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Reliability of Radiographic Evaluation in Distal Radius Fractures: Implications for Clinical Practice

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Purpose: To assess the interobserver reliability of standard radiographic parameters in non-operatively managed distal radius fractures.
Methods: Two independent hand and microsurgery specialists evaluated the radiographs. Reliability was assessed using intraclass correlation coefficients (ICCs), Cohen's kappa, and Bland–Altman plots.
Results: Continuous measurements, including ulnar variance, dorso-volar angulation, and radial inclination, demonstrated excellent reliability (ICC > 0.90). The categorical evaluation of associated ulnar fracture yielded substantial reliability ($\kappa = 0.79$).
Conclusions: Continuous radiographic parameters can be applied mostly with confidence in both clinical decision-making and research settings, whereas categorical assessments may warrant more cautious interpretation.

Keywords: Distal Radius Fractures, Interobserver Reliability, Intraclass Correlation Coefficient, Fracture Instability

Distal radius fractures (DRFs) are among the most common fractures in adults, occurring in both older adults with osteoporotic bone and younger individuals after high-energy trauma [1–4]. Their incidence is expected to increase, contributing to a growing healthcare burden. Because DRFs can substantially impair wrist function and quality of life, accurate evaluation and appropriate management are essential to optimize outcomes.

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Radiographic assessment is central to treatment planning and guides the choice between conservative and surgical approaches. Standard posteroanterior (PA) and lateral wrist radiographs are used to measure distal radius alignment parameters, including radial inclination, radial height, dorso-volar angulation, and ulnar variance. Predictors of instability, as described by Lafontaine et al.[5], include dorsal angulation greater than 20°, dorsal comminution, intra-articular involvement, the presence of an ulnar fracture, and patient age greater than 60 years. These parameters reflect the three-dimensional alignment of the distal forearm and provide a consistent framework for assessing fracture reduction, alignment, and postoperative outcomes. Maintaining values close to anatomic norms is important because deviations may disrupt wrist biomechanics and hinder recovery. For example, loss of volar angulation can limit wrist flexion-extension and increase radiocarpal joint impingement, whereas positive ulnar variance can shift loading toward the distal radioulnar joint and triangular fibrocartilage complex [4]. Collectively, these findings suggest that restoring radial inclination, radial height, volar angulation, and ulnar variance toward anatomic norms is important for maximizing strength, motion, and long-term wrist function.

However, radiographic measurements in DRFs are inherently variable. Plain radiographs provide only two-dimensional projections of a complex three-dimensional structure, and measurements can be affected by forearm rotation, wrist position, and subjective landmark identification. Recent studies have found only moderate interobserver consistency for these parameters [1,6,7], suggesting that even experienced surgeons may record different values from the same image. Such variability complicates research comparisons and may influence clinical decisions, particularly when treatment thresholds rely on small differences in radiographic values. Therefore, assessing the reproducibility of these parameters is essential for ensuring both research validity and clinical reliability.

Previous studies have focused primarily on continuous radiographic parameters, although categorical parameters remain important in clinical practice, as reflected in the Lafontaine criteria. Most studies have evaluated reliability at a single time point, whereas more recent research has used post-reduction or early follow-up radiographs to predict fracture instability [8–11]. However, the reliability and clinical relevance of radiographic parameters at fracture union, a critical time point for determining treatment acceptability and guiding further management, have not been well studied.

This study evaluated interobserver reliability using Cohen's kappa for categorical variables and the intraclass correlation coefficient (ICC) for continuous measurements. Two independent hand surgeons assessed standard PA and lateral radiographs of distal radius fractures. By analyzing agreement across commonly used radiographic parameters, we aimed to determine their reproducibility and clarify the degree of confidence that clinicians and researchers can place in these measurements.

METHODS

Study Design and Participants

This retrospective cohort study included adult patients with DRFs who underwent non-operative treatment at Rajavithi Hospital, a 1,200-bed tertiary care center. The study period extended from January 1, 2014, to December 31, 2022, during which hand surgeons were consistently available for patient care. The study was conducted after approval by the Human Research Ethics Committee of Rajavithi Hospital (COA No. 185/2023) and the Ethics Committee of Thammasat University (Project No. MTU-EC-ES-4-162/66), with patient consent waived because of the retrospective design. Eligible participants were identified using International Classification of Diseases, 10th Revision (ICD-10) codes from the hospital database. Inclusion criteria comprised adults aged ≥ 18 years with DRFs managed by closed reduction and immobilization. Diagnoses were confirmed clinically and with standard PA and lateral wrist radiographs obtained on the day of injury. Patients were excluded if they were skeletally immature, were initially managed surgically (such as those with open fractures, volar Barton fractures, severe intra-articular fractures, and polytrauma), or had incomplete medical records. Patients were also excluded if follow-up until fracture union was insufficient or if treatment decisions were influenced by patient or physician preference.

All patients were treated according to a standardized non-operative protocol that included hematoma block anesthesia, closed reduction with longitudinal traction, and immobilization using either a U-shaped or anteroposterior short-arm splint. Follow-up radiographs were obtained immediately before and after reduction, at 1, 2, and 4 weeks, and then every 2–4 weeks until fracture union. If redisplacement occurred at the 1-week follow-up, re-reduction was performed before casting. Fracture union was defined radiographically by trabecular bridging, and final alignment was assessed at 6 weeks or earlier if surgical intervention was required.

Radiographic Assessments

Standard PA and lateral wrist radiographs were obtained at four time points: initial presentation, immediately after closed reduction, 1-week follow-up, and fracture union (Figures 1 and 2) [7,12]. All radiographs were calibrated within the hospital picture archiving and communication system (PACS), ensuring linear accuracy of 1 mm and angular accuracy of 1°.

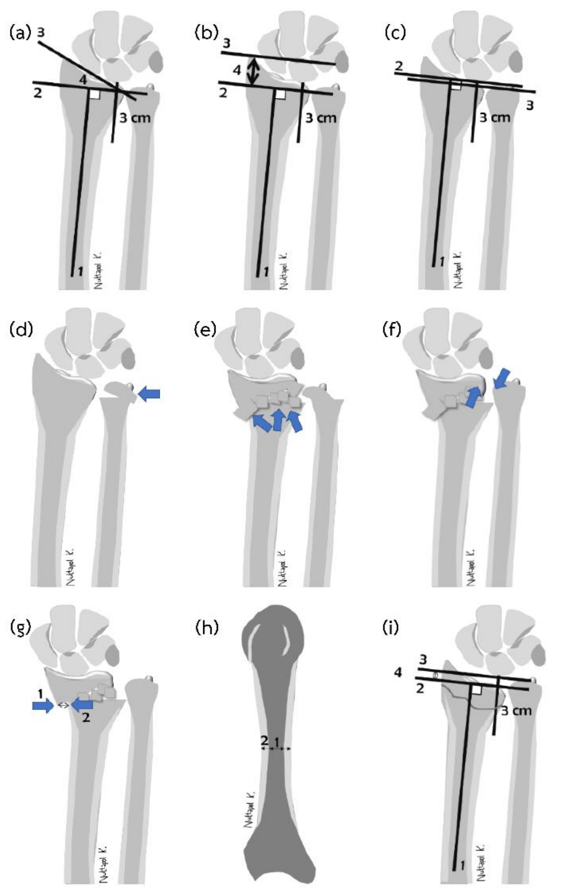

Fig. 1 Radiographic assessments on standardized posteroanterior wrist views.

Note for (a)–(c) and (i): Line (1) = radial long axis, defined by the midpoint 3 cm proximal to the proximal lunate midpoint; line (2) = line perpendicular to line (1) at the ulnar margin of the distal radius. For significant dorso-volar angulation, the dorsal and volar midpoints were used.

(a) Radial Inclination: Angle (°) between line (2) and line (3) [line connects the radial and ulnar edges].

(b) Radial Height: Distance (mm) between line (2) and line (3) [perpendicular line at distal-most radial articular surface].

(c) Ulnar Variance: Distance (mm) between line (2) and line (3) [perpendicular line at distal ulnar articular surface].

(d) Ulnar Fracture: Distal ulnar fracture fragment.

(e) Metaphyseal Comminution: More than two fracture fragments at the distal radius metaphysis.

(f) DRUJ Separation: Sigmoid notch misalignment with the ulnar head; contralateral comparison was used to distinguish subtle widening from normal variation.

(g) Radial Translation: Distance (mm) between the horizontal radial edges of the distal (1) and proximal (2) fracture fragments.

(h) Second Metacarpal Cortical Percentage (2MCP): [(2) – (1) / (2)] × 100%, measured at the narrowest point of the second metacarpal mid-diaphysis [(2) = outer cortical diameter; (1) = intramedullary width].

(i) Radial Shortening: Distance (mm) between line (2) and line (3) [parallel line at distal-most ulnar articular surface].

Abbreviations: 2MCP = second metacarpal cortical percentage; DRUJ = distal radioulnar joint.

Categorical parameters included the presence of associated ulnar fracture, dorsal comminution, second metacarpal cortical percentage (2MCP) ≤ 50% [8,13], metaphyseal comminution, distal radioulnar joint (DRUJ) separation, and restoration of the volar cortex after reduction. Continuous parame-ters were recorded at different time points. At initial injury, dorso-volar angulation (DA), intraarticular fracture stepping (IAFS), ulnar variance (UV), radial inclination (RI), and radial height (RH) were measured. After reduction, DA, radial translation, and three-point molding distance were evaluated. At the 1-week follow-up, UV and DA were measured; at fracture union, RI, radial shortening (RS) [14], DA, and IAFS were recorded.

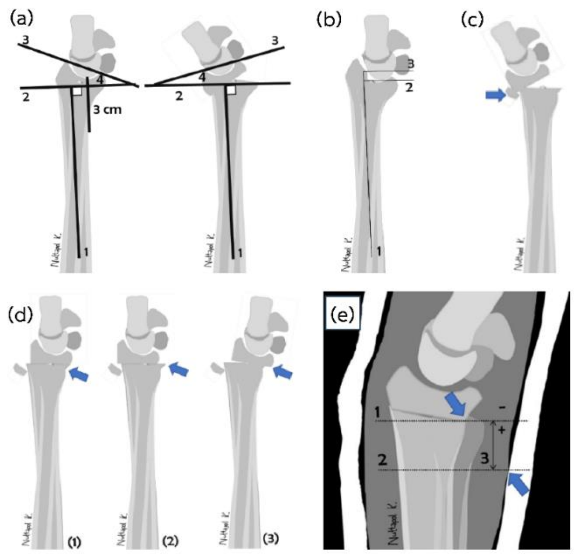

Fig. 2 Radiographic assessments on standardized lateral wrist views.

Note for (a) and (b): Line (1) = radial long axis, defined by the midpoint 3 cm proximal to the proximal lunate midpoint.

(a) Volar/Dorsal Angulation: Angle (°) between line (2), perpendicular to line (1), and line (3), connecting the dorsal and volar radial articular margins. Dorsal angulation is expressed as a negative value.

(b) Intra-articular Fracture Stepping: Distance (mm) between perpendicular lines from line (1) to the volar (2) and dorsal (3) margins of the articular cortical discontinuity.

(c) Dorsal Comminution: Free-floating bone fragments along the dorsal cortex.

(d) Restoration of Volar Cortex: Palmar cortical alignment classified as follows: (1) anatomic, aligned; (2) dorsal overlapping, distal fragment dorsal to the proximal fragment; and (3) volar overlapping, distal fragment volar to the proximal fragment.

(e) Three-Point Molding Distance: Distance (mm) between line (1), a horizontal line through the volar fracture site, and line (2), drawn through the narrowest cast-to-skin apex; a positive value indicates an apex proximal to the fracture site.

Observer Training

Radiographic measurements were independently performed by two hand and microsurgery specialists with 2 and 13 years of clinical experience. Observers were selected based on their expertise in hand surgery and radiographic assessment of DRFs. Before data collection, both observers followed a standardized protocol to ensure consistent measurement techniques. Each observer performed a single measurement for each parameter, and both observers were blinded to each other's results. Data were collected and managed using Research Electronic Data Capture (REDCap) version 13.10.2 hosted at Faculty of Medicine, Thammasat University [15,16] and anonymized before analysis to minimize bias.

Statistical Analysis

For interobserver reliability testing, a minimum of 20 participants was required, as determined according to Walter et al. [17,18]. This calculation was based on two raters, a minimum acceptable ICC of 0.65, a target ICC of 0.90, and an expected dropout rate of 10%.

Interobserver reliability was assessed for both categorical and continuous radiographic parameters. Categorical variables were assessed using Cohen's kappa, with agreement interpreted as poor (0.00), slight (0.01–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), or almost perfect (0.81–1.00) [19].

Continuous variables were analyzed using ICCs according to the guidelines of Koo and Li [20]. A two-way mixed-effects model was used, with the same set of images treated as random effects and raters treated as fixed effects, reflecting the specific raters included in this study. ICCs were calculated for single measures, with absolute agreement as the primary metric. Reliability was classified as poor (< 0.50), moderate (0.50–0.75), good (0.76–0.90), or excellent (> 0.90). This approach quantifies the proportion of total variance attributable to variability between subjects while accounting for rater effects.

Bland–Altman plots were also constructed to further illustrate interobserver agreement for continuous parameters and to evaluate consistency between the two raters [21–23]. Each plot displayed the mean difference and 95% limits of agreement. All statistical analyses were performed using Stata version 17.0 (StataCorp, College Station, TX, USA)[24].

RESULTS

Twenty adult patients with distal radius fractures met the inclusion criteria. The mean age was 57 ± 15.2 years, and 80% of participants were women. All fractures were managed non-operatively with closed reduction and immobilization, and standard PA and lateral wrist radiographs were available for all cases. Characteristics of the study population are summarized in Table 1. Comparisons of radiographic parameters between raters are shown in Table 2.

Table 1 Characteristics of the study population.

Factors	Total (N = 20)
Women, n (%)	16 (80)
Age, year	57 ± 15.2
Occupation, n (%)	
Labor	4 (20)
Maid	6 (30)
Officer	3 (15)
Other	7 (35)
Dominant hand, n (%)	
Right	20 (100)
Left	0 (0)
Injured hand, n (%)	
Right	9 (45)
Left	11 (55)

Table 2 Comparison of radiographic parameters between raters.

Factors	Rater 1 (N = 20)	Rater 2 (N = 20)	Kappa (95% CI)	ICC (95% CI)
Initial injury				
Ulnar fracture	9 (45)	7 (35)	0.79 (0.53–1.00)	
Dorsal comminution	14 (70)	14 (70)	0.76 (0.45–1.00)	
2MCP measurement ≤ 50%	6 (30)	5 (25)	0.63 (0.24–1.00)	
Metaphyseal comminution	12 (60)	15 (75)	0.67 (0.34–1.00)	
Distal radioulnar joint separation	9 (45)	7 (35)	0.69 (0.38–1.00)	
Dorso-volar angulation, degree	−8.6 ± 20.4	−8.4 ± 19.9		0.95 (0.89–0.98)
Intra-articular fracture stepping [a], mm	1.5 [0, 4]	0 [0, 2]		0.70 (0.39–0.87)
Ulnar variance, mm	3.8 ± 2.5	4.2 ± 2.9		0.92 (0.81–0.97)
Radial inclination, degree	14.6 ± 4.9	12.8 ± 7.2		0.76 (0.48–0.90)
Radial height, mm	7.2 ± 2.9	6.6 ± 3.8		0.84 (0.63–0.93)
After reduction				
Restoration of volar cortex			0.62 (0.52–0.72)	
Anatomic type	4 (20)	3 (15)		
Dorsal overlapping type	7 (35)	9 (45)		
Volar overlapping type	9 (45)	8 (40)		
Dorso-volar angulation, degrees	5.1 ± 13.7	5.4 ± 13.2		0.91 (0.79–0.96)
Radial translation [a], mm	2 [1, 3.5]	2.5 [1, 4]		0.83 (0.61–0.93)
Three-point molding distance, mm	6.3 ± 27.0	13.0 ± 32.8		0.82 (0.60–0.92)

Factors	Rater 1 (N = 20)	Rater 2 (N = 20)	Kappa (95% CI)	ICC (95% CI)
At union				
Radial inclination, degree	16.8 ± 8.1	16.5 ± 9.0		0.93 (0.84–0.97)
Radial shortening, mm	4.1 ± 2.9	3.8 ± 2.9		0.95 (0.87–0.98)
Dorso-volar angulation, degrees	−2.3 ± 18.9	−0.4 ± 19.3		0.96 (0.91–0.98)
Intra-articular fracture stepping [a], mm	0.5 [0.0, 2.5]	0 [0, 2]		0.67 (0.34–0.86)

Data are presented as mean ± standard deviation for continuous variables and number (percent) for categorical variables. Percentages may not total 100 because of rounding.

[a] Non-normally distributed variables are presented as median [interquartile range].

Abbreviations: 2MCP, second metacarpal cortical percentage; CI, confidence interval; ICC, intraclass correlation coefficient.

Interobserver Reliability

Table 2 presents Cohen's kappa values and ICCs with corresponding 95% confidence intervals (CIs) for all radiographic parameters. Interobserver reliability for categorical parameters was substantial, with the highest agreement observed for ulnar fracture (kappa = 0.79). Continuous parameters demonstrated moderate to excellent reliability across all time points. Specifically, dorso-volar angulation showed excellent reliability at all time points, whereas ulnar variance at initial injury and radial shortening and radial inclination at union also demonstrated excellent agreement (Table 3). Intra-articular fracture stepping showed slightly lower but still moderate reliability. High reliability was maintained immediately after reduction and at fracture union.

Table 3 Levels of interobserver reliability.

Categorical Parameters			
	Almost Perfect	**Substantial**	**Moderate**
Initial injury		Ulnar fracture	
		Dorsal comminution	
		2MCP measurement ≤ 50 %	
		Metaphyseal comminution	
		DRUJ separation	
After reduction		Restoration of volar cortex	
Continuous Parameters			
	Excellent	**Good**	**Moderate**
Initial injury	Dorso-volar angulation	Radial height	Intra-articular fracture stepping
	Ulnar variance	Radial inclination	
After reduction	Dorso-volar angulation	Radial translation	
		Three-point molding distance	
At union	Dorso-volar angulation		Intra-articular fracture stepping
	Radial shortening		
	Radial inclination		

Agreement for categorical parameters was interpreted using Cohen's kappa as poor (0.00), slight (0.01–0.20), fair (0.21–0.40), moderate (0.41–0.60), substantial (0.61–0.80), or almost perfect (0.81–1.00). Agreement for continuous parameters was assessed using ICCs, classified as poor (< 0.50), moderate (0.50–0.75), good (0.76–0.90), or excellent (> 0.90).

Abbreviations: 2MCP, second metacarpal cortical percentage; DRUJ, distal radioulnar joint.

Bland–Altman plots (Figure 3) further confirmed agreement for continuous parameters between the two raters. Although the ICC provides a single numerical index of overall reliability, Bland–Altman scatter plots allow visual assessment by identifying outliers and showing the relationship between measurement error and the magnitude of the measured value. Most measurements fell within the limits of agreement, demonstrating strong reproducibility between raters.

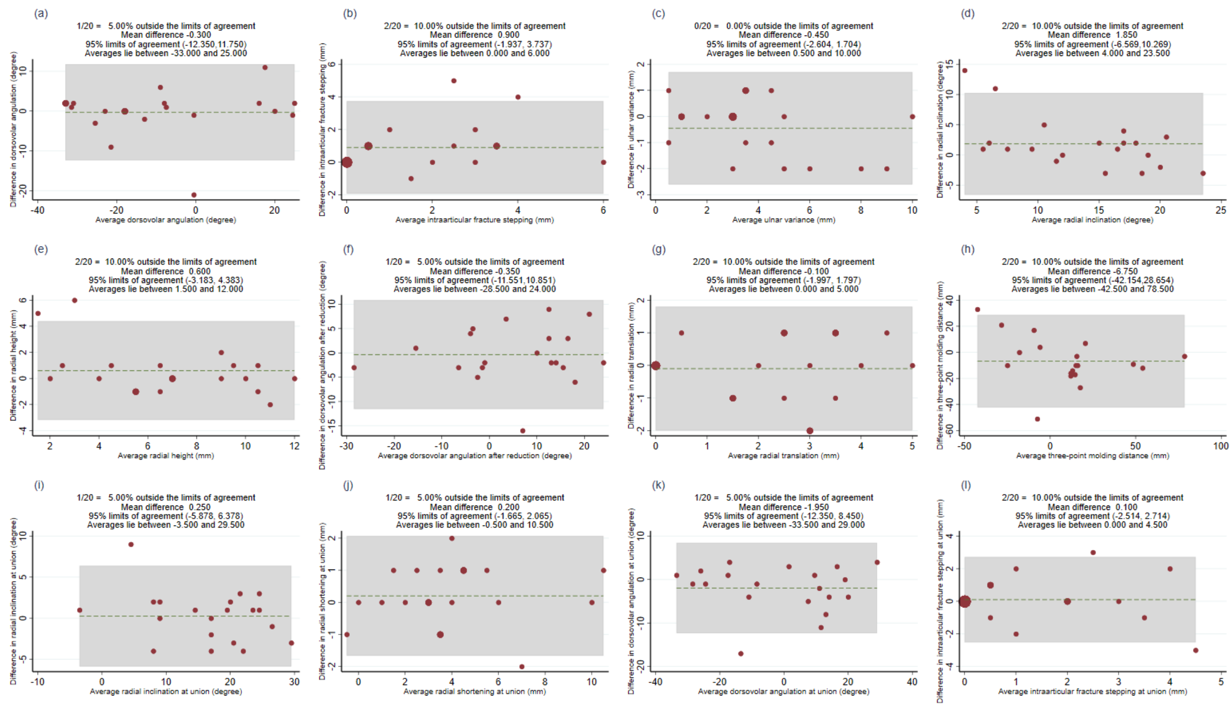

Fig. 3 Bland–Altman plots: (a) dorso-volar angulation, (b) intra-articular fracture stepping, (c) ulnar variance, (d) radial inclination, (e) radial height, (f) dorso-volar angulation after reduction, (g) radial translation, (h) three-point molding distance, (i) radial inclination at union, (j) radial shortening at union, (k) dorso-volar angulation at union, and (l) intra-articular fracture stepping at union. The x-axis represents the mean of the two measurements, and the y-axis represents their difference. The mean difference is indicated by a dashed line, with 95% limits of agreement shown as shaded areas.

DISCUSSION

This study demonstrated that both categorical and continuous radiographic parameters in DRFs can be measured with high interobserver consistency. Categorical parameters achieved substantial agreement, whereas continuous parameters demonstrated moderate to excellent reliability across time points. DA maintained excellent reliability throughout; UV, radial shortening, and radial inclination also showed excellent reliability at specific time points. Although IAFS had lower reproducibility, it remained within the moderate range. Bland–Altman analysis further confirmed strong measurement agreement, with most data points lying within acceptable limits.

Categorical assessments showed substantial agreement, reflecting the difficulty of identifying subtle cortical disruptions on plain radiographs. Few studies have reported kappa values for these parameters. Dissaneewate et al. [25] reported almost perfect agreement for ulnar fractures and moderate agreement for dorsal comminution. These differences highlight the potential for misclassification in clinical and research settings, particularly when categorical descriptors lack quantitative validation. Restoration of the volar cortex, or volar hook, showed substantial agreement in our study, although agreement was slightly lower than that reported by Dissaneewate et al.[25]. This difference likely reflects the use of three categories in the present study rather than two. Increasing the number of categories tends to lower kappa values by amplifying minor interpretive differences.

The observed levels of agreement may have been influenced by differences in the raters' clinical experience. Parameters such as restoration of the volar cortex were newly introduced or lacked established consensus, making them inherently more subjective. This subjectivity likely contributed to lower agreement, whereas parameters that have been routinely assessed for a longer period showed higher agreement because experienced raters share a more standardized frame of reference.

Continuous parameters demonstrated moderate to excellent agreement, supporting their value as objective indicators of alignment in both clinical practice and research. DA showed consistently strong agreement across all time points, consistent with previous reports [7,12,25,26]. DA is a key marker for predicting instability; therefore, reliable measurement is critical for accurate diagnosis and appropriate treatment decision-making [27]. In contrast, IAFS demonstrated only moderate reliability, which is consistent in direction with prior reports of poor reproducibility [6,7,12]. Because IAFS is a critical factor in clinical outcomes, these radiographic measurements should be interpreted with caution. When treatment decisions depend heavily on the degree of articular stepping, computed tomography (CT) should be considered for precise assessment of joint congruity.

For the remaining continuous parameters, UV achieved excellent reliability in this study despite earlier reports describing only moderate-to-good agreement [7,12]. Both radial inclination and radial height showed good agreement, slightly lower than the excellent agreement reported by Dissaneewate et al. [25], but higher than the poor-to-moderate agreement reported in other studies [7,12]. After reduction, radial translation also demonstrated good reliability, contrasting with the findings of Paasikallio et al., who reported poor agreement [6]. At union, all parameters except IAFS demonstrated excellent reliability, likely reflecting improved clarity of cortical landmarks after fracture consolidation. Taken together, these findings support the reproducible measurement of radiographic alignment indices on standard radiographs. Variation in agreement across studies is likely explained by differences in observer experience, measurement protocols, and categorization thresholds.

We also assessed novel parameters, including 2MCP, DRUJ separation, three-point molding distance, and radial shortening, to help predict outcomes and guide DRF treatment. We used 2MCP to evaluate bone quality because it is strongly associated with systemic osteoporosis [13] and fracture instability [8]. Bone mineral density scans are also not always available. In addition, DRUJ separation and three-point molding distance are useful predictors of fracture instability. The latter represents splint quality and was adapted from traditional cast-based indices [28]. For RS, we measured the distance between the distal radial and ulnar surfaces, the most accurate method according to Warwick et al. [14], to assess alignment and the success of conservative treatment. Overall, these parameters showed good interobserver reliability, except for 2MCP and DRUJ separation, suggesting that these parameters may be useful for clinical decision-making.

The strengths of this study include the use of a standardized imaging protocol and evaluation by two experienced hand surgeons. Furthermore, our analysis incorporated several parameters not commonly used in prior studies, including 2MCP measurement ≤ 50%, metaphyseal comminution, DRUJ separation, and specific parameters assessed at fracture union. The raters' varying clinical experience may have influenced the lower agreement observed when assessing these newly incorporated parameters. Limitations include the single-center retrospective design, analysis restricted to interobserver reliability between two raters, and the small sample size of 20 patients. This limited sample size reduces statistical power. Although the sample size was formally calculated, our results showed that many parameters had narrow 95% CIs, whereas some had wide 95% CIs, such as intra-articular fracture stepping at initial injury and at union, and radial inclination at initial injury. Consequently, reliability coefficients with wide CIs should be interpreted with caution. Furthermore, the study relied on plain radiographs. Although standard radiographs can effectively detect gross misalignment or significant widening, CT remains the gold standard and is highly recommended for evaluating equivocal cases. Future studies with more observers of varied experience and alternative imaging modalities could help validate and expand these findings. Additionally, a prospective study design would enhance measurement accuracy by controlling patient positioning. In our study, all radiographs were obtained using a standard positioning protocol, ensuring acceptable film quality before measurement.

CONCLUSIONS

Continuous radiographic parameters of DRFs can be used mostly with confidence for both clinical decision-making and research endpoints because of their excellent reproducibility. In contrast, categorical assessments, although clinically useful, should be interpreted with caution and confirmed with advanced imaging when findings are ambiguous.

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