

Association between Radiological and Functional Outcomes Following Volar Locking Plate Fixation of Distal Radius Fractures: A One-Year Prospective Cohort Study

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ABSTRACT

Introduction: Restoring anatomical alignment is a primary objective in the surgical treatment of distal radius fractures. However, the extent to which radiographic restoration influences functional recovery at different stages after surgery remains uncertain. Clarifying this relationship may help guide postoperative assessment and rehabilitation.

Aim: To investigate the association between radiological alignment and functional outcomes over one year in adults with distal radius fractures treated with Volar Locking Plate (VLP) fixation.

Materials and Methods: This prospective observational cohort study was conducted at the Department of Orthopaedics, Himalayan Institute of Medical Sciences, Jolly Grant, Dehradun, Uttarakhand, India, from November 2024 to May 2025. A total of 55 adults aged 18-60 years with distal radius fractures were managed by open reduction and internal fixation using a VLP. Radiological outcomes were assessed using the Sarmiento radiological scoring system, while functional recovery was evaluated with the Modified Mayo Wrist Score (MMWS). Patients

were assessed immediately after surgery and subsequently at six weeks, three months, six months, and 12 months. Changes in functional outcomes over time were analysed, and the association between radiological and functional outcomes was examined using the Chi-square test.

Results: The mean age of the subjects was 44.75 ± 12.45 years, comprising 29 males and 26 females. The majority of fractures were complex intra-articular injuries, with Frykman Type VII accounting for 34.5% (n=19) and Type VIII accounting for 21.8% (n=12) of the study population. Functional recovery progressed steadily, with the mean MMWS increasing from 68.27 at six weeks to 84.50 at one year. No significant association was observed between radiological alignment and functional outcome at six weeks ($p=0.107$). However, a significant positive association emerged at three months ($p=0.005$) and persisted through the six-month and one-year follow-up assessments.

Conclusion: The relationship between radiological alignment and functional recovery is time-dependent and appears to evolve during fracture healing.

Keywords: Alignment, Fracture healing, Modified mayo wrist score, Sarmiento score

INTRODUCTION

Distal Radius Fractures (DRFs) are among the most frequently encountered fractures in orthopaedic practice, accounting for nearly one-sixth of all fractures treated in emergency departments [1]. They occur across a wide age spectrum, typically resulting from high-energy trauma in younger adults and low-energy falls in older individuals with osteoporotic bone. Despite advances in surgical techniques, these fractures continue to present challenges because of their potential to impair wrist biomechanics, grip strength, and upper-limb function if anatomical alignment is not adequately restored [2].

Achieving an anatomical reduction has traditionally been regarded as a key objective of surgical management. Restoration of radial height, radial inclination, volar tilt, and ulnar variance is believed to preserve normal wrist kinematics, optimise load transmission across the radiocarpal joint, and reduce the likelihood of complications such as post-traumatic arthritis, chronic pain, and restricted range of motion. Consequently, postoperative radiographic parameters have often been used as surrogate indicators of successful treatment [3].

Over the past two decades, VLP fixation has become the preferred surgical option for unstable distal radius fractures. Numerous clinical studies have demonstrated favourable radiological and functional outcomes following volar plate fixation, contributing to its widespread acceptance as the standard treatment for displaced and unstable distal radius fractures [4,5].

Patients may regain satisfactory wrist function despite minor residual deformities on postoperative radiographs, suggesting that early functional recovery is influenced by factors beyond fracture alignment alone. Pain relief, soft-tissue healing, rehabilitation compliance, patient motivation, and muscle recovery all contribute substantially to postoperative function, particularly during the initial weeks after surgery [6]. In contrast, maintaining anatomical alignment has been shown to be associated with superior long-term functional outcomes, including improved grip strength, greater range of motion, and higher patient-reported outcome scores [7].

Consequently, there is limited evidence describing how the relationship between these two parameters changes throughout fracture healing.

The present prospective observational study was therefore undertaken to evaluate the evolving relationship between radiological alignment and functional recovery in adults with distal radius fractures treated with VLP fixation. It was hypothesised that radiological alignment would show a weak association with functional outcome during the early postoperative period but would become increasingly important as fracture union and rehabilitation progressed.

MATERIALS AND METHODS

A prospective observational cohort study was conducted at the Department of Orthopaedics, Himalayan Institute of Medical

Sciences, Jolly Grant, Dehradun, Uttarakhand, India, from November 2024 to May 2025, allowing for a minimum of a one-year follow-up for all participants before data analysis. Approval was obtained from the Institutional Ethics Committee (Approval Number: SRHU/HIMS/ETHICS/358). All consecutive eligible patients presenting during the study period were included.

Sample size: A complete-enumeration, time-bound consecutive sampling strategy was employed for this study. All eligible adult patients presenting with acute closed distal radius fractures who met the predefined selection criteria during the recruitment period (November 2024 to May 2025) were prospectively enrolled (N=55). This cohort size is consistent with published single-centre prospective observational cohorts evaluating functional and radiological outcomes after volar locking plate fixation (e.g., Gowda RHP et al., n=30; Mohankumar M et al., n=60), providing an adequate distribution of fracture patterns to evaluate longitudinal functional recovery and categorical outcome associations across all follow-up intervals.

Inclusion criteria: Adult patients aged 18-60 years presenting with fresh closed distal radius fractures within two weeks of injury were included.

Exclusion criteria: Patients with open fractures, pathological fractures, previous fractures involving the same wrist, associated neurovascular injuries, polytrauma affecting rehabilitation, or those unwilling to participate were excluded.

Study Procedure

Preoperative assessment: All patients underwent a detailed clinical evaluation at presentation. Standard posteroanterior and lateral radiographs of the injured wrist were obtained to assess fracture morphology, and fractures were classified according to the Frykman classification system [8]. Demographic information, mechanism of injury, and fracture characteristics (associated ulnar styloid fracture, articular involvement, displacement direction) were documented.

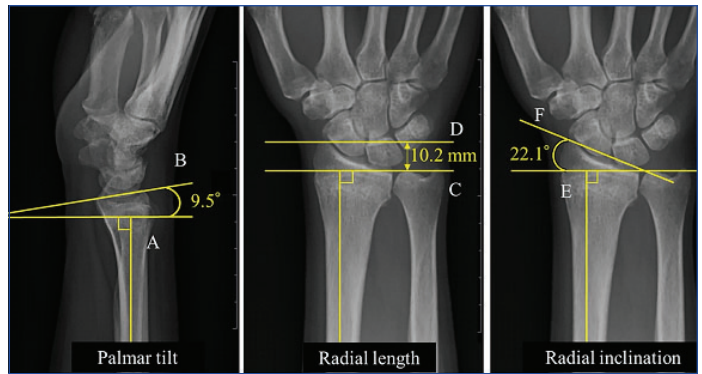
Surgical technique: All patients underwent open reduction and internal fixation using a precontoured VLP through the standard volar Henry approach [9]. Surgical procedures were performed under appropriate anaesthesia with tourniquet control.

Following exposure of the fracture site, meticulous reduction was achieved under fluoroscopic guidance, with particular attention to restoring radial height, radial inclination, volar tilt, and articular congruity. The fracture was stabilised using a fixed-angle VLP. Implant position and restoration of alignment were confirmed intraoperatively with anteroposterior and lateral fluoroscopic images before wound closure. The incision was closed in layers, and a sterile dressing was applied.

Postoperative rehabilitation: A below-elbow splint was applied primarily for comfort during the immediate postoperative period. Active finger movements were encouraged from the first postoperative day to minimise stiffness and oedema. Wrist mobilisation exercises were initiated according to fracture stability, pain tolerance, and clinical progress. All patients followed a standardised rehabilitation protocol and attended scheduled outpatient follow-up visits throughout the study period.

Outcome assessment: Radiological assessment was performed using standard posteroanterior and lateral wrist radiographs. Measurements included radial height, radial inclination, volar tilt, and ulnar variance [Table/Fig-1], which were performed by two independent observers blinded to the clinical scores. Interobserver and intraobserver reliability were not formally assessed. Overall radiological outcome was graded according to the Sarmiento radiological scoring system and categorised as excellent, good, fair, or poor [10].

Functional recovery was assessed using the MMWS [11], which incorporates pain, functional status, range of motion, and grip



[Table/Fig-1]: Measurements of radial height, radial inclination, volar tilt, and ulnar variance.

strength. The MMWS was evaluated by the same independent clinical assessor at every visit, who remained blinded to the patients' radiographs. Wrist movements were measured with a goniometer, while grip strength was assessed using a hand dynamometer and compared with the contralateral, unaffected limb. Radiological and functional outcomes were evaluated immediately after surgery and at six weeks, three months, six months, and 12 months.

STATISTICAL ANALYSIS

Data were analysed using IBM Statistical Package for Social Sciences (SPSS) Statistics software version 26.0 (IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean±standard deviation, whereas categorical variables are expressed as frequencies and percentages. Changes in MMWSs over time were analysed using repeated-measures Analysis Of Variance (ANOVA). The association between radiological outcome categories (Sarmiento score) across repeated follow-up intervals were evaluated using the Friedman test. The association between radiological outcome categories (Sarmiento score) and functional outcome categories (MMWS) at each follow-up interval was evaluated using the Chi-square test. A two-tailed p-value of <0.05 was considered statistically significant.

RESULTS

A total of 55 patients were enrolled and completed the one-year follow-up. The mean age of the study population was 44.75±12.45 years. Patients aged 51-60 years constituted the largest subgroup (41.8%). There was a slight male predominance, with 29 men (52.7%) and 26 women (47.3%). The mean time from injury to surgical intervention was 5±2 days [Table/Fig-2].

Analysis of the continuous radiographic parameters demonstrated near-anatomical reduction immediately post-surgery, with mean radial height restored to 11.2±1.8 mm, radial inclination to 21.5°±2.4°, and volar tilt to 9.8°±3.5° [Table/Fig-3].

Variables	Category	n (%)
Mechanism of injury	Fall on Outstretched Hand (FOOSH)	47 (85.45%)
	Road Traffic Accident (RTA)	8 (14.54%)
Side of injury	Right	37 (67.27%)
	Left	18 (32.73%)
	Dominant hand involved	39 (70.90%)
Age group (years)	18-20	3 (5.5%)
	21-30	8 (14.5%)
	31-40	9 (16.4%)
	41-50	12 (21.8%)
	51-60	23 (41.8%)
Gender	Male	29 (52.7%)
	Female	26 (47.3%)

Frykman classification	I	1 (1.8%)
	II	1 (1.8%)
	III	3 (5.5%)
	IV	1 (1.8%)
	V	10 (18.2%)
	VI	8 (14.5%)
	VII	19 (34.5%)
	VIII	12 (21.8%)
Associated ulnar styloid fracture	Present	22 (40%)
	Absent	33 (60%)
Articular involvement	Intra-articular	53 (96.36%)
	Extra-articular	2 (3.64%)
Displacement direction	Dorsal	7 (12.73%)
	Volar	48 (87.27%)

[Table/Fig-2]: Demographic and fracture characteristics of study population (N=55).

Radiographic parameters	Immediate Post-op (Mean±SD)	6 weeks (Mean±SD)	3 months (Mean±SD)	6 months (Mean±SD)	1 year (Mean±SD)
Radial height (mm)	11.2±1.8	11.0±1.9	10.9±1.9	10.8±2.0	10.8±2.0
Radial inclination (°)	21.5±2.4	21.2±2.5	21.1±2.5	21.0±2.6	21.0±2.6
Volar tilt (°)	9.8±3.5	9.4±3.7	9.3±3.8	9.2±3.8	9.2±3.8
Ulnar variance (mm)	0.5±1.2	0.7±1.3	0.8±1.4	0.8±1.4	0.8±1.4

[Table/Fig-3]: Descriptive statistics for radiographic parameters over time.

Before treatment, 37 patients (67.3%) were classified as having poor radiological alignment. Following fixation, 48 patients (87.2%) achieved good or excellent radiological grades. Overall improvement in radiological outcome over time was statistically significant as determined by the Friedman Test ($p<0.001$) [Table/Fig-4].

The mean total MMWS increased significantly from 68.27 ± 7.83 at six weeks to 84.50 ± 7.95 at one year ($p=0.001$) [Table/Fig-5].

Time point	Poor	Fair	Good/Excellent	Total
Pre-op	37 (67.3%)	12 (21.8%)	6 (10.9%)	55 (100%)
Post-op	1 (1.8%)	6 (10.9%)	48 (87.2%)	55 (100%)
6 weeks	1 (1.8%)	6 (10.9%)	48 (87.2%)	55 (100%)
3 months	1 (1.8%)	6 (10.9%)	48 (87.2%)	55 (100%)
6 months	1 (1.8%)	5 (9.1%)	49 (89.1%)	55 (100%)
1 year	1 (1.8%)	5 (9.1%)	49 (89.1%)	55 (100%)

[Table/Fig-4]: Radiological outcomes over time evaluated via Sarmiento scores using Friedman test ($p<0.001$).

MMWS component (maximum score)	0 weeks (Mean±SD)	6 weeks (Mean±SD)	3 months (Mean±SD)	6 months (Mean±SD)	1 year (Mean±SD)	p-value (Repeated-measures ANOVA)
Pain (25)	0	18.50±5.40	21.50±4.20	22.50±3.50	23.50±2.50	<0.001
Functional status (25)	0	17.50±4.80	22.00±3.50	23.00±3.00	23.50±2.50	<0.001
Range of motion (25)	0	16.50±3.50	19.50±3.20	20.00±2.80	20.50±2.50	<0.001
Grip strength (25)	0	15.77±4.20	18.64±3.80	17.65±3.50	17.00±3.00	<0.001
Total MMWS (100)	0	68.27±7.83	81.64±8.87	83.15±8.10	84.50±7.95	<0.001

[Table/Fig-5]: Descriptive data of Modified Mayo Wrist Score (MMWS) components over 1 year.

At six weeks, most patients (65.5%) were classified as having fair functional outcomes, whereas only 29.1% had achieved good or excellent function. This proportion increased to 85.5% at six months and reached 89.1% at the final one-year evaluation [Table/Fig-6].

At the six-week follow-up, no statistically significant association was observed between Sarmiento radiological grades and MMWS categories ($\chi^2=4.21$, $p=0.107$) [Table/Fig-7].

At the three-month assessment, radiological alignment showed a significant positive association with functional outcome [Table/Fig-8]. This relationship remained significant at the six-month ($\chi^2=14.12$, $p=0.003$) and one-year ($\chi^2=15.65$, $p=0.001$) assessments [Table/Fig-9,10].

Sequential radiographs showed satisfactory maintenance of fracture reduction and implant stability, with minimal fracture settling during the early postoperative period, progressive fracture union by three months, and complete radiological union with maintained alignment at one year [Table/Fig-11]. The clinical photographs demonstrate satisfactory restoration of wrist range of motion, including maximal voluntary palmar flexion, dorsiflexion, and forearm pronation-supination, at the final follow-up [Table/Fig-12].

Wrist stiffness was the most frequently encountered complication and occurred in seven patients (12.7%). All seven patients were managed conservatively with an intensive, structured physical therapy regimen focusing on active-assisted range of motion exercises, stretching, and occupational therapy, which resulted in satisfactory functional recovery without requiring surgical release or manipulation under anaesthesia.

One patient (1.8%) developed transient median nerve symptoms, which resolved with conservative management. No complications were observed in the remaining 47 patients (85.5%) during the one-

year follow-up period. No cases of implant failure, loss of fixation requiring revision surgery, deep infection, tendon rupture, or complex regional pain syndrome were encountered during the study.

DISCUSSION

The most important observation in the present study was the absence of a significant association between radiological alignment and functional outcome at six weeks after surgery ($p=0.107$). Similar findings have been reported by Gutiérrezz-Monclus RG et al., who prospectively evaluated 180 patients aged over 60 years with extra-articular distal radius fractures managed conservatively [6]. Only 68 patients (37.8%) achieved acceptable radiological alignment, yet no significant correlation was observed between radiological alignment and functional outcomes either immediately after cast removal (DASH: $r=0.071$, $p=0.546$; PRWE: $r=0.03$, $p=0.823$; VAS: $r=0.12$, $p=0.631$) or at the 6-month follow-up (DASH: $r=0.029$, $p=0.768$; PRWE: $r=0.014$, $p=0.895$; VAS: $r=0.09$, $p=0.614$). These findings

Time point	Poor	Fair	Good/Excellent	Total
Post-op	55 (100%)	0	0	55 (100%)
6 weeks	3 (5.5%)	36 (65.5%)	16 (29.1%)	55 (100%)
3 months	0	11 (20.0%)	44 (80.0%)	55 (100%)
6 months	0	8 (14.5%)	47 (85.5%)	55 (100%)
1 year	0	6 (10.9%)	49 (89.1%)	55 (100%)

[Table/Fig-6]: Categorical functional outcome shifts over 1 year.

indicate that minor deviations in radiographic parameters may not adversely influence short- or medium-term functional recovery, particularly in the early stages following injury [6].

Radiological outcome (Sarmiento)	Poor function (MMWS)	Fair function (MMWS)	Good/Excellent function (MMWS)	Total
Poor	1	0	0	1
Fair	2	3	1	6
Good/excellent	0	33	15	48
Total	3	36	16	55

[Table/Fig-7]: Association between radiological and functional outcomes at 6 weeks ($\chi^2=4.21$, $p=0.107$) (non significant).

Radiological outcome (Sarmiento)	Poor function (MMWS)	Fair function (MMWS)	Good/Excellent function (MMWS)	Total
Poor	0	1	0	1
Fair	0	5	1	6
Good/excellent	0	5	43	48
Total	0	11	44	55

[Table/Fig-8]: Association between radiological and functional outcomes at 3 months ($\chi^2=12.84$, $p=0.005$) (Significant).

Radiological outcome (Sarmiento)	Poor function (MMWS)	Fair function (MMWS)	Good/Excellent function (MMWS)	Total
Poor	0	1	0	1
Fair	0	3	2	5
Good/Excellent	0	4	45	49
Total	0	8	47	55

[Table/Fig-9]: Association between radiological and functional outcomes at 6 months. ($\chi^2=14.12$, $p=0.003$) (Significant).

Radiological outcome (Sarmiento)	Poor function (MMWS)	Fair function (MMWS)	Good/Excellent function (MMWS)	Total
Poor	0	1	0	1
Fair	0	2	3	5
Good/Excellent	0	3	46	49
Total	0	6	49	55

[Table/Fig-10]: Association between radiological and functional outcomes at 1 year ($\chi^2=15.65$, $p=0.001$) (Significant).



[Table/Fig-11]: Sequential anteroposterior and lateral radiographs demonstrating fracture healing and minimal settling over one year: (a) Immediate postoperative alignment showing stable volar plate fixation; (b) At six weeks, displaying excellent alignment with expected, minimal physiological fracture settling; (c) Structural consolidation at 3 months; (d) Stable, fully consolidated structural alignment at the 1-year follow-up interval.



[Table/Fig-12]: Panels display maximal voluntary palmar flexion, dorsiflexion, and forearm rotation.

Gowda RHP et al., who evaluated 30 patients treated with volar plating and reported excellent radiological outcomes in 15 (50%) patients and good outcomes in the remaining 15 (50%), while the corresponding functional assessment demonstrated excellent results in 15 (50%), good in 13 (43.3%), and fair in 2 (6.7%) [7]. Importantly, they demonstrated a 93.33% agreement between radiological and clinical outcomes ($\kappa=0.7647$, $p=0.0001$), indicating that restoration of anatomical alignment was strongly associated with improved functional recovery.

Similar findings were reported by Bilal RS et al., who prospectively evaluated 78 patients undergoing VLP fixation and found that palmar tilt was an independent predictor of better functional outcomes (regression coefficient=-0.36, $p=0.035$), whereas increased ulnar variance was significantly associated with poorer outcomes (regression coefficient=1.28, $p<0.001$) [12].

Mohankumar M et al., who evaluated 60 patients treated with VLP fixation and reported excellent restoration of anatomical parameters (mean radial length 8.8 mm, radial inclination 17.6°, and palmar tilt 8.9°) with progressive improvement in wrist motion by six months. Their correlation analysis demonstrated that restoration of palmar tilt and articular congruity significantly influenced functional recovery, emphasising the importance of accurate anatomical reduction following surgical fixation [13].

Future multicentre studies involving larger patient populations, longer follow-up, and the inclusion of validated patient-reported outcome measures are needed to further clarify how radiological restoration influences functional recovery over time.

Limitation(s)

This was a single-centre study with a relatively small sample size, which may limit the generalisability of the results. The follow-up period of one year was not sufficient for evaluation of late complications such as post-traumatic osteoarthritis. Furthermore, several factors known to influence the MMWS were not controlled for in the present study, including smoking status, diabetes, osteoporosis, physiotherapy compliance and occupational demands/manual labour.

CONCLUSION(S)

The present study demonstrated that the relationship between radiological alignment and functional recovery following VLP fixation is time-dependent. Although anatomical reduction was achieved and maintained in most patients, radiological alignment did not significantly influence functional outcomes during the early postoperative period. In contrast, a significant positive association emerged after fracture consolidation and persisted through the one-year follow-up, indicating that preservation of anatomical alignment becomes increasingly important for long-term wrist function.

Authors' contribution: SS, CP, SK: Concept, study design and Data collection, Data analysis and interpretation, Manuscript preparation; CP, SK: Critical revision of the manuscript, Supervision. All authors reviewed and approved the final manuscript and accept responsibility for the integrity and accuracy of the work.

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