixation of fractures of the distal part of the radius. J. Bone Jt Surg., 90-A: 1297–1304, 2008.
40. LUCADO, A. M., LI, Z.: Static progressive splinting to improve wrist stiffness after distal radius fracture: a prospective, case series study. Physiother. Theory Pract., 25: 297–309, 2009.
41. MACDERMID, J. C., ROTH, J. H., RICHARDS, R. S.: Pain and disability reported in the year following a distal radius fracture: a cohort study. BMC Musculoskelet. Disord., 4: 24, 2003.
42. MACINTYRE, N. R., ILYAS, A. M., JUPITER, J. B.: Treatment of forearm fractures. Acta Chir. orthop. Traum. čech., 76: 7–14, 2009.
43. MCAULIFFE, T. B., HILLIAR, K. M., COATES, C. J., GRANGE, W. J.: Early mobilisation of Colles‘ fractures. A prospective trial. J. Bone Jt Surg., 69-B: 727–729, 1987.
44. MCCALL, T. A., CONRAD, B., BADMAN, B., WRIGHT, T.: Volar versus dorsal fixed-angle fixation of dorsally unstable extra-articular distal radius fractures: a biomechanic study. J. Hand Surg. Am., 32: 806–812, 2007.
45. MCFADYEN, I., FIELD, J., MCCANN, P., WARD, J., NICOL, S., CURWEN, C.: Should unstable extra-articular distal radial fractures be treated with fixed-angle volar-locked plates or percutaneous Kirschner wires? A prospective randomised controlled trial. Injury, 42: 162–166, 2011.
46. MICHLOVITZ, S. L., LASTAYO, P. C., ALZNER, S., WATSON, E.: Distal radius fractures: therapy practice patterns. J. Hand Ther., 14: 249–257, 2001.
47. MILLETT, P. J., RUSHTON, N., MILLET, P. J.: Early mobilization in the treatment of Colles‘ fracture: a 3 year prospective study. Injury, 26: 671–675, 1995.
48. MONUMENT, M. J., HART, D. A., SALO, P. T., BEFUS, A. D., HILDEBRAND, K. A.: Posttraumatic elbow contractures: targeting neuroinflammatory fibrogenic mechanisms. J. Orthop. Sci., 18: 869–877, 2013.
49. MURAKAMI, K., ABE, Y., TAKAHASHI, K.: Surgical treatment of unstable distal radius fractures with volar locking plates. J. Orthop. Sci., 12: 134–140, 2007.
50. NANA, A. D., JOSHI, A., LICHTMAN, D. M.: Plating of the distal radius. J. Am. Acad. Orthop. Surg., 13: 159–171, 2005.
51. NESBITT, K. S., FAILLA, J. M., LES, C.: Assessment of instability factors in adult distal radius fractures. J. Hand Surg. Am., 29: 1128–1138, 2004.
52. NEUHAUS, V., KING, J. D., JUPITER, J. B.: Fixation of osteoporotic fractures in the upper limb with a locking compression plate. Acta Chir. orthop. Traum. čech., 79: 404–410, 2012.
53. O‘NEILL, T. W., COOPER, C., FINN, J. D., LUNT, M., PURDIE, D., REID, D. M., ROWE, R., WOOLF, A. D., WALLACE, W. A.: Incidence of distal forearm fracture in British men and women. Osteoporos. Int., 12: 555–558, 2001.
54. OSADA, D., FUJITA, S., TAMAI, K., IWAMOTO, A., TOMIZAWA, K., SAOTOME, K.: Biomechanics in uniaxial compression of three distal radius volar plates. J. Hand Surg. Am., 29: 446–451, 2004.
55. OSADA, D., KAMEI, S., MASUZAKI, K., TAKAI, M., KAMEDA, M., TAMAI, K.: Prospective study of distal radius fractures treated with a volar locking plate system. J. Hand Surg. Am., 33: 691–700, 2008.
56. OSADA, D., VIEGAS, S. F., SHAH, M. A., MORRIS, R. P., PATTERSON, R. M.: Comparison of different distal radius dorsal and volar fracture fixation plates: a biomechanical study. J. Hand Surg. Am., 28: 94–104, 2003.
57. OSTI, M., MITTLER, C., ZINNECKER, R., WESTREICHER, C., ALLHOFF, C., BENEDETTO, K. P.: Locking versus nonlocking palmar plate fixation of distal radius fractures. Orthopedics, 35: e1613–7, 2012.
58. PROMMERSBERGER, K.-J., PILLUKAT, T., MÜHLDORFER, M., VAN SCHOONHOVEN, J.: Malunion of the distal radius. Arch. Orthop. Trauma Surg., 132: 693–702, 2012.
59. PUTTER, C. E. DE, SELLES, R. W., POLINDER, S., HARTHOLT, K. A., LOOMAN, C. W., PANNEMAN, M. J. M., VERHAAR, J. A. N., HOVIUS, S. E. R., VAN BEECK, E. F.: Epidemiology and health-care utilisation of wrist fractures in older adults in The Netherlands, 1997–2009. Injury, 44: 421–426, 2013.
60. QU, Y., XU, J., JIANG, T., ZHAO, H., GAO, Y., HOU, W.: Unstable distal radius fractures: restoration of the radial length with use of special palmar fixed-angle plate. Handchir. Mikrochir. Plast. Chir., 45: 1–5, 2013.
61. S1-LEITLINIE DER DEUTSCHEN GESELLSCHAFT FÜR UNFALLCHIRURGIE DISTALE RADIUSFRAKTUR.: AWMF-Registernummer 012 – 015. http://www.awmf.org/leitlinien/detail/ll/012–015.html, 2008.
62. SCHUPP, A., TUTTLIES, C., MÖHLIG, T., SIEBERT, H. R.: Der distale Speichenbruch. Winkelstabile Osteosynthese mit 2.4 mm Formplatten. Ist der Aufwand gerechtfertigt? Chirurg, 74: 1009–1017, 2003.
63. SCHÜTZ, M., KOLBECK, S., SPRANGER, A., ARNDT-KOLBECK, M., HAAS, N. P.: Die winkelstabile palmare Plattenosteosynthese bei der dorsal dislozierten distalen Radiusfraktur-Anwendung und erste klinische Erfahrungen. Zentralbl. Chir., 128: 997–1002, 2003.
64. SHIN, E. K., JUPITER, J. B.: Current concepts in the management of distal radius fractures. Acta Chir. orthop. Traum. čech., 74: 233–246, 2007.
65. SMITH, P., ADAMS, W. P., LIPSCHITZ, A. H., CHAU, B., SOROKIN, E., ROHRICH, R. J., BROWN, S. A.: Autologous human fat grafting: effect of harvesting and preparation techniques on adipocyte graft survival. Plast. Reconstr. Surg., 117: 1836–1844, 2006.
66. SOONG, M., VAN LEERDAM, R., GUITTON, T. G., GOT, C., KATARINCIC, J., RING, D.: Fracture of the distal radius: risk factors for complications after locked volar plate fixation. J. Hand Surg. Am., 36: 3–9, 2011.
67. SOUER, J. S., BUIJZE, G., RING, D.: A prospective randomized controlled trial comparing occupational therapy with independent exercises after volar plate fixation of a fracture of the distal part of the radius. J. Bone Jt Surg., 93-A: 1761–1766, 2011.
68. SÜGÜN, T. S., GÜRBÜZ, Y., OZAKSAR, K., TOROS, T., KAYALAR, M., BAL, E.: Results of volar locking plating for unstable distal radius fractures. Acta Orthop. Traumatol. Turc., 46: 22–25, 2012.
69. TAHRIRIAN, M. A., JAVDAN, M., NOURAEI, M. H., DEHGHANI, M.: Evaluation of instability factors in distal radius fractures. J. Res. Med. Sci., 18: 892–896, 2013.
70. VANG HANSEN, F., STAUNSTRUP, H., MIKKELSEN, S.: A comparison of 3 and 5 weeks immobilization for older type 1 and 2 Colles‘ fractures. J. Hand Surg. Br., 23: 400–401, 1998.
71. WENTZENSEN, A., LEUTFINK, D.: Externe Qualitässicherung am Beispiel der distalen Speichenbrüche. Ein Pilotprojekt der gesetzlichen Unfallversicherung. Z. Arztl. Fortbild. Qualitatssich., 91: 484–485, 1997.
72. WILCKE, M. K. T., HAMMARBERG, H., ADOLPHSON, P. Y.: Epidemiology and changed surgical treatment methods for fractures of the distal radius: a registry analysis of 42,583 patients in Stockholm County, Sweden, 2004–2010. Acta Orthop., 84: 292–296, 2013.
73. WILDNER, M., DÖRING, A., MEISINGER, C., CLARK, D. E.: Frakturen im höheren Lebensalter -- eine Herausforderung für Prävention und Gesundheitsförderung -- Ergebnisse der KORA-Frakturstudie Augsburg. Gesundheitswesen, 67 (Suppl. 1): S180–6, 2005.
74. WILLIS, A. A., KUTSUMI, K., ZOBITZ, M. E., COONEY, W. P.: Internal fixation of dorsally displaced fractures of the distal part of the radius. A biomechanical analysis of volar plate fracture stability. J. Bone Jt Surg., 88-A: 2411–2417, 2006.

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