A Randomized Comparison of Volar Plate and External Fixation for Intra-Articular Distal Radius Fractures

Young Hak Roh, MD, Beom Koo Lee, MD, Jong Ryoon Baek, MD, Jung Ho Noh, MD, Hyun Sik Gong, MD, Goo Hyun Baek, MD

Purpose To compare surgical outcomes of volar locking plates (VP) and external fixation (EF) (with or without intra-focal fixation) for AO-type C2 and C3 fractures of the distal radius.

Methods From an initial group of 92 patients with AO-type C2 and C3 distal radius fractures who were enrolled in a prospective, randomized study comparing volar plate fixation with external fixation (with or without intra-focal fixation), 74 patients were studied. The researchers evaluated functional assessments (wrist range of motion, grip strength, and Michigan Hand Questionnaire) at each patient visit and measured radiographic assessment (radial inclination, volar tilt, ulnar variance, and articular congruity) at 12 months.

Results The grip strength of the VP group was significantly greater than that of the EF group at 3 and 6 months. The range of motion was significantly greater in the VP group than in the EF group at 3 months. There were no significant differences in the range of motion and grip strength between the 2 groups at 12 months. The Michigan Hand Questionnaire score was higher in the VP group than in the EF group at 3 months but was same at 12 months. There was no significant difference between groups with respect to volar tilt or radial inclination. The VP group showed superior radiologic outcomes in terms of the ulnar variance. One patient in the VP group and 3 in the EF group had an intra-articular stepoff deformity greater than 2 mm. This difference did not reach statistical significance.

Conclusions These results for functional recovery after distal radius surgery offer insight into treatment decisions and interpretations of treatment outcomes for patients with comminuted intra-articular distal radius fractures. *(J Hand Surg Am. 2015;40(1):34–41. Copyright © 2015 by the American Society for Surgery of the Hand. All rights reserved.)*

Type of study/level of evidence Therapeutic I.

Key words Distal radius fractures, complex articular fracture, volar plating, external fixation, functional outcome.

Distal radius fractures (DRFs) represent the most common type of fracture in the upper extremity and pose a serious public health concern.[1] Increasing life expectancy, population aging, and subsequent increases in osteoporosis have resulted in the rising incidence of DRFs, with reports of 17% to 100% increases over the past 3 to 4 decades.[2,3] Although some literature focusing on DRFs

From the Department of Orthopedic Surgery, Gil Medical Center, Gachon University School of Medicine, Incheon; the Department of Orthopedic Surgery, Kangwon National University Hospital, Chuncheon-si, Gangwon-do; and the Department of Orthopedic Surgery, Seoul National University College of Medicine, Seoul, Korea.

Received for publication July 21, 2014; accepted in revised form September 22, 2014.

This work was supported by a grant from the Gachon University Gil Medical Center.

No benefits in any form have been received or will be received related directly or indirectly to the subject of this article.

Corresponding author: Jung Ho Noh, MD, Department of Orthopedic Surgery, Kangwon National University Hospital, Chuncheon-si, Gangwon-do 200-722, Korea; e-mail: bestknee@hotmail.com.

0363-5023/15/4001-0008$36.00/0
http://dx.doi.org/10.1016/j.jhsa.2014.09.025

 © 2015 ASSH ◆ Published by Elsevier, Inc. All rights reserved.

in patients over age 65 years have not found a notable difference between operative and nonsurgical management,[4] surgical fixation of DRF enables patients to resume daily activity earlier and more independently.[1,5] Thus, there has been a trend toward more aggressive fracture fixation in patients with a DRF.[1,6] However, comminuted and displaced intra-articular DRFs make anatomic reduction and stable fixation difficult and often lead to poor functional outcomes.[7–9]

Closed or limited open reduction with percutaneous pinning and external fixation (EF), which has traditionally been used in unstable intra-articular fractures, does not always lead to anatomic reductions and can result in residual instability with secondary displacement.[10,11] Volar plates (VP) have gained popularity because of their low complication rates and high stability in osteoporotic bone without joint distraction.[9] However, fractures with distal articular fragments that are too small or comminuted may not allow fragment reduction and stable fixation with open reduction. Several studies have shown that even open reduction internal fixation (ORIF) fails to produce anatomic reductions in some complex fractures.[12,13]

Our study prospectively studied a random comparison of results for VP and EF in complex fractures of the distal radius combining comminution and articular involvement. We hypothesized that at 12 months VP would provide better clinical and radiologic outcomes than EF for the treatments of AO-type C2 and C3 DRFs without additional complications.

MATERIALS AND METHODS

A total of 92 consecutive patients with complex articular DRFs based on plain radiographs and computed tomography scans were recruited from June 2012 to May 2013. These patients were recruited from a tertiary care university hospital serving as a regional emergency-trauma center. Inclusion criteria were patients with AO-type C2 or C3 DRFs confirmed by computed tomography scans (determined by 2 orthopedic hand surgeons), aged less than 70 years, and treated less than 2 weeks after injury. Patients with the following were excluded: systemic, multiorgan, or head injuries; concomitant wrist or upper extremity injuries; bilateral fractures; and open fractures or associated nerve lesions. Of 92 eligible subjects, 10 were excluded owing to these criteria and 8 were lost to follow-up: 3 at 6 months and 5 more at 12 months. One patient died before 12-month follow-up from causes unrelated to the fracture; the others did not respond to phone calls or letters. Thus, 74 subjects formed the basis for all subsequent analyses. The protocol was approved by the ethics committee of the institution, and all patients provided informed consent before participation. Each patient was assigned using a computer-generated random number table to either the VP or EF group.

All surgical procedures were performed by 1 of 2 orthopedic hand surgeons with 16 and 9 years of orthopedic experience, respectively. Open reduction for the VP group was performed through the flexor carpi radialis approach. Two different plates were used: Synthes 2.4 LCP distal radius systems (Oberdorf, Switzerland) and Medartis Aptus Radius 2.5 (Basel, Switzerland). Closed or limited open reduction was performed for EF group using image intensification. In cases of incomplete reduction (eg, stepoff deformity greater than 2 mm, dorsal tilting, or radial shortening greater than 2 mm) after closed manipulation, we used a percutaneous K-wire or a small elevator, which was inserted through a small incision, to manipulate the fragments. An arthrotomy was not performed. Typically, 3 1.6-mm (0.062-in) K-wires and a few additional 1.1-mm subchondral K-wires were used to secure the intra-articular fragments, including lunate facet fragments. One uniplanar bridging EF system (Orthotech Multi-Fix, Seoul, South Korea) was used throughout the study.

Patients undergoing VP were treated with a short arm orthosis for 2 weeks followed by a removable short arm orthosis for about 2 weeks as required by the patient. Patients undergoing closed reduction and EF (with or without intra-focal K-wire fixation) were treated with a short arm orthosis for 2 weeks. The external fixator was removed 5 to 6 weeks after surgery (average, 5.3 wk; range, 5.0–7.1 wk), followed by a removable orthosis as required. Removal of the external fixator was performed in the outpatient clinic. Patients were advised to elevate the affected limb and perform exercises for finger motion immediately after surgery. Exercises for wrist range of motion were initiated immediately after removal of the orthosis in the case of VP and after removal of the frame in the case of EF. All patients had formal physiotherapy for 2 weeks and were given a standardized home exercise program emphasizing active and passive range of motion and edema control of the hand and wrist. The frequency of physiotherapy was typically twice per week, although more or less frequent therapy sessions took place for some patients based on individual circumstances. They were instructed to perform the exercises at home for a minimum of 5 times/d and were offered oral nonsteroidal anti-inflammatory drugs.

Patients returned for a functional assessment 3 months (range, 3−4 mo), 6 months (range, 5−7 mo), and 12 months (range, 12−14 mo) after surgery. A trained nurse who did not know the patients' clinical information assessed wrist range of motion and grip strength, and the Michigan Hand Questionnaire (MHQ) was administered after the clinical examination during each visit. At the 12-month follow-up, an independent radiologist interpreted plain radiographs to evaluate volar tilt, radial inclination, ulnar variance, and articular incongruity, using a software tool in PACS (Pviewstar, INFINITT, Seoul, Korea). Grip strength was measured using the Jamar dynamometer (Asimow Engineering, Los Angeles, CA) with the elbow flexed at 90° and the forearm in neutral rotation. Grip strength was recorded in kilograms and then the values were changed as a percentage of the injured side relative to the uninjured side. Wrist range of motion was evaluated by recording wrist flexion-extension and pronation-supination with a standard goniometer, and was reported as a percentage of the injured side relative to the uninjured side. We selected the ratios of injured/uninjured (side of the wrist) MHQ scores[14−16] at each measurement time for the functional state of the patients. Because there is no measurement of pre-injury functional state, differences in outcome between groups may have reflected only the pre-injury functional state rather than the outcome of surgical treatment.

Statistical methods

To determine the sample size, we used the MHQ score for primary outcomes to detect a 10-point difference between groups, which we considered clinically relevant. Standard deviation of MHQ scores after distal radius surgery is about 15 points.[17] Based on the normative data, the inclusion of 36 patients in each group provided 80% power and a 2-sided alpha of .05 based on use of the *t* test.

We calculated descriptive statistics to determine patients' demographics and clinical characteristics. The Kolmogorov−Smirnov test was employed to identify the normality of variable distributions. We conducted a *t* test to determine significant differences between groups in terms of continuous variables, and chi-square or Fisher exact test to determine significant differences in the categorical variables. $P < .05$ was considered significant.

RESULTS

Age, sex, affected side, ulnar involvement, and time to surgery for the 2 groups were similar. The duration of surgical treatment was longer for VP patients than for EF ones ($P = .02$) and EF patients had a longer period of immobilization ($P < .01$) (Table 1).

TABLE 1. Demographic and Clinical Characteristics of Patients

	VP Group	EF Group	*P*
Patients, n	36	38	
Sex, M/F	16/7	14/8	NS
Age, y	54.4 ± 10.9	55.3 ± 11.2	NS
≤ 65	30	33	NS
> 65 and < 70	6	5	NS
Affected side, R/L	12/11	10/12	NS
Fracture type			
C2	21	24	NS
C3	15	14	NS
Ulnar involvement	18	16	NS
Time to surgery, d	3.2 ± 1.3	2.9 ± 1.5	NS
Operation time, min	59 ± 19	49 ± 17	.02
Immobilization, wk	4.2 ± 1.7	5.7 ± 1.2	< .01

Values are expressed as means ± SD or number.
NS, not significant.

During the 12-month follow-up, there were 6 complications (17%) in the VP group and 13 (29%) in the EF group (Table 2). Neither the overall difference in complication by treatment nor the specific differences by complication type was statistically significant. Complications included 3 cases of the late development of carpal tunnel syndrome (2 in the EF group and 1 in the VP group), which resolved after a corticosteroid injection; 2 cases of complex regional pain syndrome type I (CRPS I) (1 in the EF group and 1 in the VP group), which were managed by physiotherapy and medication; and 2 cases of adhesive capsulitis of the shoulder (1 in each group), which were treated with exercise. There were 3 cases of superficial pin-track infection in the EF group and 1 of superficial wound site infection in the VP group, which was treated with local wound care and oral antibiotics. There were 2 cases of neuritis of the sensory branch of the radial nerve and 1 of broken fixator pin, which required removal of the pin under local anesthesia, in the EF group. There were 2 cases of ulnar impaction syndrome in the EF group, which were treated by medication and physiotherapy. Two plates were removed because of extensor tendon irritation by screws at 6 and 7 months after surgery, respectively.

Grip strength of the VP group was significantly greater than that of the EF group at 3 and 6 months ($P = .02$ and .04, respectively). There was no significant

TABLE 2. Final Radiologic and Functional Outcome After Distal Radius Surgery

	VP Group (n = 36)	EF Group (n = 38)	*P*
Ulnar variance, mm*			
Injured side	0.7 ± 1.4	1.5 ± 1.7	.02
Uninjured side	0.5 ± 1.3	0.4 ± 1.2	NS
Volar tilt (degrees)*	5 ± 5	3 ± 4	NS
Radial inclination (degrees)*	24 ± 3	23 ± 3	NS
Articular incongruity stepoff, mm†			
0−1	14	12	NS
1−2	21	23	NS
2−3	1	3	NS
> 3	0	0	NS
Grip strength (%)*	78 ± 16	75 ± 14	NS
Range of motion (%)*			
Flexion-extension	86 ± 12	84 ± 13	NS
Pronation-supination	92 ± 8	90 ± 9	NS
Michigan Hand Questionnaire score*	81 ± 15	79 ± 14	NS

NS, not significant.
**t* test.
†Chi-square or Fisher exact test.

difference in grip strength between the VP and EF groups at 12 months (Fig. 1). Range of motion was significantly greater in the VP group than in the EF group only at the 3-month follow-up ($P = .01$) (Fig. 2). There was a significant difference in functional score between the VP and EF groups only at 3 months ($P = .02$) (Fig. 3).

At 12 months, the VP group showed superior radiologic outcomes in terms of ulnar variance ($P = .02$) (Table 2). Ulnar variance greater than 2 mm was found in 6 of 38 patients (16%) in the EF group and 2 of 36 patients in the VP group (8%). There were no significant differences in terms of volar tilt or radial inclination between the VP and EF groups. One patient in the VP group (3%) and 3 in the EF group (8%) had an intra-articular stepoff deformity greater than 2 mm, which did not reach statistical significance.

DISCUSSION

Although there were no significant differences in grip strength, motion, or functional scores between the VP and EF groups at 12 months, the VP group showed superior short-term results for functional recovery. The VP group showed superior radiological outcome in terms of the ulnar variance, but this outcome had no effect on functional outcomes at 12 months.

Previous studies indicated that VP patients resume daily activity more quickly than EF patients,[18,19] but it remains uncertain whether this is because VP is better adapted to younger patients with simpler fractures, whereas EF may have been used more often for less active (older) patients with more complex fractures. The results suggest that EF treatment is associated with delayed functional recovery up to 3 months after distal radius surgery. Rozental et al[20] reported similar findings on EF, radial column plating, and VP and found a correlation between use of a VP and an improved Disabilities of the Arm, Shoulder, and Hand score only at 3 months, with all groups doing equally well by 6 months.

In the current study, VP fixation had an overall decreased incidence of complications compared with external fixation. The results are in concordance with prior studies,[21,22] which have tended to show decreased complications in patients treated with VP. Rizzo et al[21] reported 3 complications in 17 patients treated with EF and no complications in 41 patients treated with VP. Wright et al[22] reported 8 complications in 11 patients treated with EF and 3 complications in 21 patients treated with VP. Conversely, a similar incidence of complications was reported in some previous studies. Kreder et al[23] reported 11 complications in 88 patients with EF (13%) and 12 complications in 91 patients with open reduction internal fixation (13%). Williksen et al[24] reported 18 complications in 59 patients treated with EF (30%) and 15 complications in 52 patients treated with VP (29%).

Some studies suggested that CRPS I is more likely to occur after EF than after other surgical procedures.[25,26] In the current study, there was no significant difference in the occurrence of CRPS I between the VP and EF groups, which is consistent with other studies.[27] This suggests that the high incidence of CRPS I after EF in the literature may be related to the recruitment of subjects with more severe DRFs or excessive distraction during EF.

Distal radius fractures represent the most common osteoporosis-related injury in the upper extremity. Patients with a DRF have a higher incidence of underlying osteoporosis,[28] and osteoporosis has been associated with increased fracture severity and a higher incidence of early instability.[29] Although open reduction with an arthrotomy may represent the most reliable means of obtaining an anatomical reduction, intra-articular fragments can be too small or comminuted

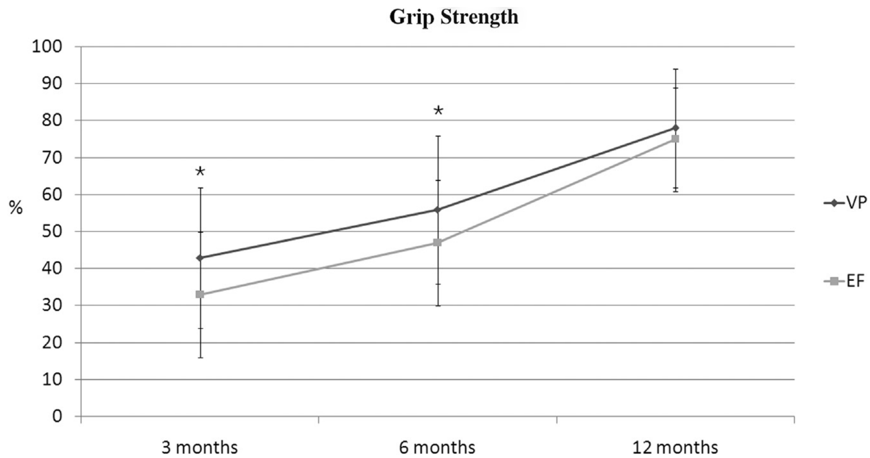

FIGURE 1: Grip strength in the VP group was significantly greater than that of the EF group at months 3 and 6. *$P < .05$; error bars = 1 SD; % = percentage of the injured side relative to the uninjured side.

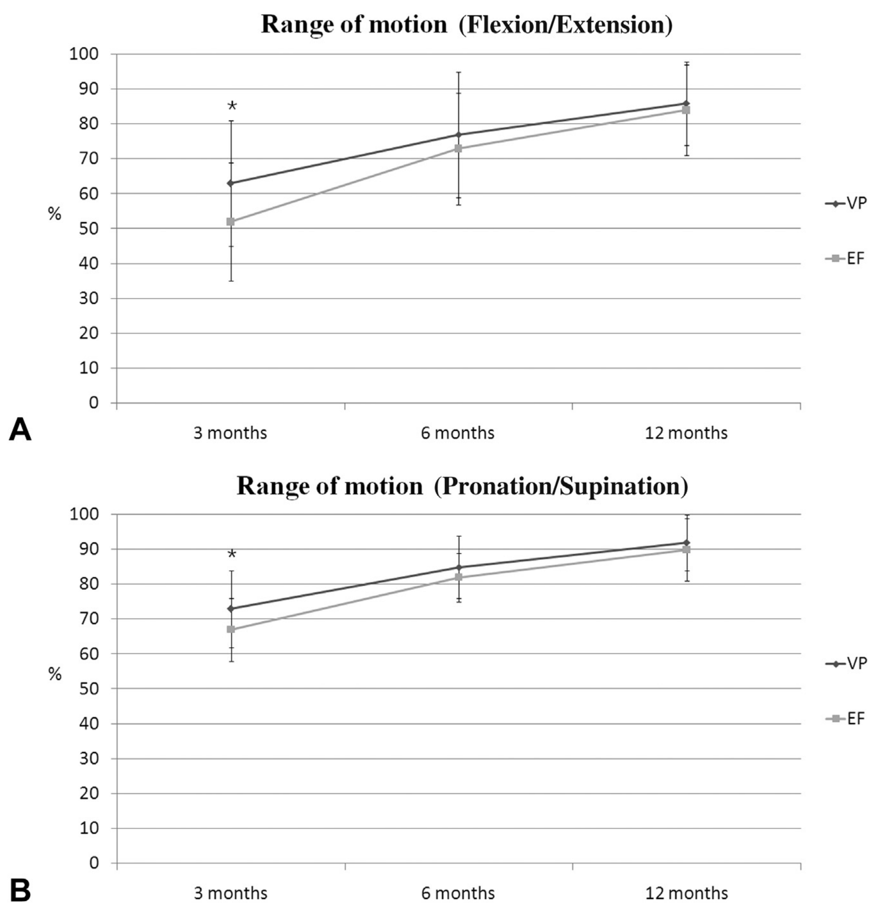

FIGURE 2: Range of motion in **A** flexion-extension and **B** pronation-supination was significantly greater in the VP group than in the EF group at the 3-month follow-up. *$P < .05$; error bars = 1 SD; % = percentage of the injured side relative to the uninjured side.

and may not allow fragment reduction and stable fixation, particularly in the case of AO-type C2 and C3 fractures.[18,23] Our results are in accordance with the findings of Kreder et al[23] and Jeudy et al,[18] who performed prospectively randomized comparisons of ORIF and EF for intra-articular displaced fractures of distal radius. Both studies found no significant difference in articular stepoff between ORIF and EF for intra-articular comminuted or displaced fractures (Table 3).

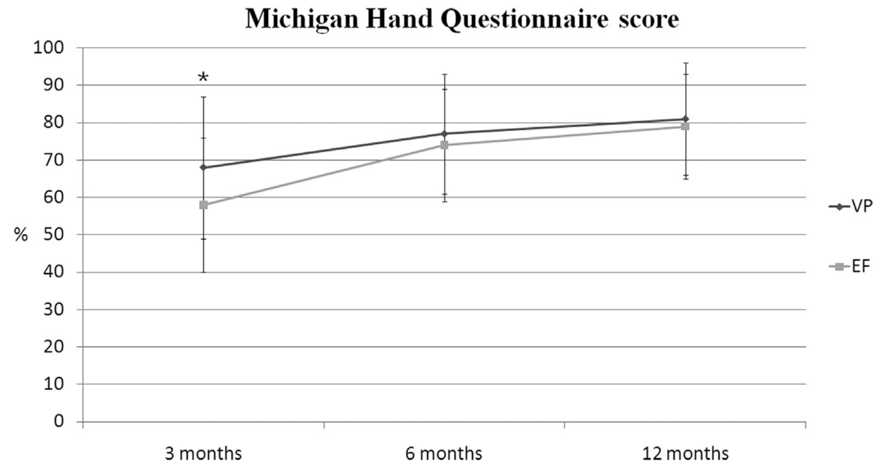

FIGURE 3: There was a significant difference in MHQ scores between the VP and EF groups at the 3-month follow-up. *$P < .05$; error bars = 1 SD; % = percentage of the injured side relative to the uninjured side.

TABLE 3. Literature Review Comparing Radiologic Outcomes of EF Versus ORIF for DRF

Study (Year)	Design	Subjects	Measured Radiologic Variables	Findings EF	ORIF	P
Wright et al[22] (2005)	Retrospective	32 patients with unstable fracture (AO type A or C)	Ulnar variance, mm	+2.2	−0.5	< .05
			Radial inclination (degrees)	25	22	NS
			Volar tilt (degrees)	5	10	< .05
			Articular stepoff, mm	1.4	0.4	< .05
Kreder et al[23] (2005)	Prospective, randomized	179 patients with intra-articular displaced fracture (AO type B or C)	**Step deformity, %**			
			Any step	14	14	.91
			> 2 mm	3	2	.68
			Gap deformity, %			
			Any gap	13	9	.42
			> 2 mm	3	1	.36
Rizzo et al[21] (2008)	Retrospective	55 patients with intra-articular unstable fracture (AO type B or C)	Ulnar variance, mm	−0.3	+1.3	.01
			Articular stepoff, mm	0.2	0.8	NS
			Volar tilt (degrees)	11	3	.04
			Radial height, mm	11	10	NS
			Radial inclination (degrees)	23	21	NS
Jeudy et al[18] (2011)	Prospective, randomized	75 patients with intra-articular comminuted fracture (AO type C2 or C3)	**Stepoff, mm**			
			0−1	4	6	NS
			1−2	1	2	NS
			2−3	3	0	NS
			> 3	0	0	
Williksen et al[24] (2013)	Prospective, randomized	104 patients with unstable fracture (AO type A or C)	Volar tilt (degrees)	5	4	NS
			Radial inclination (degrees)	25	25	NS
			Ulnar variance, mm	+2.2	+1.4	.01
Current study	Prospective, randomized	74 patients with AO type C2 or C3 fracture	Ulnar variance, mm	1.5	0.7	.02
			Volar tilt (degrees)	3	5	NS
			Radial inclination (degrees)	23	24	NS
			Stepoff > 2 mm	3 (8%)	1 (3%)	NS

NS, not significant.

Fractures with initially poor reductions or some secondary reduction loss may result in articular step-offs greater than 2 mm, which can lead to osteoarthritis in the long term.[7] Functional outcomes are highly dependent on the restoration of wrist anatomy and the restoration of articular anatomy is the most critical factor in obtaining good functional results.[30] Conversely, the types of fracture and radiographic outcomes have minimal or no correlations with the patient's symptom, impairment, and disability in the long term.[31,32] More specifically, a DRF with articular involvement and residual articular incongruity has been correlated with future arthrosis[7,33,34] but arthrosis is not correlated with the patient's functional impairment, symptom, or disability.[35–37] In the current study, VP showed a superior radiologic outcome in terms of the ulnar variance, but this radiographic outcome did not influence functional outcomes at 12 months.

Study limitations include the fact that there were no follow-up data on functional outcomes beyond 12 months after surgery, although some improvement in motion and grip strength could be anticipated. Second, we used only one type of questionnaire (MHQ) to evaluate patient functional outcome. Minimal clinical important difference or responsiveness of questionnaire after DRF differs across functional assessments, and another functional assessment might result in different conclusions. Third, the patient's functional baseline state, a potential factor influencing the recovery process, could not be examined because all patients presented after sustaining a fracture. Instead, the ratios of MHQ scores between the injured and uninjured hands at each measurement time were employed. Future research should consider potential contributors not measured in this study, including socioeconomic[38] and psychological[39] factors, for a better understanding of delayed functional recovery.

REFERENCES

1. Chung KC, Shauver MJ, Birkmeyer JD. Trends in the United States in the treatment of distal radial fractures in the elderly. *J Bone Joint Surg Am*. 2009;91(8):1868−1873.
2. Melton LJ III, Amadio PC, Crowson CS, et al. Long-term trends in the incidence of distal forearm fractures. *Osteoporos Int*. 1998;8(4):341−348.
3. Bengner U, Johnell O. Increasing incidence of forearm fractures: a comparison of epidemiologic patterns 25 years apart. *Acta Orthop Scand*. 1985;56(2):158−160.
4. Arora R, Lutz M, Deml C, et al. A prospective randomized trial comparing nonoperative treatment with volar locking plate fixation for displaced and unstable distal radial fractures in patients sixty-five years of age and older. *J Bone Joint Surg Am*. 2011;93(23):2146−2153.
5. Ring D, Jupiter JB. Treatment of osteoporotic distal radius fractures. *Osteoporos Int*. 2005;16(suppl 2):S80−S84.
6. Mattila VM, Huttunen TT, Sillanpaa P, et al. Significant change in the surgical treatment of distal radius fractures: a nationwide study between 1998 and 2008 in Finland. *J Trauma*. 2011;71(4):939−942; discussion 942−933.
7. Knirk JL, Jupiter JB. Intra-articular fractures of the distal end of the radius in young adults. *J Bone Joint Surg Am*. 1986;68(5):647−659.
8. Chung KC, Watt AJ, Kotsis SV, et al. Treatment of unstable distal radial fractures with the volar locking plating system. *J Bone Joint Surg Am*. 2006;88(12):2687−2694.
9. Orbay JL, Touhami A. Current concepts in volar fixed-angle fixation of unstable distal radius fractures. *Clin Orthop Relat Res*. 2006;(445):58−67.
10. Fernandez DL. Should anatomic reduction be pursued in distal radial fractures? *J Hand Surg Br*. 2000;25(6):523−527.
11. Kawaguchi S, Sawada K, Nabeta Y, et al. Recurrent dorsal angulation of the distal radius fracture during dynamic external fixation. *J Hand Surg Am*. 1998;23(5):920−925.
12. Gliatis JD, Plessas SJ, Davis TR. Outcome of distal radial fractures in young adults. *J Hand Surg Br*. 2000;25(6):535−543.
13. Bini A, Surace MF, Pilato G. Complex articular fractures of the distal radius: the role of closed reduction and external fixation. *J Hand Surg Eur Vol*. 2008;33(3):305−310.
14. Chung KC, Pillsbury MS, Walters MR, et al. Reliability and validity testing of the Michigan Hand Outcomes Questionnaire. *J Hand Surg Am*. 1998;23(4):575−587.
15. Kotsis SV, Lau FH, Chung KC. Responsiveness of the Michigan Hand Outcomes Questionnaire and physical measurements in outcome studies of distal radius fracture treatment. *J Hand Surg Am*. 2007;32(1):84−90.
16. Roh YH, Yang BK, Noh JH, et al. Cross-cultural adaptation and validation of the Korean version of the Michigan hand questionnaire. *J Hand Surg Am*. 2011;36(9):1497−1503.
17. Chung KC, Squitieri L, Kim HM. Comparative outcomes study using the volar locking plating system for distal radius fractures in both young adults and adults older than 60 years. *J Hand Surg Am*. 2008;33(6):809−819.
18. Jeudy J, Steiger V, Boyer P, et al. Treatment of complex fractures of the distal radius: a prospective randomised comparison of external fixation "versus" locked volar plating. *Injury*. 2012;43(2):174−179.
19. Grewal R, MacDermid JC, King GJ, et al. Open reduction internal fixation versus percutaneous pinning with external fixation of distal radius fractures: a prospective, randomized clinical trial. *J Hand Surg Am*. 2011;36(12):1899−1906.
20. Rozental TD, Blazar PE, Franko OI, et al. Functional outcomes for unstable distal radial fractures treated with open reduction and internal fixation or closed reduction and percutaneous fixation: a prospective randomized trial. *J Bone Joint Surg Am*. 2009;91(8):1837−1846.
21. Rizzo M, Katt BA, Carothers JT. Comparison of locked volar plating versus pinning and external fixation in the treatment of unstable intraarticular distal radius fractures. *Hand (N Y)*. 2008;3(2):111−117.
22. Wright TW, Horodyski M, Smith DW. Functional outcome of unstable distal radius fractures: ORIF with a volar fixed-angle tine plate versus external fixation. *J Hand Surg Am*. 2005;30(2):289−299.
23. Kreder HJ, Hanel DP, Agel J, et al. Indirect reduction and percutaneous fixation versus open reduction and internal fixation for displaced intra-articular fractures of the distal radius: a randomised, controlled trial. *J Bone Joint Surg Br*. 2005;87(6):829−836.
24. Williksen JH, Frihagen F, Hellund JC, et al. Volar locking plates versus external fixation and adjuvant pin fixation in unstable distal radius fractures: a randomized, controlled study. *J Hand Surg Am*. 2013;38(8):1469−1476.
25. Suso S, Combalia A, Segur JM, et al. Comminuted intra-articular fractures of the distal end of the radius treated with the Hoffmann external fixator. *J Trauma*. 1993;35(1):61−66.
26. Hegeman JH, Oskam J, Vierhout PA, et al. External fixation for unstable intra-articular distal radial fractures in women older than 55 years: acceptable functional end results in the majority of the patients despite significant secondary displacement. *Injury*. 2005;36(2):339−344.
27. Zollinger PE, Kreis RW, van der Meulen HG, et al. No higher risk of CRPS after external fixation of distal radial fractures: subgroup analysis under randomised vitamin C prophylaxis. *Open Orthop J*. 2010;(4):71−75.
28. Koval KJ, Harrast JJ, Anglen JO, et al. Fractures of the distal part of the radius: the evolution of practice over time. Where's the evidence? *J Bone Joint Surg Am*. 2008;90(9):1855−1861.
29. Clayton RA, Gaston MS, Ralston SH, et al. Association between decreased bone mineral density and severity of distal radial fractures. *J Bone Joint Surg Am*. 2009;91(3):613−619.

30. Ruch DS, Papadonikolakis A. Volar versus dorsal plating in the management of intra-articular distal radius fractures. *J Hand Surg Am*. 2006;31(1):9–16.
31. Bolmers A, Luiten WE, Doornberg JN, et al. A comparison of the long-term outcome of partial articular (AO type B) and complete articular (AO type C) distal radius fractures. *J Hand Surg Am*. 2013;38(4):753–759.
32. Souer JS, Ring D, Jupiter JB, et al. Comparison of AO type-B and type-C volar shearing fractures of the distal part of the radius. *J Bone Joint Surg Am*. 2009;91(11):2605–2611.
33. Jupiter JB. Fractures of the distal end of the radius. *J Bone Joint Surg Am*. 1991;73(3):461–469.
34. Bradway JK, Amadio PC, Cooney WP. Open reduction and internal fixation of displaced, comminuted intra-articular fractures of the distal end of the radius. *J Bone Joint Surg Am*. 1989;71(6):839–847.
35. Gruber G, Zacherl M, Giessauf C, et al. Quality of life after volar plate fixation of articular fractures of the distal part of the radius. *J Bone Joint Surg Am*. 2010;92(5):1170–1178.
36. Lutz M, Arora R, Krappinger D, et al. Arthritis predicting factors in distal intraarticular radius fractures. *Arch Orthop Trauma Surg*. 2011;131(8):1121–1126.
37. Ng CY, McQueen MM. What are the radiological predictors of functional outcome following fractures of the distal radius? *J Bone Joint Surg Br*. 2011;93(2):145–150.
38. MacDermid JC, Roth JH, Richards RS. Pain and disability reported in the year following a distal radius fracture: a cohort study. *BMC Musculoskelet Disord*. 2003;(4):24.
39. Ring D, Kadzielski J, Fabian L, et al. Self-reported upper extremity health status correlates with depression. *J Bone Joint Surg Am*. 2006;88(9):1983–1988.