

Research Article

Anatomical and Acceptable Radiographic Restoration After Volar Locking Plate Fixation in Distal Radius Fractures

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Abstract

Objectives: The aim of this study was to evaluate whether early postoperative radiographic alignment after volar locking plate fixation for distal radius fractures reached accepted anatomical reference ranges.

Methods: In this retrospective observational study, patients who underwent volar locking plate fixation between January 2023 and January 2024 were reviewed. Standard postoperative day-0 posteroanterior and lateral wrist radiographs were evaluated. Volar tilt, radial inclination, radial height, and ulnar variance were measured according to published anatomical reference ranges.

Results: Forty-six patients were included (mean age: 52.9±13.2 years; 50.0% male). Most fractures were AO type C (80.4%). Mean volar tilt, radial inclination, radial height, and ulnar variance were 7.85±3.81°, 17.52±4.46°, 10.85±2.47 mm, and –0.35±3.13 mm, respectively. Anatomical reference ranges were achieved in 21.7% of cases for volar tilt, 21.7% for radial inclination, 37.0% for radial height, and 56.5% for ulnar variance. Complete anatomical restoration was observed in 2 patients (4.3%). Interobserver reliability was excellent for all measurements.

Conclusion: Although complete anatomical restoration was uncommon, postoperative alignment met the predefined acceptable radiographic alignment criteria in most patients. Strict anatomical restoration and acceptable radiographic alignment according to the predefined criteria should be considered separately when evaluating postoperative radiographs after distal radius fracture fixation.

Keywords: Anatomical reduction, Distal radius fracture, Radiographic parameters, Volar locking plate

Cite This Article: Tekşan E, Aksoy S, Arı B, Açıl S. Anatomical and Acceptable Radiographic Restoration After Volar Locking Plate Fixation in Distal Radius Fractures. EJMI 2026;10(3):418–424.

Distal radius fractures are among the most common injuries encountered in adult fracture populations, and their incidence increases particularly in the elderly due to osteoporosis.^[1] When not treated appropriately, these fractures may lead to functional problems such as limitation of wrist motion, decreased grip strength, and chronic pain.^[2]

Currently, volar locking plate fixation is widely preferred for the surgical treatment of unstable distal radius fractures. This technique provides advantages in achieving anatomical reduction and stable fixation, allowing early mobilization.^[3] Following surgical treatment, radiographic evaluation plays a key role in objectively assessing the quality of fracture reduction.

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Submitted Date: July 8, 2026 **Revised Date:** August 18, 2026 **Accepted Date:** August 19, 2026

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Volar tilt, radial inclination, radial height, and ulnar variance are accepted as standard radiographic parameters in the assessment of distal radius anatomy.^[4] Restoration of these parameters within normal anatomical limits is important for maintaining biomechanical balance and preserving wrist function.

However, the extent to which these radiographic parameters reach accepted anatomical reference ranges after volar locking plate fixation has shown variability in the literature.^[5] Therefore, objectively evaluating postoperative radiographic alignment and determining the rate of anatomical restoration in distal radius fractures are important for assessing clinical practice and surgical outcomes.

Methods

In this retrospective observational study, the medical records and radiographs of patients treated with volar locking plate fixation for distal radius fractures at our institution between January 2023 and January 2024 were reviewed. Because of the retrospective design of the study, no formal sample size calculation was performed; all eligible patients who met the inclusion criteria during the study period were included consecutively. The study protocol was approved by the Giresun Training and Research Hospital Scientific Research Ethics Committee (approval date: April 1, 2026; decision number: 14).

Inclusion Criteria

- Patients treated with volar locking plate fixation for distal radius fractures between January 2023 and January 2024
- Availability of standard postoperative day-0 postero-anterior (PA) and lateral wrist radiographs
- Radiographs of sufficient quality to allow accurate radiographic measurements
- Patients aged 18 years or older

Exclusion Criteria

- Patients with missing or inadequate postoperative radiographs for measurement
- Pathological fractures
- Open fractures
- Patients who underwent another surgical procedure on the same extremity simultaneously
- Patients with a previous history of surgery on the same wrist
- Patients whose medical records could not be accessed

During the study period, 65 patients were assessed for eligibility. Nineteen patients were excluded according to the

predefined exclusion criteria, and the final study cohort consisted of 46 patients. The patient selection process is shown in Figure 1.

Radiographic Evaluation Standard postoperative day-0 PA and lateral wrist radiographs of all patients were evaluated. AO fracture classification was performed by a single observer (E.T.), an orthopaedic surgeon.

The following parameters were measured on the radiographs:

- Volar tilt (°)
- Radial inclination (°)
- Radial height (mm)
- Ulnar variance (mm)

All measurements were performed using a digital radiography system. Radiographic measurements were conducted independently by two orthopaedic surgeons. Interobserver reliability was assessed using the single-measures intraclass correlation coefficient (ICC) based on a two-way random-effects model for absolute agreement (ICC [2,1]). The primary radiographic analysis was based on the measurements of the first observer.

To determine whether postoperative measurements were anatomical, reference ranges reported in the literature were used: volar tilt 10–15°, radial inclination 21–25°, radial height 11–13 mm, and ulnar variance –2 to +2 mm.^[6] These narrow reference intervals were used to assess strict anatomical radiographic restoration rather than general acceptable alignment; acceptable radiographic alignment was evaluated separately using broader criteria described in the literature. Complete anatomical radiographic restoration was defined as the simultaneous presence of all four parameters within their respective anatomical reference ranges.

In addition, acceptable radiographic alignment criteria described in the literature were considered to evaluate whether fracture reduction was radiographically acceptable. In the present study, acceptable reduction was assessed using the available postoperative radiographic parameters and was defined as radial inclination $\geq 15^\circ$, radial height > 5 mm, and volar tilt between -10° and 15° .^[7] Ulnar variance was not included in the predefined acceptable radiographic alignment criteria because the literature-based criteria adopted in the present study were defined using radial inclination, radial height, and volar tilt; therefore, ulnar variance was evaluated separately as part of strict anatomical restoration.

Radiographic measurements are demonstrated in Figures 2 and 3. Figure 2 illustrates the measurement of radial inclination, radial height, and ulnar variance on the postero-

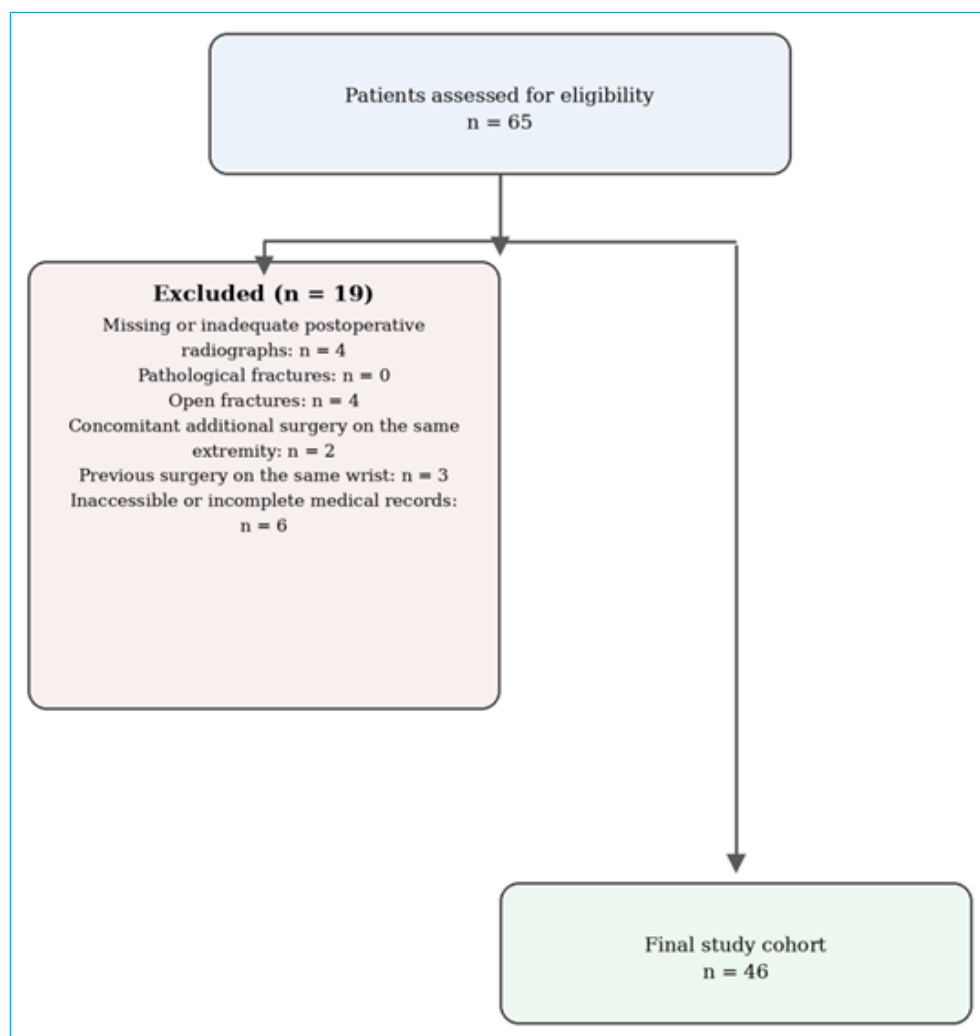


Figure 1. Flow diagram of patient selection.

anterior (PA) wrist radiograph, whereas Figure 3 shows the measurement of volar tilt on the lateral wrist radiograph.

Statistical Analysis

The statistical evaluation of the data was performed using descriptive statistical methods. Continuous variables were summarized as mean±standard deviation, while categorical variables were expressed as counts and percentages. Interobserver reliability for radiographic measurements was assessed using the single-measures intraclass correlation coefficient (ICC), based on a two-way random-effects model for absolute agreement, and interpreted according to the criteria described by Koo and Li.^[8] All statistical analyses were conducted using SPSS Statistics for Windows (version 26.0; IBM Corp., Armonk, NY, USA).

Results

The demographic and fracture characteristics of the patients are presented in Table 1. The final study cohort

consisted of 46 patients. The mean age of the patients was 52.9±13.2 years. The study population consisted of 23 males (50.0%) and 23 females (50.0%). Regarding the side of injury, 27 patients (58.7%) had right-sided distal radius fractures and 19 patients (41.3%) had left-sided fractures. According to the AO classification, 4 patients (8.7%) had type B2 fractures, 5 (10.9%) had type B3 fractures, 20 (43.5%) had type C2 fractures, and 17 (37.0%) had type C3 fractures.

Postoperative radiographic measurements are presented in Table 2. The mean volar tilt was 7.85±3.81°, radial inclination was 17.52±4.46°, radial height was 10.85±2.47 mm, and ulnar variance was -0.35±3.13 mm.

The rates of radiographic parameters falling within the anatomical reference ranges are presented in Table 3. Accordingly, volar tilt was within the anatomical reference range in 10 patients (21.7%), radial inclination in 10 patients (21.7%), radial height in 17 patients (37.0%), and ulnar variance in 26 patients (56.5%). Complete anatomical

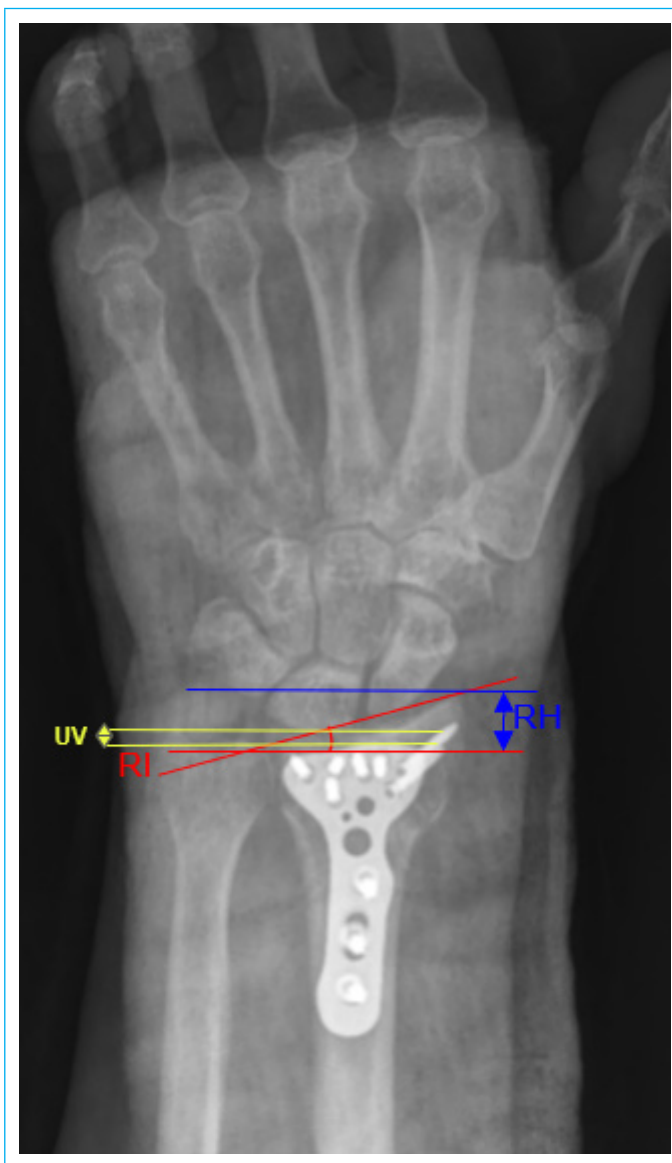


Figure 2. Measurement of radial inclination, radial height, and ulnar variance on the posteroanterior wrist radiograph. RI: radial inclination; RH: radial height; UV: ulnar variance.

radiographic restoration, defined as all parameters being simultaneously within the anatomical reference ranges, was observed in only 2 patients (4.3%).

The evaluation of fractures according to the predefined acceptable radiographic alignment criteria is presented in Table 4. Radial inclination $\geq 15^\circ$ was observed in 35 patients (76.1%), radial height > 5 mm in 46 patients (100%), and volar tilt between -10° and 15° in 43 patients (93.5%). Complete acceptable radiographic alignment, defined as meeting all predefined acceptable radiographic criteria simultaneously, was observed in 34 patients (73.9%). These findings indicate that although the rate of strict anatomical restoration was low, fracture alignment met the predefined acceptable radiographic alignment criteria in the majority of patients.

Interobserver reliability of radiographic measurements is presented in Table 5. Interobserver reliability was excellent for all radiographic parameters. The ICC values were 0.966 for volar tilt, 0.963 for radial inclination, 0.912 for radial height, and 0.967 for ulnar variance.

Discussion

In this study, the rate at which radiographic parameters on immediate postoperative day-0 radiographs reached the anatomical reference ranges was evaluated in patients who underwent volar locking plate fixation for distal radius fractures. The most notable finding of our study was that although individual radiographic parameters reached anatomical limits at certain rates, the rate of complete anatomical radiographic restoration, defined as all parameters simultaneously falling within the anatomical ranges, was low (4.3%).

Most fractures in the present cohort were AO type C fractures. Although this fracture distribution may have contributed to the low rate of complete anatomical restoration, this possibility cannot be confirmed because no subgroup

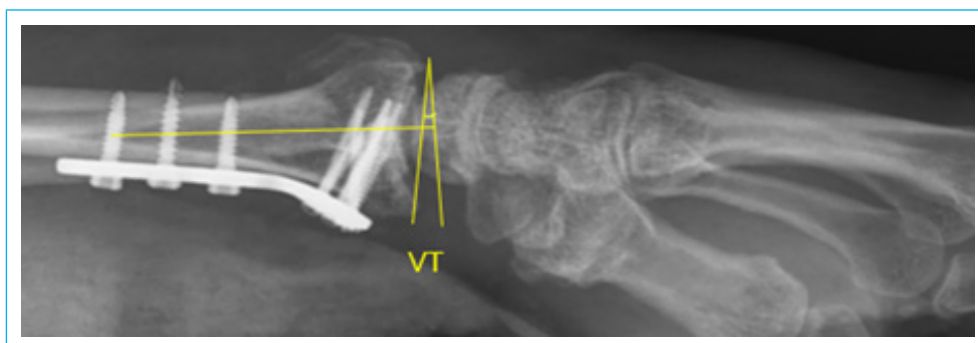


Figure 3. Measurement of volar tilt on the lateral wrist radiograph. VT: Volar Tilt.

Table 1. Demographic and Fracture characteristics of patients

Variable	Value
Number of patients	46
Age (years), mean $\pm$ SD	52.9 $\pm$ 13.2
Male, n (%)	23 (50.0)
Female, n (%)	23 (50.0)
Right side, n (%)	27 (58.7)
Left side, n (%)	19 (41.3)
AO classification, n (%)	
Type B2	4 (8.7)
Type B3	5 (10.9)
Type C2	20 (43.5)
Type C3	17 (37.0)

Values are presented as mean $\pm$ standard deviation or number (percentage).
 AO: Arbeitsgemeinschaft für Osteosynthesefragen classification; SD: Standard deviation.

Table 2. Postoperative radiographic parameters

Parameter	Mean $\pm$ SD
Volar tilt (°)	7.85 $\pm$ 3.81
Radial inclination (°)	17.52 $\pm$ 4.46
Radial height (mm)	10.85 $\pm$ 2.47
Ulnar variance (mm)	-0.35 $\pm$ 3.13

Values are presented as mean $\pm$ standard deviation (SD).

Table 3. Achievement of anatomical radiographic parameters

Parameter	N	%
Volar tilt (10–15°)	10	21.7
Radial inclination (21–25°)	10	21.7
Radial height (11–13 mm)	17	37.0
Ulnar variance (-2 to +2 mm)	26	56.5
Complete anatomical restoration (all parameters)	2	4.3

Values are presented as number (percentage). Complete anatomical restoration was defined as all parameters simultaneously falling within the anatomical reference ranges.

analysis according to fracture type was performed. However, when fractures were evaluated according to the predefined acceptable radiographic alignment criteria based on the available postoperative radiographic parameters, fracture alignment met these criteria in a substantial proportion of patients. In our study, when these parameters were assessed as components of predefined acceptable radiographic alignment, the criteria were met in 76.1% of

Table 4. Achievement of predefined acceptable radiographic alignment criteria

Parameter	N	%
Radial inclination $\geq 15^\circ$	35	76.1
Radial height > 5 mm	46	100
Volar tilt -10° to 15°	43	93.5
Complete acceptable radiographic alignment	34	73.9

Values are presented as number (percentage). Acceptable radiographic alignment according to the predefined criteria was defined as radial inclination $\geq 15^\circ$, radial height > 5 mm, and volar tilt between -10° and 15° . Complete acceptable radiographic alignment was defined as meeting all predefined criteria simultaneously.

Table 5. Interobserver reliability of radiographic measurements

Parameter	ICC
Volar tilt	0.966
Radial inclination	0.963
Radial height	0.912
Ulnar variance	0.967

ICC: Interobserver reliability was assessed using the single-measures intraclass correlation coefficient; two-way random-effects model, absolute agreement. ICC values > 0.90 indicate excellent reliability. [8]

patients for radial inclination, 100% for radial height, and 93.5% for volar tilt. However, the radial height threshold should not be interpreted as an isolated marker of surgical success, because it represents a broad predefined radiographic criterion. The rate of complete acceptable radiographic alignment, defined as meeting all predefined acceptable radiographic criteria simultaneously, was 73.9%. These findings indicate that although strict anatomical restoration was achieved in only a small proportion of patients, the predefined acceptable radiographic alignment criteria were met in the majority of the cohort. Therefore, strict anatomical restoration and acceptable radiographic alignment according to the predefined criteria should be interpreted as different radiographic concepts.

In addition, interobserver reliability was excellent for all radiographic measurements, supporting the reproducibility of the radiographic assessment. The mean postoperative radiographic values also supported this finding, as volar tilt, radial inclination, and radial height were close to but not consistently within the strict anatomical reference intervals, whereas ulnar variance was relatively closer to the anatomical reference range.

It should also be recognized that the anatomical reference ranges used in radiographic assessment are primarily derived from measurements obtained in healthy populations. In routine clinical practice, particularly in middle-aged and

older patients with intra-articular or complex distal radius fractures, achieving complete anatomical restoration may not always be feasible. This issue may be more evident in fracture patterns involving the articular surface, metaphyseal comminution, or complex displacement. In the present cohort, the predominance of AO type C fractures suggests that many patients had relatively complex fracture patterns, which may have limited the ability to restore all radiographic parameters simultaneously within narrow anatomical reference intervals. Therefore, acceptable radiographic alignment may represent a more practical radiographic target than complete anatomical restoration in selected patients. Nevertheless, the clinical relevance of this distinction should be interpreted with caution because functional outcomes were not evaluated in the present study.

Previous studies have reported that radiographic parameters can be substantially improved following volar plate fixation. For instance, in the study by Mohankumar et al.^[9], most patients treated with volar locking plates achieved good or excellent postoperative radiographic outcomes. Nevertheless, some studies have also indicated that achieving complete restoration of anatomical radiographic parameters may not always be possible. Indeed, several series have reported limited rates of complete restoration of parameters such as volar tilt, radial inclination, and ulnar variance to their normal values.^[10] In this regard, our findings are consistent with the concept that volar locking plate fixation can improve postoperative alignment, but complete restoration of all anatomical parameters may remain difficult, especially when strict reference intervals are used.

Although previous studies have investigated the relationship between radiographic alignment and clinical outcomes after distal radius fractures, this relationship remains controversial. Some studies have demonstrated that unacceptable radiographic reduction is associated with worse patient-reported outcomes.^[11] In contrast, other studies suggest that minor deviations in radiographic parameters may have a limited impact on clinical function. In particular, it has been shown that the relationship between dorsal tilt and clinical outcomes may be nonlinear and that functional differences may not be clinically significant below a certain threshold.^[12] However, the present study evaluated only radiographic parameters and did not include functional outcome scores, grip strength, range of motion, pain scores, or patient-reported outcome measures. Therefore, our findings should be interpreted as radiographic results only, and no direct conclusion can be drawn regarding clinical function from the present data.

Recent studies have shown that volar locking plate fixation can provide satisfactory radiographic outcomes in the

treatment of distal radius fractures.^[13] However, in our study, the rate at which certain radiographic parameters reached strict anatomical reference ranges was lower than those reported in the literature. Several factors may explain this finding. First, most fractures in the present cohort were AO type C fractures, indicating a predominance of intra-articular and more complex fracture patterns. This fracture distribution may have influenced the observed radiographic restoration rates; however, because no subgroup analysis according to fracture type was performed, the specific effect of fracture type on anatomical restoration cannot be determined from the present study. Second, the surgical procedures were performed by different surgeons rather than by a single surgeon, and variability in surgical experience and technique may have contributed to differences in postoperative radiographic alignment. Third, the study was conducted in a high-volume trauma center, where trauma workload and emergency surgical conditions may influence the operative environment. Furthermore, only immediate postoperative radiographs were evaluated; therefore, this study reflects early postoperative radiographic alignment rather than maintenance of reduction over time. Future prospective studies including standardized fracture classification, serial radiographic follow-up, and functional outcome measures are needed to determine the clinical relevance of these radiographic findings.

Conclusion

Volar locking plate fixation is a widely used surgical method in the treatment of distal radius fractures. In this study, the rate at which postoperative radiographic parameters reached strict anatomical reference ranges was low. However, when fractures were evaluated according to the predefined acceptable radiographic alignment criteria based on the available postoperative radiographic parameters, alignment met these criteria in the majority of patients. These findings suggest that strict anatomical restoration and acceptable radiographic alignment according to the predefined criteria should be considered separately when evaluating postoperative radiographs after distal radius fracture fixation. Because functional outcomes were not evaluated in this study, future prospective studies including both radiographic and functional assessments are needed to determine the clinical relevance of these findings.

Limitations

This study has several limitations. First, it has a retrospective design and was conducted at a single center. Second, only immediate postoperative day-0 radiographs were evaluated; therefore, maintenance of reduction, late displacement, or radiographic changes during follow-up could not be as-

sessed. Third, functional clinical outcomes and patient-reported outcome measures were not analyzed, which limits the ability to directly correlate radiographic restoration with clinical function. Fourth, contralateral wrist radiographs were not available; therefore, ulnar variance was evaluated using fixed anatomical reference ranges rather than patient-specific contralateral comparison. Fifth, intra-articular step-off could not be evaluated because it was not routinely available in the dataset. In addition, the radial height threshold used for acceptable reduction was relatively broad; therefore, radial height >5 mm should be interpreted as part of the overall acceptable radiographic alignment definition rather than as an isolated marker of surgical success. Another potential factor influencing radiographic outcomes is that the surgical procedures were performed by different surgeons. Despite these limitations, the inclusion of AO fracture classification and interobserver reliability analysis strengthens the methodological quality of the study. Our findings contribute to the literature by demonstrating the rate at which radiographic parameters reach anatomical reference ranges following volar locking plate fixation in distal radius fractures.

Disclosure

Ethics Committee Approval: The study protocol was approved by the Giresun Training and Research Hospital Scientific Research Ethics Committee (approval date: 01.04.2026, decision number: 14).

Informed Consent: Not applicable due to the retrospective observational design of the study.

Author Contributions: Concept – ET, SA; Design – ET, SA, BA, SAÇ; Supervision – BA, SAÇ; Materials – ET, SA; Data Collection and/or Processing – BA, SAÇ; Analysis and/or Interpretation – ET, SA, BA; Literature Review – ET, SA; Writing – ET, SA; Critical Review – BA, SAÇ.

Conflict of Interest: The authors declare no conflict of interest.

Funding: The author declares that this research received no external funding.

Use of AI for Writing Assistance: No artificial intelligence tools were used in the writing, editing, proofreading, analysis, or preparation of this manuscript.

Peer-review: Externally peer-reviewed.

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