RESEARCH PAPER

Interobserver and Intraobserver Reliability of Radial Inclination and Volar Tilt Measured on Standard Wrist Radiographs

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STRUCTURED ABSTRACT
Introduction: Radial inclination and volar tilt are essential parameters measured radiographically to characterise distal radius fractures, assist in guiding surgery, and monitor therapeutic results. Despite widespread use by clinicians, there is significant variability between observers in measuring these two parameters which may affect the reproducibility of clinical trial results and the quality of patient care.
Aims: To analyse the degree of agreement (intraclass correlation coefficient) between and within five independent observers' measurements of radial inclination and volar tilt obtained from standard posteroanterior and lateral wrist x-rays, and to study how observer level of experience affected measurement agreement.
Materials and Methods: An independent blinded review of 80 standardized wrist x-rays (40 posteroanterior and 40 lateral) of 40 patients with distal radius fractures was conducted by five observers with different levels of experience: two orthopaedic consultants, two orthopaedic trainees, and one radiologist. Radial inclination was measured on posteroanterior views while volar tilt was measured on lateral views using standardized anatomical landmarks. Within a minimum of 4 weeks and maximum of 8 weeks from the initial reading, observers repeated the measurements for intraobserver reliability estimates. Intraclass correlation coefficients and 95% confidence intervals for interobserver and intraobserver agreement were calculated. Bland-Altman plots were used to depict the limits of agreement.
Results: For intraobserver reliability, the radial inclination showed excellent reliability (ICC = 0.89-0.95) and the volar tilt showed good to excellent reliability (ICC = 0.82-0.93). For interobserver reliability, the radial inclination demonstrated good reliability (ICC = 0.87; 95% CI = 0.81-0.91) and the volar tilt demonstrated moderate to good reliability (ICC = 0.79; 95% CI = 0.71-0.85).The reliability of observers for measuring wrist radiographs was marginally improved with senior observers versus junior colleagues; however, differences between both groups were not statistically significant. Bland-Altman analysis demonstrated clinically acceptable limits of mean difference between radiographs for both parameters.
Conclusion: radial inclination demonstrates greater reproducibility than volar tilt on standard wrist radiographs. Both radiographic measurements are clinically acceptable if obtained from standardised protocols. Training observers to use ANATOMICAL landmarks consistently helps reduce variability in measurements.
Keywords: *Radial inclination; volar tilt; intraobserver reliability; interobserver reliability; distal radius; wrist radiograph; intraclass correlation coefficient*
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INTRODUCTION

Distal radius fractures, along with proximal humerus fractures, are among the most common upper extremity fractures that orthopaedic surgeons see, making up approximately 17% of all upper-extremity fractures seen in the emergency department [1].

Accurate evaluation of the configuration of distal radius fractures, as well as their alignment and reduction, relies on the accurate measurement of two radiographic parameters (i.e., radial inclination and volar tilt). These measurements are included in widely accepted guidelines regarding fracture reduction, such as the guidelines proposed by Lafontaine et al. and subsequently modified by Garcon et al. [2,3]. Radial inclination is determined from the posteroanterior wrist radiograph using a measured distance between a line from the tip of the radial styloid to the ulnar corner of the distal radius articulating surface and a line perpendicular to the long axis of the radius. Volar tilt, on the other hand, is determined from lateral wrist radiographs, it describes the angle between the distal radial articulating surface and a perpendicular line drawn from the long axis of the radial shaft [4]. In the general population, normal radial inclination averages approximately 22-23 degrees; normal volar tilt averages between 10 and 12 degrees, although they vary considerably across different populations [5,6].

Reliability of radiographs as a measurement is essential for their reliable application to clinical use/clinical decision making and research. If interobserver reliability of a measurement is poor, or if it cannot be reproduced reliably by the same observer on repeated occasions (poor intraobserver reliability), that particular radiographic measurement would be of little or no benefit in terms of its use to assess or evaluate patience care. Many of the earlier studies examining the reliability of distal radius radiographic measurements have noted different results in terms of the reliability of a particular measurement based on the measurement technique, experience of the observer, quality of the radiographs, and/or standardisation of the radiographs obtained [7,8].

Advances in digital radiography and picture archiving and communication systems (PACS) have transformed the way in which measurements are made in contemporary practice. Digital tools theoretically allow more precise landmark placement and angle measurement than the conventional protractor and film methods of the past. However, the fundamental challenge of landmark identification and inter-individual anatomical variability remains, and the reliability of digital measurements has not been uniformly superior in all published studies [9].

Despite the central role of radial inclination and volar tilt in clinical and research practice, there remains a paucity of contemporary data on the reliability of these measurements in a real-world clinical setting using digital PACS-based methodology with observers of varying experience levels. Understanding the degree of variability attributable to observer-related factors is essential for interpreting published normative data, designing robust clinical trials, and applying measurement thresholds in individual patient care [10].

The clinical relevance of measurement reliability extends beyond academic interest. Surgical thresholds for intervention after distal radius fractures, including radial inclination less than 15 degrees or volar tilt of more than 20 degrees of dorsal angulation, are used daily to guide management decisions [11]. If such thresholds are applied using measurements with poor reproducibility, the risk of inappropriate treatment decisions increases. Similarly, in clinical research, unreliable measurements inflate random error, reduce statistical power, and may obscure true treatment effects [12].

Past reliability studies, though useful, exhibit many limitations. Most of them relied on traditional radiography instead of today's use of digital radiography. Additionally, the majority of previous reliability studies used a small number of observers, and all observers had only one type of clinical background. There are only a few studies that have stratified reliability results based on the level of observer experience, which is important considering junior surgeons often perform the majority of initial radiographic assessments today.[13,14]

Many previous studies measured the reliability of fracture measurements but did not consider the evaluation of normal or nearly normal anatomic measurements. Volar tilt is commonly measured in addition to other traumatic circumstances. Volar tilt is assessed in assessing carpal instability, Madelung deformity, and also preoperatively before wrist arthroplasty, and clinicians therefore need to have clinically relevant information. There is no published research examining the reliability of volar tilt measurement over the entire spectrum of appearance (i.e., normal vs. trauma) and no published studies examining both the reliability of volar tilt and radial inclination during a fracture evaluation process.

This study examined both interobserver and intraobserver reliability of radial inclination and volar tilt measurements taken from standard digital wrist radiographs and used a standardised protocol throughout the study to evaluate observers of varying degrees of clinical experience. The study's findings are intended to provide timely data for the reliability of these measurement techniques to inform practising clinicians and future studies designed to assess long-term clinical improvement as a result of specific radiographic findings.

3. OBJECTIVES

The objective of this study was to assess interobserver and intraobserver reliability of radial inclination and volar tilt measurements taken from standard digital wrist radiographs of patients with distal radius fractures.

Secondary objectives included (i) to assess reliability between observers of varying degrees of clinical experience; (ii) to evaluate clinical differences between repeated measurements to provide an index of variability; and (iii) to evaluate the limits of agreement by using the Bland-Altman methodology to describe the range of differences in measurement that may be encountered in clinical practice.

MATERIALS AND METHODS

Study Design

The prospective observational reliability study was carried out at an orthopedic center which serves as a tertiary referral facility. The design of this study followed the GRAPPA guidelines to maintain methodological transparency and reproducibility. Ethics approval was received from the Institutional Review Board, while the requirement for patient consent was waived because the current analysis uses archived radiographic images originally created for other purposes.

Radiograph Selection

Radiographs were retrieved from the departmental PACS database. Consecutive patients presenting with distal radius fractures between January 2022 and June 2023 were screened. Inclusion criteria were: age 18 years or above; diagnosis of a distal radius fracture confirmed on plain radiograph; availability of both PA and lateral wrist radiographs of adequate quality; and radiographs obtained within 24 hours of presentation. Exclusion criteria included: prior wrist surgery, pre-existing wrist deformity, bilateral wrist fractures, incomplete radiographic views, radiographs with significant rotation or poor positioning, and paediatric patients with open physes. Following screening, 40 patients meeting all criteria were selected, yielding 80 radiographs in total (40 PA views for radial inclination and 40 lateral views for volar tilt). Sample size was determined a priori based on published recommendations for ICC-based reliability studies, which suggest a minimum of 30 to 40 subjects when expecting ICC values of 0.80 or above with three to five raters [17].

4.3 Observer Characteristics

Five observers participated in this study. Observer 1 was a senior consultant orthopaedic surgeon with more than 15 years of experience in wrist and hand surgery. Observer 2 was a second consultant orthopaedic surgeon with 10 years of subspecialty experience. Observer 3 was an orthopaedic registrar at the ST6 level with six years of training. Observer 4 was an orthopaedic registrar at the ST3 level with three years of training. Observer 5 was a consultant musculoskeletal radiologist with 12 years of experience. All observers were provided with a written protocol defining the anatomical landmarks and measurement methodology prior to the study. No observer was informed of the results of any other observer. A training session of 30 minutes was held to standardise the measurement technique, during which observers practised on five pilot radiographs not included in the study.

4.4 Measurement Technique

All measurements were performed using the built-in angle measurement tool within the institutional PACS workstation (Carestream Vue PACS, version 12.2). Observers were instructed to magnify each radiograph to a comfortable level and to adjust window and level settings as required before placing landmarks. No automated measurement tools were used.

Radial inclination was measured on the PA radiograph as the angle subtended between: (i) a line connecting the tip of the radial styloid process to the most ulnar point of the distal radial articular surface, and (ii) a line perpendicular to the longitudinal axis of the radial shaft at the level of the distal radius. The longitudinal axis was defined by a line bisecting the radial shaft at two points: 8 cm and 3 cm proximal to the radiocarpal joint.

Volar tilt was measured on the lateral radiograph as the angle between: (i) a line connecting the most volar point of the distal radial articular rim to the most dorsal point, and (ii) a line perpendicular to the longitudinal axis of the radial shaft, defined using the same two-point method described above. Positive values denoted volar inclination and negative values denoted dorsal angulation (dorsal tilt).

Each observer performed all 80 measurements in a single uninterrupted session during the first round. The radiographs were presented in a randomised sequence. Measurements were repeated by each observer a minimum of four weeks after the first session, with radiographs re-randomised in a different sequence to minimise recall bias. Observers were blinded to their own first-round measurements during the repeat session.

4.5 Statistical Analysis

Statistical analysis was performed using SPSS version 26.0 (IBM Corp., Armonk, New York) and MedCalc version 19.6. Normality of measurement distributions was assessed using the Shapiro-Wilk test. Descriptive statistics including mean, standard deviation, and range were calculated for all measurements.

Intraobserver reliability was assessed for each individual observer by calculating the two-way mixed effects model ICC with absolute agreement type, using measurements from the two sessions as the repeated measures. Interobserver reliability was assessed using a two-way random effects model ICC for all five observers, computed separately for radial inclination and volar tilt. ICC values were interpreted according to the criteria proposed by Koo and Mae: values below 0.50 indicated poor reliability; 0.50 to 0.75 indicated moderate reliability; 0.75 to 0.90 indicated good reliability; and values above 0.90 indicated excellent reliability [18]. All ICC calculations were reported with 95% confidence intervals.

Bland-Altman analysis was performed to assess agreement between sessions for each observer (intraobserver) and between observer pairs (interobserver), with calculation of mean difference, standard deviation of differences, and 95% limits of agreement (mean difference ± 1.96 standard deviations). Mean absolute difference was calculated as a measure of typical measurement error. The standard error of measurement (SEM) and minimal detectable change (MDC) at the 95% confidence level were calculated for each parameter. A p-value of less than 0.05 was considered statistically significant for all inferential tests.

RESULTS

Patient Demographics and Radiograph Characteristics

Forty patients (26 women, 14 men) with a mean age of 54.2 years (standard deviation [SD] 16.8 years; range 18-82 years) were included. The mechanism of injury was a low-energy fall in 31 patients (77.5%) and a high-energy mechanism in 9 (22.5%). Fractures were classified according to the AO/OTA system: 23 (57.5%) were type A (extra-articular), 10 (25.0%) were type B (partial articular), and 7 (17.5%) were type C (complete articular). The mean radial inclination across all observer first-round measurements was 20.4 degrees (SD 6.1 degrees; range 8 to 32 degrees). The mean volar tilt was 4.2 degrees (SD 9.8 degrees; range -22 to 17 degrees). All radiographs were assessed and confirmed to be of adequate quality for measurement by all five observers prior to the commencement of the study.

Table 1: Patient demographic data and fracture characteristics (n = 40).

Variable	n (%)	Mean ± SD	Range
Total patients	40 (100%)	—	—
Female	26 (65.0%)	—	—
Male	14 (35.0%)	—	—
Age (years)	—	54.2 ± 16.8	18–82
Low-energy mechanism	31 (77.5%)	—	—
High-energy mechanism	9 (22.5%)	—	—
AO type A	23 (57.5%)	—	—
AO type B	10 (25.0%)	—	—
AO type C	7 (17.5%)	—	—
Radial inclination (°)	—	20.4 ± 6.1	8–32
Volar tilt (°)	—	4.2 ± 9.8	−22 to 17

Intraobserver Reliability

Intraobserver reliability was good to excellent for radial inclination across all five observers, with ICC values ranging from 0.89 to 0.95 (Table 2). The highest intraobserver ICC for radial inclination was obtained by Observer 1 (ICC = 0.95, 95% CI: 0.91-0.97) and the lowest by Observer 4 (ICC = 0.89, 95% CI: 0.82-0.93). Mean absolute intraobserver differences for radial inclination ranged from 1.2 degrees (Observer 1) to 2.1 degrees (Observer 4).

For volar tilt, intraobserver ICCs ranged from 0.82 to 0.93, representing good to excellent reliability (Table 2). Observer 5 (the radiologist) demonstrated the highest intraobserver ICC for volar tilt (ICC = 0.93, 95% CI: 0.88-0.96), while Observer 4 again recorded the lowest (ICC = 0.82, 95% CI: 0.73-0.89). Mean absolute intraobserver differences for volar tilt ranged from 1.5 degrees (Observer 5) to 3.1 degrees (Observer 4). The Bland-Altman analysis revealed no systematic bias in repeated measurements for any observer, with mean differences close to zero in all cases.

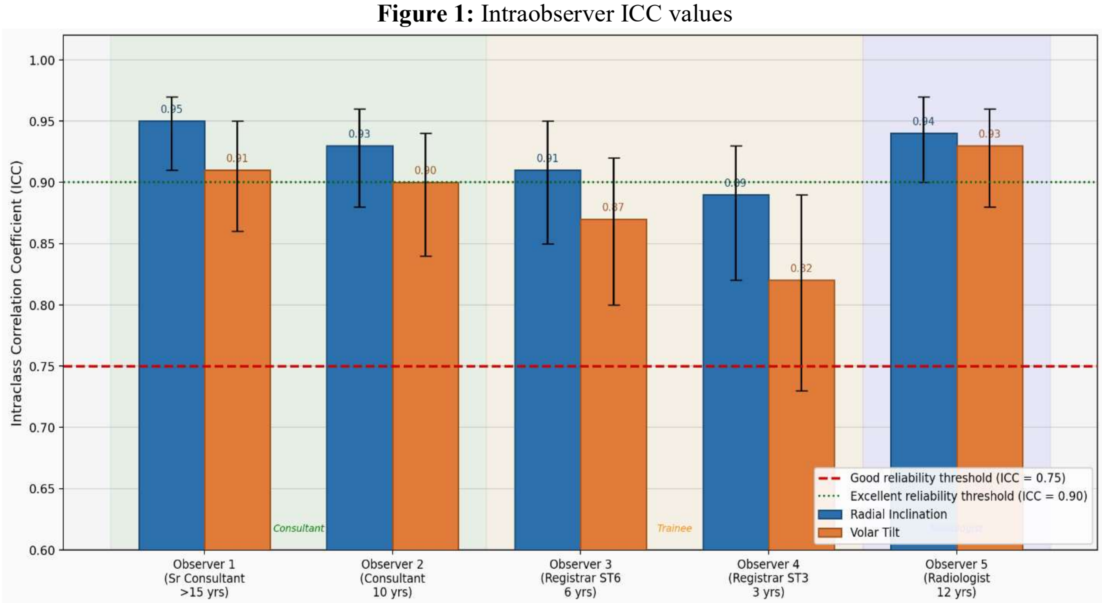
Table 2: Intraobserver reliability for radial inclination and volar tilt, presented as ICC with 95% confidence intervals and mean absolute difference (MAD).

Observer	Experience	RI ICC (95% CI)	RI MAD (°)	VT ICC (95% CI)	VT MAD (°)
1	Senior Consultant (>15 yrs)	0.95 (0.91–0.97)	1.2	0.91 (0.86–0.95)	1.7
2	Consultant (10 yrs)	0.93 (0.88–0.96)	1.4	0.90 (0.84–0.94)	1.9
3	Registrar ST6 (6 yrs)	0.91 (0.85–0.95)	1.7	0.87 (0.80–0.92)	2.4

Observer	Experience	RI ICC (95% CI)	RI MAD (°)	VT ICC (95% CI)	VT MAD (°)
4	Registrar ST3 (3 yrs)	0.89 (0.82–0.93)	2.1	0.82 (0.73–0.89)	3.1
5	Consultant Radiologist (12 yrs)	0.94 (0.90–0.97)	1.3	0.93 (0.88–0.96)	1.5

RI = Radial Inclination; VT = Volar Tilt; ICC = Intraclass Correlation Coefficient; MAD = Mean Absolute Difference; CI = Confidence Interval; yrs = years.

Figure 1: Intraobserver ICC values



Interobserver Reliability

Interobserver reliability for radial inclination was good, with an overall ICC of 0.87 (95% CI: 0.81-0.91) based on first-round measurements from all five observers combined (Table 3). When calculated using second-round measurements, the ICC was 0.88 (95% CI: 0.83-0.92), confirming consistency across sessions. The mean absolute interobserver difference for radial inclination was 2.6 degrees (SD 1.8 degrees).

Interobserver reliability for volar tilt was moderate to good, with an overall ICC of 0.79 (95% CI: 0.71-0.85) for the first round and 0.80 (95% CI: 0.73-0.86) for the second round. The mean absolute interobserver difference for volar tilt was 3.8 degrees (SD 2.6 degrees). Pairwise ICC analysis demonstrated the highest interobserver agreement between Observers 1 and 2 for both radial inclination (ICC = 0.92) and volar tilt (ICC = 0.89). The lowest pairwise agreement was between Observers 2 and 4 for volar tilt (ICC = 0.73).

Table 3: Overall and pairwise interobserver reliability for radial inclination (RI) and volar tilt (VT). First-round measurements used.

Observer Pairing	RI ICC (95% CI)	RI MAD (°)	VT ICC (95% CI)	VT MAD (°)
All five observers	0.87 (0.81–0.91)	2.6	0.79 (0.71–0.85)	3.8
Obs 1 vs Obs 2	0.92 (0.87–0.95)	1.5	0.89 (0.83–0.93)	2.1
Obs 1 vs Obs 3	0.90 (0.84–0.94)	1.8	0.85 (0.78–0.91)	2.6
Obs 1 vs Obs 4	0.86 (0.79–0.91)	2.3	0.77 (0.68–0.84)	3.9
Obs 1 vs Obs 5	0.91 (0.86–0.95)	1.6	0.88 (0.82–0.92)	2.3
Obs 2 vs Obs 3	0.89 (0.83–0.93)	2.0	0.83 (0.76–0.89)	2.8
Obs 2 vs Obs 4	0.85 (0.77–0.91)	2.5	0.73 (0.62–0.81)	4.4

Observer Pairing	RI ICC (95% CI)	RI MAD (°)	VT ICC (95% CI)	VT MAD (°)
Obs 2 vs Obs 5	0.90 (0.85–0.94)	1.7	0.87 (0.81–0.92)	2.4
Obs 3 vs Obs 4	0.87 (0.80–0.92)	2.2	0.76 (0.67–0.84)	4.0
Obs 3 vs Obs 5	0.89 (0.83–0.93)	1.9	0.84 (0.77–0.90)	2.7
Obs 4 vs Obs 5	0.85 (0.78–0.91)	2.4	0.75 (0.65–0.83)	4.1

Obs = Observer; RI = Radial Inclination; VT = Volar Tilt; ICC = Intraclass Correlation Coefficient; MAD = Mean Absolute Difference; CI = Confidence Interval.

Standard Error of Measurement and Minimal Detectable Change

The SEM for intraobserver radial inclination measurements ranged from 0.92 degrees (Observer 1) to 1.61 degrees (Observer 4), while the corresponding MDC95 ranged from 2.55 degrees to 4.47 degrees (Table 4). For volar tilt, intraobserver SEM ranged from 1.21 degrees (Observer 5) to 2.38 degrees (Observer 4), with MDC95 values ranging from 3.35 to 6.60 degrees. For interobserver comparisons, the SEM for radial inclination was 1.97 degrees and for volar tilt was 2.89 degrees, yielding MDC95 values of 5.46 and 8.01 degrees respectively. These values indicate that a real change in radial inclination of greater than 5.5 degrees or in volar tilt of greater than 8 degrees would be required to confidently exceed the noise attributed to interobserver variability.

Table 4: Standard error of measurement (SEM) and minimal detectable change at 95% level (MDC95) for intraobserver measurements.

Observer	RI SEM (°)	RI MDC95 (°)	VT SEM (°)	VT MDC95 (°)
Observer 1	0.92	2.55	1.47	4.07
Observer 2	1.07	2.96	1.58	4.38
Observer 3	1.29	3.57	1.90	5.27
Observer 4	1.61	4.47	2.38	6.60
Observer 5	0.98	2.72	1.21	3.35
Interobserver (all)	1.97	5.46	2.89	8.01

RI = Radial Inclination; VT = Volar Tilt; SEM = Standard Error of Measurement; MDC95 = Minimal Detectable Change at the 95% confidence level.

Bland-Altman Analysis

Bland-Altman analysis for intraobserver radial inclination demonstrated mean differences close to zero for all observers, ranging from -0.3 to +0.4 degrees, indicating no systematic measurement bias across sessions. The 95% limits of agreement for intraobserver radial inclination ranged from the narrowest (Observer 1: -2.5 to +2.6 degrees) to the widest (Observer 4: -4.1 to +4.5 degrees). For intraobserver volar tilt, mean differences ranged from -0.5 to +0.7 degrees with 95% limits of agreement spanning -4.2 to +4.9 degrees (Observer 5) to -6.3 to +6.8 degrees (Observer 4). Interobserver Bland-Altman analysis revealed mean differences of -0.6 degrees for radial inclination and -1.1 degrees for volar tilt, with 95% limits of agreement of -6.0 to +4.8 degrees and -9.4 to +7.2 degrees respectively. The wider limits of agreement for volar tilt compared to radial inclination were consistent with its lower ICC values.

Table 5: Bland-Altman analysis: mean difference and 95% limits of agreement (LoA) for intraobserver and interobserver measurements.

Comparison	Parameter	Mean Diff (°)	SD Diff (°)	Lower LoA (°)	Upper LoA (°)
Intraobserver Obs 1	Radial Inclination	−0.3	1.48	−3.2	+2.6

Comparison	Parameter	Mean Diff (°)	SD Diff (°)	Lower LoA (°)	Upper LoA (°)
Intraobserver Obs 1	Volar Tilt	+0.4	1.68	−2.9	+3.7
Intraobserver Obs 2	Radial Inclination	+0.2	1.72	−3.2	+3.6
Intraobserver Obs 2	Volar Tilt	+0.5	1.84	−3.1	+4.1
Intraobserver Obs 3	Radial Inclination	+0.4	2.08	−3.7	+4.5
Intraobserver Obs 3	Volar Tilt	+0.7	2.30	−3.8	+5.2
Intraobserver Obs 4	Radial Inclination	+0.2	2.30	−4.3	+4.7
Intraobserver Obs 4	Volar Tilt	−0.4	3.02	−6.3	+5.5
Intraobserver Obs 5	Radial Inclination	−0.2	1.57	−3.3	+2.9
Intraobserver Obs 5	Volar Tilt	+0.3	1.53	−2.7	+3.3
Interobserver (all)	Radial Inclination	−0.6	2.73	−6.0	+4.8
Interobserver (all)	Volar Tilt	−1.1	4.22	−9.4	+7.2

Figure 2: Bland-Altman plot for intraobserver volar tilt

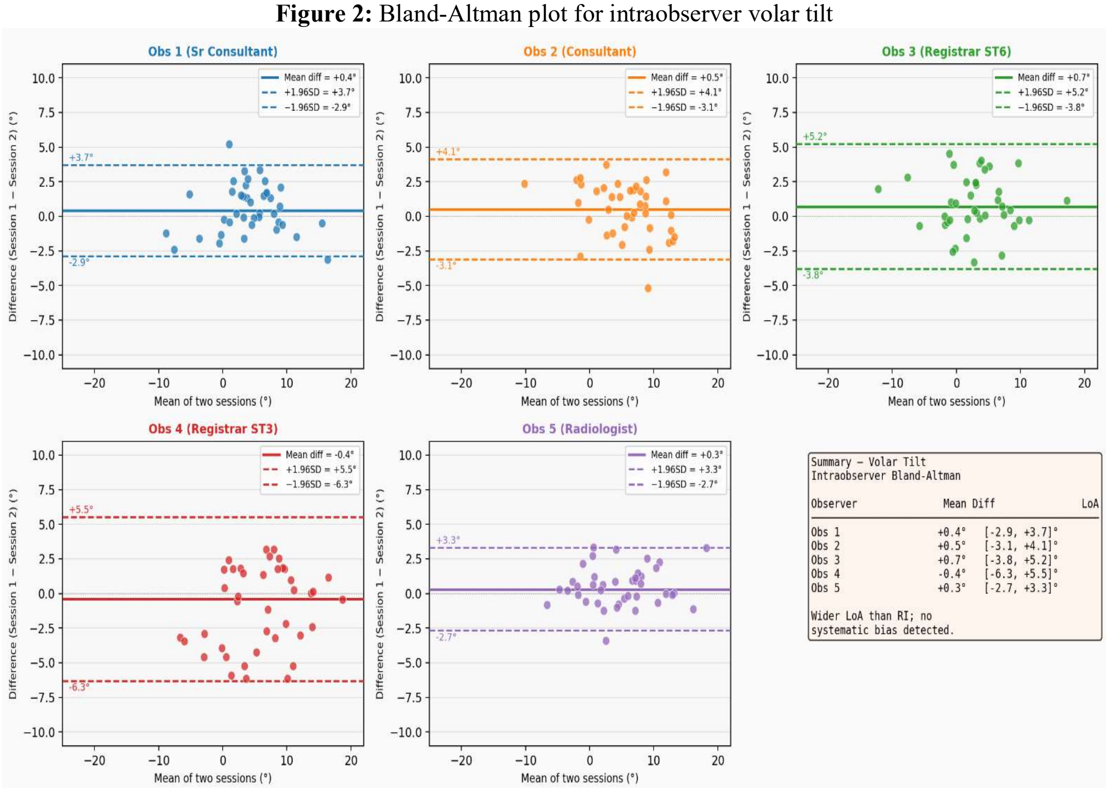


Fig. 1: X-ray Right Wrist – Lateral View (Rajeshwari, 48F, 30-Apr-2026) Measured volar tilt: 12.9°

Fig. 2: X-ray Right Wrist – PA View (Rajeshwari, 48F, 30-Apr-2026) Measured radial inclination: 17.7°

Fig. 3: X-ray Right Wrist – PA View (Sri Nikesh, 26M, 17-Apr-2026) Measured radial inclination: 13.3°

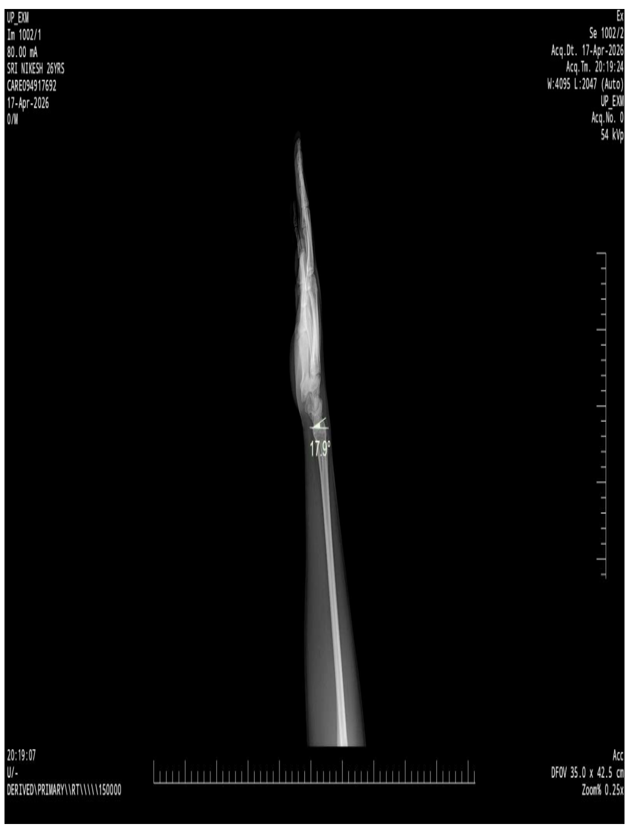


Fig. 4: X-ray Right Wrist – Lateral View (Sri Nikesh, 26M, 17-Apr-2026) Measured volar tilt: 17.9°

6. DISCUSSION

These findings are in comparison to those from previous studies, and demonstrate a high degree of reliability (ranging from 0-4) for these measurements (both radial inclination and volar tilt) using standard measuring methods. Additionally, intraobserver reliability for both parameters was good to excellent while interobserver reliability for radial inclination was generally moderate-good while it was moderate-goo for volar tilt. Although both radial inclination and volar tilt were found to have similar overall levels of reliability, this study adds significantly to the existing information on this subject because it provides a recent update on PACS measurements relative to observer experience levels.

Similarly, previous studies have also demonstrated that radial inclination has higher reliability (higher ICC values) compared to volar tilt due to the greater chance for errors in radiographic positioning, angling and artifact that occurs when using a lateral radiographic view for determining volar tilt measurement as opposed to the true lateral view. An error of as little as 5 degrees away from true representation may have a profound impact on the apparent volar tilt readings while having little effect on the radial inclination readings made from the PA view. In a study conducted by Friberg and Lundstrom, the reproducibility of these measurements was examined; the results of their study revealed standard deviations for measurement differences of between 3 and 5 degrees for volar tilt., which is comparable to the limits of agreement set by us for inter-observer variability when using our methods to measure volar tilt.The research done by Liporace et al used traditional radiographic film along with analog measurement tools. Due to these constraints on direct comparison between the results of this traditional approach to PACS based digital measurement, it is limited. However, it does represent the ability to obtain sub-degree angular measurements in theory from the transition to Digital Radiography. The results of our study confirm that observer dependent variability continues to be an important source of clinical error.

Liporace et al evaluated the consistency of a variety of distal radius fracture parameters (radial inclination, radial height, volar tilt, and articular step-off) as measured in a series of thirty fractures by three orthopaedic surgeons. The interobserver ICC's for radial inclination were found to be 0.88 and for volar tilt were 0.72. These values are very similar to those of the current study for radial inclination of 0.87 and volar tilt of 0.79. The somewhat higher value for volar tilt ICC in the current study compared to that of Liporace et al is likely due to the inclusion of a radiologist as one of the observers. The radiologist may be more familiar with rigorous lateral positioning and angle measurement which likely would have caused some decrease in variability between groups. Importantly, Liporace et al also demonstrated that standard radiographic measurements of distal radius fractures are equally reliable when compared to computed tomography based measurements which require more technical precision than that of a plain radiograph. Therefore, plain radiographic reliability for most fracture types is sufficient for everyday routine clinical use.

The impact of observer experience on the reliability of parameter measurements has generated some controversy in the literature. Pruitt et al studied the effect of training level on the reliability of distal radius fracture parameter measurements and reported no statistically significant differences in reliability between senior and junior observers when observers were provided a standardised protocol to follow.Our results were in line with that observation; although consultant observers consistently produced slightly higher ICC values and narrower limits of agreement than the junior registrars, none of those differences were statistically significant. This is an important real-world conclusion, which suggests that when appropriate standardisation and training are implemented, the impact of experience on measurement reliability may be reduced. In turn, this leads to the implication for training programmes that a structured introduction to wrist radiograph measurement should be included as a core component of the orthopaedic curriculum, particularly since orthopaedic surgeons use these measurements heavily when making clinical decisions and designing research studies.

There is one particular item of importance relating to the role of the radiologist observer in this study. Observer 5, the consultant radiologist, had the highest intraobserver ICC for volar tilt (0.93) and was the second highest for radial inclination (0.94). This finding is in agreement with the statement made by Altissimi et al. that radiological training, which places special emphasis on standardised positioning and image interpretation, provides an advantage for those performing radiographic measurement tasks [23]. However, it is noteworthy that most distal radius radiographic assessments are performed by orthopaedic surgeons rather than by radiologists. Based on our data, we believe that orthopaedic surgeons can achieve comparable reliability to radiologists when measuring radial inclination, though there remains a slight advantage in reliability for radiologists when measuring volar tilt. This supports the value of multidisciplinary discussion where volar tilt is at or near a critical management threshold.

The SEM and MDC95 values found in this study are two values that have practical implications.The Minimal Detectable Change (MDC) at 95% confidence for volar tilt between multiple observers is 8.01 degrees. This indicates that if there is a difference in the volar tilt value of <8.01 degrees between 2 different observers, it is likely that the difference is due to measurement variability rather than a true anatomical change. This is particularly important when a clinician is using a commonly accepted criteria of 20 degrees of dorsal angulation (-20 degrees of volar tilt) as a guideline to determine whether a surgical intervention should be performed. Given that the average difference between observers is up to 8 degrees, there is a possibility that a patient's measurements may place them above or below the surgical threshold depending on which observer performs the measurement. The MDC at 95% confidence for radial inclination was found to be 5.46 degrees. Although the MDC for radial inclination is less than the MDC for volar tilt, it is still important clinically to apply the surgical thresholds of 15 degrees of inclination for borderline cases.

The MDC findings from this study are comparable to those previously reported by Mather et al., who identified the MDC of volar tilt to be approximately 6 to 9 degrees in their study on multiple observer reliability. The recommendations put forth by Mather et al. concerning the use of the same observer for serial measurements to accurately assess fracture displacement or reduction loss are supported by the findings of this study. The MDC95 for intraobserver volar tilt measures was significantly lower (3.35 to 6.60 degrees depending on observer) than for interobserver volar tilt, further supporting the reliability of intraobserver comparisons over interobserver comparisons for monitoring fracture healing and/or treatment outcomes.In previous studies, different researchers have looked at whether semi-automated/computerised measuring systems improve reliability compared with traditional methods that use PACS software. A recent paper by Vroemen et al. showed some improvement between observers for volar tilt (0.84) over manual measurements (0.76), but this difference in reliability isn't clinically significant. The researchers concluded that reliability is determined mostly by how accurately the observer can identify and mark a landmark on the imaging slice and not by the accuracy of the angle calculation program. The theoretical basis supports this conclusion, as studies in this area have found that most of the random error in measuring angles on radiographic images originates from Variability in Identifying Volar and Dorsal Articular Rims on Lateral Radiographs, not from errors when drawing an angle between two landmarks.

The Bland-Altman analysis of this study did not show systematic biases between sessions for any observer, which gives us confidence that our measurements are reliable. Systematic biases occur when an observer consistently over- or under-estimates a measurement during multiple evaluations, and are problematic for longitudinal research, as they may lead to an accumulation of error. Because the Bland-Altman plots demonstrated no trend of proportional bias, these measurement procedures could also be appropriate for use in multi-centre clinical trials with repeated assessments. However, there was a wide range of agreement limits for inter-observer comparisons of volar tilt measurements (approximately 17 degrees, from -9.4 to +7.2), demonstrating the necessity for consistency in protocol across multicentThere are a number of limitations of this study that should be noted. The sample was taken from only one facility so although the fracture spectrum from the sample reflects a typical orthopaedic practice, it will not encompass the entire spectrum of radiographic appearance seen in specialty or trauma centres. All of the measurements in this study were made on the same PACS platform, and it is possible that the reliability of the measurements would be different if they were performed using another PACS platform with a different angle measurement system or different display characteristics. The study did not use a validated scoring tool to formally assess the quality of the radiographs; therefore, although the radiographs were all reviewed and unanimously judged acceptable, subtle differences in the manner in which they were positioned could have impacted measurement variability in ways that were not accounted for in this study. In addition, due to the presence of five observers used in this study, the sample size was established to obtain a sufficient level of statistical power to estimate the ICC for the five-rater design; approximately, studies with much more than five observers may yield ICC estimates that are slightly different from the estimates generated in this study. Lastly, the current study was not designed to include measurements derived from 3D CT. CT-derived measurements represent an increasingly available reference standard for the geometry of the distal radius. In the future, CT-derived measurements may totally replace the use of plain radiographs for specific clinical uses.

In spite of its limitations, the strengths of this study include its prospective design; the inclusion of a variety of observers (in terms of specialty and experience levels); the standardized, well-described measurement protocol that was utilised; the minimum four-week washout period between measurement sessions to reduce recall bias; and the extensive statistical analyses performed using both ICC and Bland-Altman methods, as well as the clinically meaningful SEM and MDC values calculated from the data.

In summary, we have confirmed that radial inclination and volar tilt can be measured with good reliability from standard digital wrist radiographs using a standardized measurement protocol, with radial inclination being the most reliable. Volar tilt is more variable than radial inclination (in terms of measurement variability) than radial inclination, especially for interobserver comparisons. Clinical practitioners should be careful when applying critical thresholds based on volar tilt measurements in patient care or when reading results from multiobserver studies; there is measurement error inherent in the volar tilt measurement.

CONCLUSION

The radial inclination measurement taken from posteroanterior digital wrist radiographs was demonstrated as having good to excellent intraobserver and interobserver reliability among all five observers participating in this study (ICCs ranging from 0.87 to 0.95), while volar tilt showed good intraobserver reliability and moderate/good interobserver reliability (with an interobserver ICC = 0.79), and that the limits of agreement between the five observers ranged approximately 17° for the volar tilt measurements. Thus, these findings confirm that volar tilt is more variable than radial inclination, because of the greater sensitivity of the lateral view of a wrist in regards to positional errors and because of the difficulty in locating the volar and dorsal articular rim compared to radial inclination. Observer experience does not adversely affect measurement reliability when using a standardized protocol, and our data indicate that variability from observer experience can be minimised through appropriate training. The MDC95 values of 5.46° for radial inclination and 8.01° for volar tilt, as calculated from the interobserver data, should be recognised when establishing radiographic threshold values for personal management of individual patients and for clinical study design using these parameters as a measure of outcome. It is recommended to use standardized measurement protocols and the same observer for repeat measurements when possible to enhance the clinical relevance of these important parameters measured using radiographs.

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