Observer variability in measurements of carpal bone angles on lateral wrist radiographs

Determinations of carpal bone angles are used in the clinical evaluation of carpal malalignment. Eleven frequently referred radiological measures in lateral projection of the wrists in 23 wrists were assessed using different definitions of axes. Interobserver- and intraobserver variations were calculated. The standard deviation of the interobserver variation ranged from 2.60 degrees to 18.15 degrees, and the intraobserver variation from 1.89 degrees to 4.66 degrees depending on the angles measured. The use of three angles for the least observer variability in assessment of carpal alignment is recommended. These angles were defined from the following carpal bone axes: radius, the line through the center of the medullary canal at 2 cm and 5 cm proximal to the radiocarpal joint; lunate, the line perpendicular to the tangent of the two distal poles; scaphoid, the tangent of the palmar proximal and distal margins, and capitate, the tangent of the dorsal margin of the diaphysis of the third metacarpal bone (substitute axis). (J Hand Surg 1991;16A:893-8.)

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The clinical and radiological diagnosis of carpal instability has received considerable attention in recent years. Often ligamentous disruption demonstrates only subtle changes in radiographs, causing many of these injuries initially to pass undiagnosed. Radiographic lateral projections are essential for evaluation of alignment of the carpal bones. Several authors have described in detail the normal angular relationships in the wrist.[1-7] The range of the angles in normals vary considerably in different studies. This variation might be caused partly by the use of different definitions of the angles measured, and partly by stochastic variation, since the materials used were small. The magnitude of the normal range for a given angle is not caused by

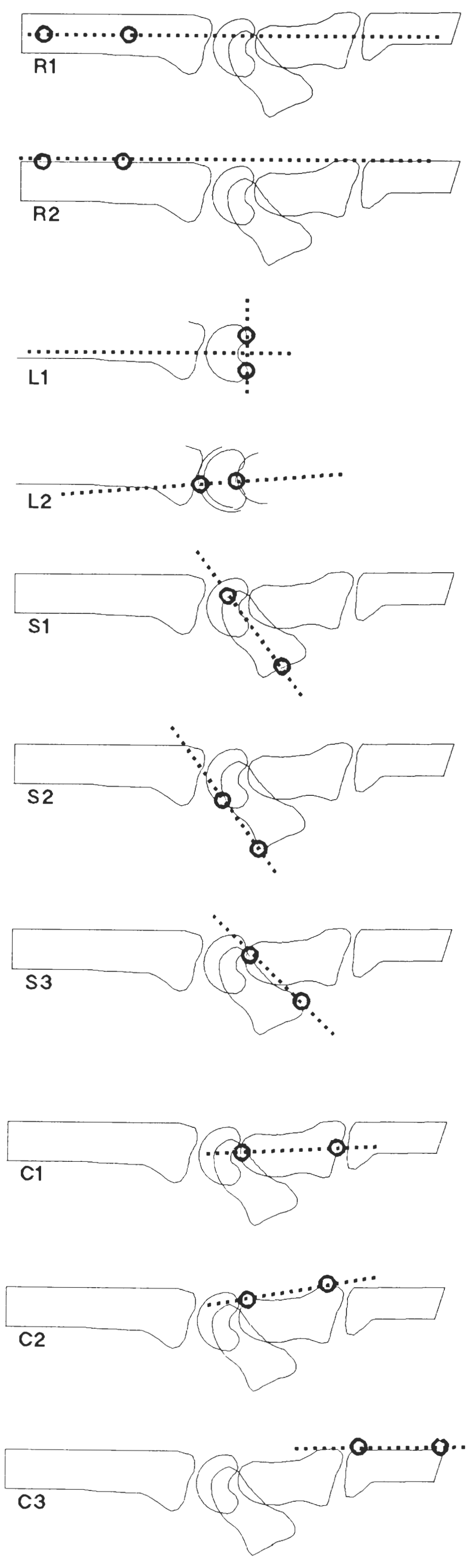

Fig. 1. The definition of the bone axes (refer to text).

biological variation alone, but also by observer variability in the radiographic assessment. Before the radiographic diagnosis of carpal instability can be established, it is important to know whether the small angular changes in carpal instability can be recognized at all with regard to observer variability. Recently Garcia-Elias et al.[8] evaluated the reliability of carpal angle determinations in an experimental study. The interobserver variations encountered in the use of the axial and the tangential methods of drawing carpal axes were reported. Information of intraobserver variation was not given. Furthermore, combinations of the two methods of drawing carpal bone axes might result in a better reproducibility.

The aim of this study was to establish the most reproducible radiographic measurements of the angles between different bones in the wrist by calculating the intraobserver and interobserver variability using different definitions of the angles.

Materials and methods

Patients entered the study consecutively. Entry stopped when 23 patients had met the following criteria: Inclusion criteria: age 18 years and above, closed epiphysial plates, contralateral wrist trauma; and exclusion criteria: history or radiologic evidence of previous injury or infection of the hand, forearm, or elbow, general affection of the skeleton (e.g., metabolic disease); overexposure or underexposure of radiograph; skew projection; less than 7 cm of radius on radiograph, and less than two thirds of third metacarpal bone on radiograph.

Each patient had a radiograph of the healthy wrist taken in lateral projection (zero position).[9] The radiographs were copied, so that there were ten identical radiographs from each patient. The radiographs were marked with the patients' initials and a patient number. Eleven frequently referred radiological measures in the lateral projection of the wrist were assessed using the following definitions of axes (Fig. 1):

1. Axis of radius:
   - R1: The line through the center of the medullary canal at 2 and 5 cm proximal to the radiocarpal joint.
   - R2: The tangent of the dorsal margin of the radius more than 3 cm from the distal articular surface.
2. Axis of the lunate:
   - L1: The line perpendicular to the tangent of the two distal poles.
   - L2: The line through the top points of the proximal convexity and the distal concavity.

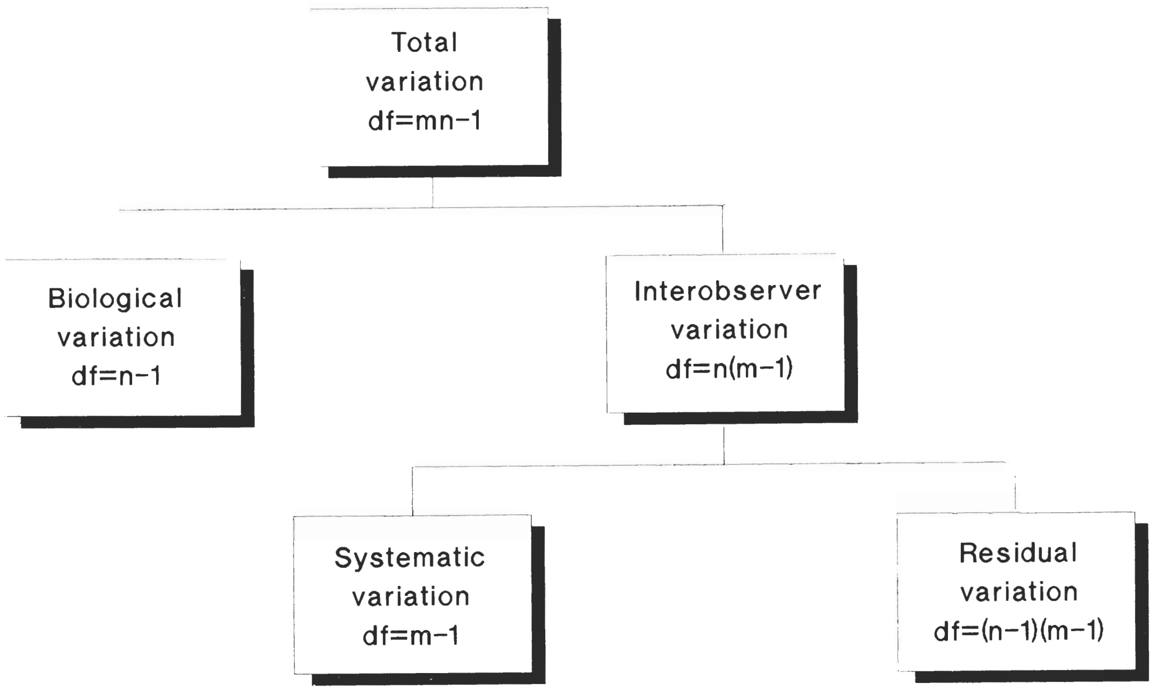

Fig. 2. The split variations resulting from the repeated measurements analysis of variance (refer to text). *df,* Degrees of freedom; *n,* number of patients; *m,* number of observers.

3. Axis of the scaphoid:
   S1: The line through the proximal and distal poles.
   S2: The tangent of the palmar proximal and distal margins.
   S3: The tangent of the dorsal proximal and distal margins.
4. Axis of capitate:
   C1: The line through the proximal and distal poles.
   C2: The tangent of the dorsal proximal and distal margins.
   C3: The tangent of the dorsal margin of the diaphysis of the third metacarpal bone (substitute axis)

Using these definitions of axes, we defined 11 angles: R1L1, R1L2, R1S1, R1S2, R1S3, R1C1, R1C2, R1C3, R2L1, R2S2, and R2C3.

The five observers were all medical doctors with about the same candidate age (average, 9 years) and level of training in orthopaedics and radiology. The observers measured the relevant angles twice (first and second round) from the radiographs using standard plastic goniometers (Protek AG, Bern, Switzerland). Measurements were done in whole degrees. The observers were allowed to draw lines to facilitate the measurements. To avoid recollection the second round was done after a period of 2 weeks. Each observer filled in one form for each round, recording for each patient the patient number, patient initials, and the measurements of the 11 angles. The correspondence between patient

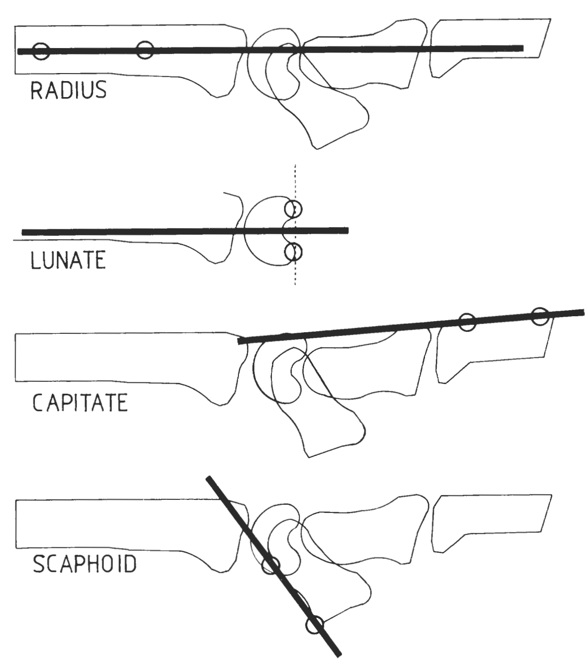

Fig. 3. The recommended four axes for assessment of carpal alignment.

Table I. Interobserver variation: The SD of the various components of variations according to repeated measurements of analysis of variance applied to measurements from the first round

	Total	*Biologic (between patients)*	*Interobserver (within patients)*	*Systematic*	*Residual*
R1L1	5.61	11.49	2.72	2.60	2.73
R1L2	5.96	12.15	2.96	5.00*	2.83
R1S1	6.73	9.99	5.68	18.15*	4.33
R1S2	4.86	10.26	2.01	4.07*	1.87
R1S3	6.47	11.72	4.36	4.11	4.38
R1C1	6.07	12.44	2.95	4.25	2.28
R1C2	7.71	15.38	4.15	5.43	4.08
R1C3	6.14	13.38	2.00	3.91*	1.86
R2L1	5.46	9.64	3.84	6.97*	3.64
R2S2	5.60	10.92	3.23	3.98	3.19
R2C3	6.36	12.99	3.12	8.90*	2.56
Degrees of freedom	114	22	92	4	88

Numbers are SDs expressed in degrees.
*Presence of significant systematic variation among the observers (n = 5 observers).

Table II. Intraobserver variation: The SD of the intraobserver variance calculated from the difference in measurements in the first and second rounds

Angle	*SD*	*SD of difference*	*MRD*
R1L1	2.31	3.26	6.52
R1L2	2.02	2.85	5.70
R1S1	2.67	3.79	7.58
R1S2	1.71	2.42	4.84
R1S3	3.30	4.66	9.32
R1C1	2.21	3.13	6.26
R1C2	3.05	4.31	8.62
R1C3	1.34	1.89	3.60
R2L1	2.58	3.65	7.30
R2S2	2.62	3.71	7.42
R2C3	1.84	2.20	4.40

SD of difference is the standard deviation of the subtraction of two measurements = 2 × SD. Minimal recognizable difference: MRD = 2 × SD of difference.
Degrees of freedom = 115.

number and patient initials were verified on each form after the two rounds. Data were entered into a computer database. A print-out from the database was verified against the original forms, and keying errors were corrected.

Statistical analysis

The *interobserver* variation (Table I) was calculated using the parametric method "repeated measurement analysis of variance"[10] applied to measurements from the first round. The *total variation* (Fig. 2) between all 115 measurements (23 patients assessed by 5 observers) consists of variation between patients *(biological variation)* and variation within patients *(interobserver variation)*. The interobserver variation again is split into the *systematic variation* (expressing the disagreement among observers in the perception of radiologic landmarks and/or rules for measurements) and the *residual variation* (expressing the remaining "unsystematic" variation among the observers). The variance ratio test (F-test) was applied to the systematic variation versus the residual variation to find possible significant *systematic variation* among the observers.

The *intraobserver* variation (Table II) was calculated from the differences between the first and second rounds.

Results

Table I shows the split variation for the 11 angles. The standard deviation (SD) of the interobserver variation ranged from 2.60 degrees to 18.15 degrees and the intraobserver variation from 1.89 degrees to 4.66 degrees depending on the angles measured. The three methods of measuring carpal angles resulting in the least inter- and intraobserver variation were:

R1L1: The interobserver variation (SD = 2.72 degrees) was split into the systematic variation (SD = 2.60 degrees) and the residual variation (SD = 2.73 degrees). The F-test, performed at the 5% level with the systematic variance as the counter with four degrees of freedom and the residual variance as the denominator with 88 degrees of freedom, turned out to be insignificant. The insignificant result of the F-test indicate the lack of systematic variation among the observers. The SD of the intraobserver variation was 2.30 degrees.

R1S2: In this case the systematic variation (SD = 4.07 degrees) was significantly greater than the residual variation (SD = 1.87 degrees), indicating the presence of systematic disagreement among the observers. This means that two observers measuring R1S2 might get different results, but they would both be able to measure the difference from the contralateral healthy side within $\pm 2 \times 1.87$ degrees = 3.74 degrees (SD) provided the two sides were identical before the trauma. This is further confirmed by the low intraobserver variation (SD = 1.44 degrees).

R1C3: As with the R1S2, the systematic variation (SD = 3.91 degrees) was significantly greater than the residual variation (SD = 1.86 degrees), indicating systematic disagreement among observers. The consistency of the method is high, indicated by the low intraobserver variation (SD = 1.34 degrees).

The angle R2S2 would be an alternative to R1S2, showing a lower and insignificant systematic variation (SD = 3.98 degrees). However, the lack of systematic variation is at the expense of a higher residual variation (SD = 3.19 degrees) and intraobserver variation (SD = 2.62 degrees).

Discussion

Several studies describe the use of angular measurements in order to evaluate carpal instability and the results of treatment. The consequences of incorrect measurements depend on the purpose for which they are used, e.g., whether diagnostic, prognostic, or otherwise.

Garcia-Elias et al.[8] have evaluated and compared the interobserver variations encountered in the use of two methods of carpal angle determination. The study was based on an experimental analysis of three fresh-frozen human cadaveric wrists of which one wrist had a serious carpal malalignment. No information on the positioning of the specimens was given, except that they were placed in neutral rotation. Standardized positioning and radiographic technique has been recommended by several authors,[9, 11] and the reproducibility and variability of these measurements should be evaluated under such circumstances. In their study Garcia-Elias et al.[8] evaluated the axial and the tangential method of carpal bone angle determination. Definitions and tracings of the axes were given in detail for the lunate, the capitate, and the scaphoid, but no information was given to define the axis of the radius used in all measurements. Statistical difference between the two methods with respect to interobserver variation could not be demonstrated.

In our study combinations of the two methods were evaluated. The angles having the least observer variability were defined from the tangential axes of the lunate, the scaphoid, and the third metacarpal bone (substitute axis for the capitate) in combination with the axis through the center of the radius. Some methods showed systematic variation among the observers, indicating that the observers had different perceptions of the radiological landmarks used for establishing the lines. Possible explanations could be that tangential profiles of the carpal bones are better landmarks than the axial contours of the carpal bones as they are often overlapping. The tracings become even more difficult in poor radiographs or in patients with decreased bone density.[8]

The intraobserver variation has not been evaluated before. The "best" method would have both low intra- and interobserver variation. However, a low intraobserver variation is of importance in the case of carpal instability since the difference in angles between the healthy and the injured side is judged by one observer only. Perhaps the most often used method for determining the scapho-lunate angle (R1S1) has an SD of 5.68 degrees of interobserver variation and a significant and high systematic variation (SD = 18.15 degrees) as well. With use of this method the observer has to record a difference of more than 7.58 degrees (Table II) between the injured and the uninjured wrist to be sure that the difference really exists. Nakamura et al.[5] reported the results of measuring carpal angles in both normal and pathological wrists. They based their measurements on the angles R2L1, R2S2, and R2C3 requiring a difference of 7 degrees or more as minimal recognizable difference (Table II). If the axes recommended in the present study are used for carpal angle determination, a difference of more than 5 degrees between the injured and the uninjured wrist can be considered as significant. This observation alone might not have any clinical relevance, but it is a useful indication of the need for further radiographic evaluation. In such cases an imaging algorithm has been suggested[12] including fluoroscopy and instability series.

Our results were obtained from very dedicated observers who knew that their measurements were recorded and analyzed. In daily clinical practice, a higher observer variation is to be expected. The need for detailed definition of axes used when reporting the results of measurements of carpal bone angles on lateral wrist radiographs is essential. Radiographic examination for the classification of abnormal alignments needs standardization. Use of the same methods for determining carpal bone angles preferably with the least inter- and intraobserver variation would be an important step.

Conclusion

The definitions of axes used should always be given in detail when reporting data including carpal angles. We recommend the use of three angles for the least observer variability for assessment of carpal alignment. These angles are defined from the carpal bone axes (Fig. 3): (1) radius: the line through the center of the medullary canal at two and five cm proximal to the radiocarpal joint; (2) lunate: the line perpendicular to the tangent of the two distal poles; (3) scaphoid: the tangent of the volar proximal and distal margins; (4) capitate: the tangent of the dorsal margin of the diaphysis of the third metacarpal bone (substitute axis).

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