Distinct Wrist Patterns Founded on Measurements in Plain Radiographs

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Abstract

Background In joints, structure dictates function and consequently pathology. Interpreting wrist structure is complicated by the existence of multiple joints and variability in bone shapes and anatomical patterns in the wrist. Previous studies evaluated lunate and capitate shape in the midcarpal joint, and two distinct patterns have been identified.

Purpose Our purpose was to further characterize the two wrist patterns in normal wrist radiographs using measurements of joint contact and position. Our hypothesis was that we will find significant differences between the two distinct anatomical patterns.

Patients and Methods A database of 172 normal adult wrist posteroanterior (PA) radiographs was evaluated for radial inclination, height, length, ulnar variance, volar tilt, radial-styloid-scaphoid distance, and lunate and capitate types. We measured and calculated percent of capitate facet that articulates with the lunate, scapholunate ligament, scaphoid, and trapezoid. These values were compared between the wrist types and whole population.

Results Type-1 wrists (lunate type-1 and spherical proximal capitate) were positively associated with a longer facet between capitate and distal lunate ($p = 0.01$), capitate and base of middle metacarpal ($p = 0.004$), and shorter facet between the capitate and hamate ($p = 0.004$). The odds ratio of having a type-1 wrist when the interface between the capitate and lunate measures >8.5 mm is 2.71 (confidence interval [CI] 1.07, 6.87) and when the line between the capitate and the base of middle metacarpal >9.5 mm is 3.5 (CI 1.38, 9.03).

Conclusion We characterized the two-wrist patterns using intracarpal measurements. Translating these differences into three-dimensional contact areas may help in the understanding of biomechanical transfer of forces through the wrist.

Level of Evidence This is a Level II, diagnostic study.

Keywords
- bony anatomy
- biomechanics
- patterns
- shape
- wrist

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Anatomical structure affects function in all fields of medicine.[1] In articulations, the morphology dictates the way forces travel through the joint.[2,3] Though much is known about the structure and function of joints such as the knee and ankle, the functional anatomy of the wrist joint remains incompletely understood. This difficulty arises from the complexity of the joint; the fact that it is composed of multiple joints with complex ligamentous structures, and the relative importance of the ligamentous structures in the wrist to the biomechanics and function of the joint.[4] As in other joints, a better understanding of the structure and function of the wrist will enhance our ability to diagnose and treat wrist conditions.

The structural complexity of the wrist is further increased by variability between wrists in regards to the bony shape of the joints.[5,6] It is likely that these morphological patterns provide the basis for the different biomechanical behaviors of different wrists.[7] Some studies have evaluated this anatomic variability in the midcarpal joint.[8] In a pilot study, Kramer et al evaluated 70 normal posteroanterior (PA) radiographs. They found a significant relationship between the shapes of the distal capitate and proximal lunate. Based on this observation, they described two wrist morphologic types centered on the shape of the midcarpal joint.[9] These were described as wrist type 1 that included a spherical proximal capitate paired with a type 1 lunate as described by Nakamura et al.[10] The wrist type 2 included a flat-shaped proximal capitate paired with a lunate type 2 described by Nakamura et al.[10]

Assuming that the difference in morphological wrist type would entail associated differences in joints outside of the midcarpal joint, the purpose of this study was to further describe these two wrist patterns using measured radiographic parameters in the carpus, but outside of the midcarpal joint. We hypothesized that we will find measured differences between the two distinct anatomical patterns with radiologic measurements independent of the midcarpal joint.

Patients and Methods

Database

A database consisting of normal wrist PA and lateral radiographs was created. Though we evaluated the lateral radiograph to determine the absence of pathology, we performed measurements only on the PA radiographs. Only those radiographs that were read by the radiologist as “normal” were eligible to be included. These radiographs underwent further evaluation by two hand surgeons for general quality and the quality of wrist positioning. Out of 235 radiographs read as “normal” by our radiologists, 172 radiographs were included in the database after secondary evaluation.

Exclusion Criteria

- Radiographs of individuals under the age of 18.
- Radiographs that despite a “normal” interpretation had pathology such as early degenerative changes or nondisplaced fractures.
- Radiographs that were not true lateral or PA according to the criteria proposed by Koh et al.[11]

Inclusion Criteria

The radiographs were performed according to Hardy et al: the PA radiograph is performed with the shoulder abducted 90 degrees from the trunk and the elbow flexed at 90 degrees with the ulna perpendicular to the humerus and forearm in a fully pronated position. The wrist is in neutral position. The hand should be palm down on the cassette with the fingers extended.[11] The lateral view is obtained with the elbow flexed to 90 degrees and adducted against the trunk. The forearm is mid-prone, and the wrist should be in the neutral position such that, in the resulting radiograph, a straight line can be drawn through the axes of radius, lunate, capitate, and third metacarpal, or they should be coaxial within 10 degrees.[12]

Institutional review board (IRB) approval was obtained prior to the study commencement. Data regarding age, gender, and side were collected. Age was just collected to include only adult (over the age of 18) radiographs.

Radiographs were evaluated for the following:

- Radial inclination: Radial inclination is the angle between the long axis of the radial shaft and a line connecting the tip of the radial styloid with the ulnar corner. This is measured in degrees.
- Radial height: Radial length is measured on the PA radiograph as the distance between one line perpendicular to the long axis of the radius passing through the distal tip of the radial styloid and a second line that intersects the distal articular surface of ulnar head. This was measured in millimeters.
- Ulnar variance: Ulnar variance is described as ulna plus, minus, or neutral. The difference in axial length between the ulnar corner of the distal radius and the most distal extent of the ulnar head is measured in millimeter difference, but was described as ulna positive, negative, and neutral.
- Volar tilt: The angle formed between a perpendicular to the longitudinal axis of the radial shaft and a line formed by connecting the apex of the volar and dorsal rim. This was measured in degrees.[13]
- Radial styloid to scaphoid gap: d2/w2 was measured according to the study by Wollstein et al.[14] Three scaphoid location measurements (d) were made between the ulnar volar border of the radial styloid and the radial volar border of the scaphoid (parallel cortical surfaces of the radial styloid and scaphoid). The first point was measured at the level of the tip of the styloid (defined as d1), the second from the scaphoid base (defined as d3), and the third was a point half way in between these points (defined as d2). The scaphoid location measurements made between the ulnar border of the radial styloid to the radial border of the scaphoid were normalized by the width (w) of the scaphoid at the level of the scaphoid location measurements. The width was defined as w2 to correspond to d2. All of these parameters were measured

in the coronal plane perpendicular to the long axis of the radius. The proportion d2/w2 was calculated.[15]

Since multiple studies have found that measurements on plain radiographs did not always reflect true three-dimensional morphology, we utilized some reference lines that could possibly be used in later three-dimensional imaging for comparison[16] (►Fig. 1).

- Line of reference 1: A continuation of the line of the anatomical axis of the distal radius into the metacarpals (three points in the middle of the radial shaft).
- Line of reference 2: A continuation of the anatomical axis of the index metacarpal (three points in the middle of the shaft in its narrowest area).
- We measured the angle α between lines 1 and 2. Since this angle could depend on radial-ulnar deviation, we relied on our initial assessment of the radiographs of neutral radioulnar deviation.
- Line of reference 3: A line was drawn perpendicular to the horizontal line (horizontal to the page) used for ulnar variance and radial height that passes through the volar (anterior) ulnar corner of the radius on a PA view.
- Lunate type was classified according to the shape of the midcarpal articulation.[17]
    - Type 1: Without a facet for the hamate bone.
    - Type 2: With a clear facet for the hamate bone.

After reviewing numerous normal radiographs of the wrist bones we found it was not practical to categorize the capitate bone into a spherical, flat- or V-shape as described by Yazaki et al in their cadaver study.[18] Mclean et al found that capitate type was most accurately determined from coronal magnetic resonance imaging (MRI).[12,19] However, we felt that we could distinguish between lunates type 1 and 2 as well as flat and spherical capitates within the midcarpal joint on plain radiographs.

- Capitate type (spherical or flat), looking at the proximal facet only, spherical was classified as type 1 and flat shaped as type 2.
  A wrist type 1 was defined as having a lunate type 1 and a spherical proximal capitate (►Fig. 2). A wrist type 2 was defined as having a lunate type 2 and a flat proximal capitate (►Fig. 3).
- To try and identify spatial relationships between the shapes of the midcarpal joints and the surrounding bones, we measured how much of the lunate (%) is ulnar to the line that was drawn perpendicular to the horizontal line used for ulnar variance and radial height that passes through the volar anterior ulnar corner of the radius on a PA view (reference line 3). This was performed using the average of the proximal and distal surfaces: the distance from line of reference[3] and the proximal surface (measured at the radiocarpal joint) and the distance from line of reference [3] and the distal cortex (within the midcarpal joint) were averaged (►Fig. 4).

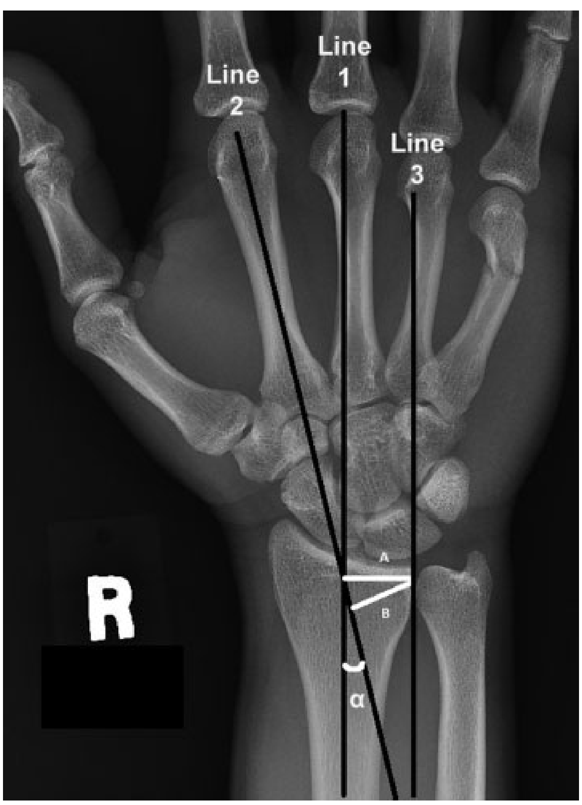

Fig. 1 Lines of reference 1, 2, and 3 (1 and 2: continuation of the index metacarpal anatomic axis and the distal radius axis) and the angles between lines 1 and 2. Line of reference 3 is the line drawn perpendicular to the horizontal line (horizontal to the page) used for ulnar variance and radial height that passes through the volar (anterior) ulnar corner of the radius on a PA view. Alfa (α) designates the angle between the two lines of reference. Angle AB = α (perpendicular to 1 and 2). PA, posteroanterior.

Fig. 2 A posteroanterior radiograph of a wrist type 1. Wrist type 1 consists of a lunate type 1 and a spherical proximal capitate.

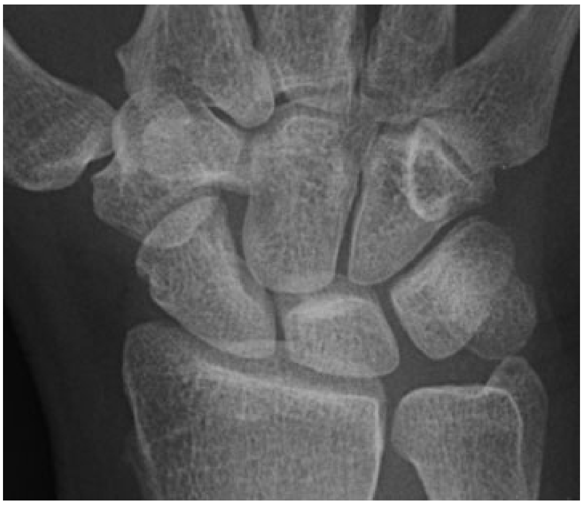

Fig. 3 A posteroanterior radiograph of a wrist type 2. Wrist type 2 consists of a lunate type 2 and a flat proximal capitate.

Fig. 4 Measurement of percent lunate ulnar to line of reference 3 (B). An extension of line of reference 3 in ►**Fig. 1** is marked by the letter B. The distance from the proximal surface (measured at the radiocarpal joint) and the distance from line of reference 3 and the distal cortex (within the midcarpal joint) are averaged and divided by the width of the lunate to give a percentage. Line B and C/line A–C.

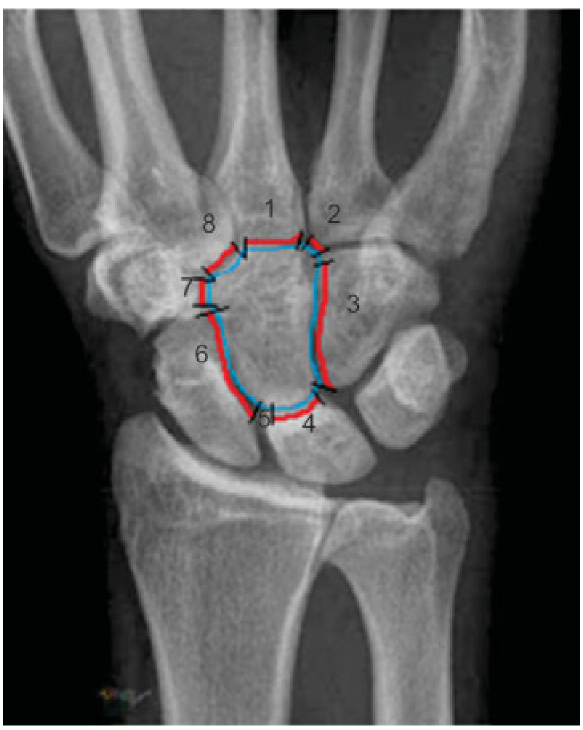

Fig. 5 A posteroanterior radiograph of a wrist with capitate circumference measurements. 1: Portion of the capitate circumference that comes in contact with the base of the middle metacarpal line. 2: Portion of the capitate circumference that comes in contact with the capitate ring metacarpal line. 3: Portion of the capitate circumference that comes in contact with the capitate hamate line.
4: Portion of the capitate circumference that comes in contact with the capitate lunate line. 5: Portion of the capitate circumference that comes in contact with the capitate scaphoid-lunate ligament line.
6: Portion of the capitate circumference that comes in contact with the capitate scaphoid line. 7: Portion of the capitate circumference that comes in contact with the capitate trapezoid line. 8: Portion of the capitate circumference that comes in contact with the capitate index metacarpal line.

- Percent capitate ulnar to this line (reference line 3) was also evaluated. If the capitate and or lunate were completely radial to this line, the distance of the ulnar-most border of the bones to this line was measured in millimeter. This was performed using the anterior border as seen on the PA view. This distance (mm) may provide information about the position of the carpus relative to the radius.
- The circumference of the capitate was measured using the outer cortical surface. (►**Fig. 5**, sum of all line segments).
- Percent of the circumference of the proximal capitate facet that articulates with the lunate was measured (►**Fig. 5**, segment 4 divided by the sum of all line segments).
- Percent (capitate circumference) that comes in contact with the scapholunate ligament (►**Fig. 5**, segment 5 divided by the sum of all line segments).
- Percent (capitate circumference) that articulates with the scaphoid (►**Fig. 5**, segment 6 divided by the sum of all line segments).
- Percent (capitate circumference) that articulates with the hamate (►**Fig. 5**, segment 3 divided by the sum of all line segments).
- Percent (capitate circumference) that articulates with the trapezoid (►**Fig. 5**, segment 7 divided by the sum of all line segments).
- Percent (capitate circumference) that articulates with the base of the index and middle and ring metacarpal bones (►**Fig. 5**, segment 8&1 divided by the sum of all line segments).

All measurements were made using the PACs Carestream Version 11.0 computer program.

Statistical Analysis

Statistical analysis included chi square and *t*-test. The Wilcoxon rank-sum test was used for categorical outcome measures. Logistic regression was used to evaluate the association of the different parameters with the two types of wrist patterns described (type 1 and type 2). A *p* value of $\leq$0.05 was considered significant. We did not include the non-classified wrist types in the analyses that examined wrist type.

Results

One hundred and seventy-two plain PA wrist radiographs were included in the study. There were 70 (41%) spherical-capitates and 102 (59%) flat-type capitates. There were 102 (59%) lunates type 1 and 70 (41%) lunates type 2. We had 49 wrist types 1 and 49 wrists type 2. The remainder of the radiographs were not classified according to our criteria into wrists type 1 or 2 (either they did not have the correct pairing of lunate and capitate type, or we felt that we were unable to definitively determine structure). Of those not classified due to difficulty in determining shape, only 3/30 radiographs were lunate types that were difficult to identify, and the rest (27/30) were indeterminate proximal capitate shapes.

There were 82 male radiographs and 90 female radiographs. There were 100 right side radiographs and 72 left hands. Gender and the side of the hand were not associated with our two wrist types.

Measurements that are related to the radiocarpal joint: volar tilt, radial height, ulnar variance radial inclination, and distance between the radial styloid and the radial scaphoid border were similar to values in the literature and were not found to be related to wrist type.[13,14,20]

There was no difference in capitate circumference between the two wrist types and as compared with the group without the classifiable wrist type. There was a significant association between capitate circumference and the distance of the capitate in millimeter (ulnar most border) to the line of reference 3 (line that was drawn perpendicular to the horizontal line used for ulnar variance and radial height that passes through the volar anterior ulnar corner of the radius on a PA view) $p = 0.03$ and to the distance between the lines 1 and 2—the anatomical axis of the radius and the index metacarpal $p = 0.000$.

There was no difference between the wrist types in regards to the angle α between lines of reference 1 and 2, $p = 0.23$. There was a negative correlation ($p = 0.008$, $r = 0.27$) between the angle between the two lines 1 and 2 (radius anatomic line and third metacarpal) and the capitate circumference. We did not find any relationship between the d2/w2 measurement and this angle—neither in the total group and nor within each group type. There was no association between this angle and radial inclination.

Within the wrist type 1 group, there was a significant association between d2/w2 and the distance to the metacarpal line (line 2) and to radial inclination. There was a significant association between radial inclination and the distance between the lunate and lines 1 and 2. There was a significant relationship between radial inclination and d2/w2 and radial inclination $p = 0.02$.

The significant associations between intracarpal measurements and the wrist types as compared with the unclassified radiographs (those radiographs that were not classified as type 1 or 2) are described (►**Table 1**). These include the amount of contact between the capitate and the lunate, capitate, and hamate and capitate and base of middle metacarpal. ►**Table 2** describes the associations between the measurements and the two wrist types. We found significant relationships between wrist types in regards to the length of the capitate circumference contacting the lunate and carpometacarpal joint of the middle finger. The mean relative length of lunate capitate facets was longer by 10.8% in wrist type 1 when compared with type 2 (type 1, 9.0 mm and type 2, 8.1 mm), the carpometacarpal (CMC)3-capitate facet was longer in type 1 when compared with type 2 by 12.8% (type 1, 10.0 mm and type 2, 8.9 mm).

Logistic regression was performed using the four independent variables that were found to be significantly associated with wrist type: capitate-lunate facet length, percentage of capitate contacting the lunate, the length of the capitate with the base of the middle metacarpal, and the percent capitate circumference contact with the hamate (►**Table 3**). The odds ratio of having a type-1 wrist when the interface between the capitate and lunate measures $>$8.5 mm is 2.71 (CI 1.07, 6.87) and when the line between the capitate and the base of middle metacarpal $>$9.5 mm is 3.5 (CI 1.38, 9.03) (►**Table 3**).

Discussion

In this study, we evaluated a database of normal wrist radiographs in an attempt to further describe the two distinct patterns based on the evaluation of the midcarpal joint.[7,9] This study supports a wrist type 1 pattern that includes a longer contact area between the lunate and capitate as well as more contact between the capitate and the base of the middle metacarpal. The type 2 pattern includes a contact area between the lunate and the hamate, as well as less contact between the capitate and the lunate, capitate and base of middle metacarpal, and more contact between the capitate and hamate. . Assuming that our two-dimensional measurements translate into corresponding three-dimensional contact areas, forces acting on the wrist during different tasks would be transferred differently through the distinctive wrists. Bain et al found that during wrist flexion and extension, the relative contributions to movement of the radiocarpal and midcarpal joints were determined by lunate morphology. They found that the midcarpal joints were relatively restricted during flexion and extension of a type II lunate.[21] This study may support transfer of mechanical forces in type 2 wrists less through the carpometacarpal joint of the middle finger (CMC3)-capitate-lunate axis and more through an alternative axis of either CMC joint of the ring finger CMC4-hamate, or CMC2-trapezoid-scaphoid.

Table 1 Comparison of wrist types to rest of group (wrists that were not classified into types 1 or 2)—intracarpal measurements

	Total $N = 172$	First comparison			Second comparison		
		Type 1 $N = 49$	Other than type 1 and 2 $N = 123$	*p*1 value	Type 2 $N = 49$	Other than type 1&2 $N = 123$	*p*2 value
Length capitate circumference contacting lunate in mm (SD) [median]	8.61 (2.06)	9.01 (2.19) [8.65]	8.46 (1.99) [8.3]	0.117	8.13 (2.35) [7.49]	8.81 (1.91) [8.65]	0.049
Length capitate circumference contacting hamate in mm (SD) [median]	18.83 (2.64)	18.21 (3.22) [18.45]	19.09 (2.33) [18.9]	0.049	18.98 (2.08) [18.75]	18.77 (2.84) [18.89]	0.647
Length capitate circumference contacting base M3 (CMC 3) in mm (SD) [median]	9.43 (1.60)	9.96 (1.36) [10.06]	9.22 (1.65) [9.22]	0.006	8.92 (1.54) [8.82]	9.64 (1.59) [9.81]	0.008
%Length capitate circumference contacting hamate% (SD) median	26.96 (3.11)	27.73 (4.00) [28.01]	27.44 (2.53) [27.48]	0.001	25.78 (2.30) [26.3]	26.65 (3.34) [26.84]	0.041
%Length capitate circumference contacting base M3 (CMC 3) (SD) median	13.49 (2.05)	12.99 (2.08) [13.05]	13.22 (1.98) [13.26]	0.007	14.16 (1.84) [14.1]	13.69 (2.10) [13.7]	0.042

Abbreviations: CMC 3, carpometacarpal joint of the third (long) finger; M3, base of third metacarpal bone; M, metacarpal bone; mm, millimeters; SD, standard deviation; total, values for the group as a whole.
Note: Only the significant relationships are documented in this table.
*p*1 values compare wrists type 1 to wrists that were not classified as type or 2. *p*2 values compare type 2 wrists to wrists that were not classified as type or 2.

We did not find any significant differences between the two wrist types in respect to the more radial area of the wrist (the scapho-trapezoid-trapezial (STT)-scaphoid joint and second metacarpal base). It is possible that we did not take the correct measurements. For example, we did not evaluate the STT joint shape or length and perhaps; these do differ between the wrist types. Bain et al found that the type of motion the wrist made predicted the transfer of forces. It is possible that despite no significant difference in our measurements, during different tasks and therefore different positions and motions, each wrist type will behave differently.[21,22]

We found differences between the two wrist types in regards to the relative position of the center of the carpus —in the capitate–to the radius (distance to lines of reference). These findings taken together may be in tandem with a transfer of forces that is more medial in a type 2 wrist as compared with a type 1 wrist. There was also a negative correlation ($r = 0.03$) between the angle between reference lines 1 and 2 and the capitate circumference (bigger bone – smaller angle/straighter wrist) which might imply that the natural position of the hand relative to the forearm is influenced by the bony anatomy of the wrist bones.

The different range of facet segmentations of the capitate bone as well as other parameters, such as the position (the relative ulnar position) of the bone and its relative size in the wrist, can define a spectrum of wrist types with the type 1 wrist on one end of the spectrum: a round proximal capitate, straight angle relative to the radius which "pushes" the hamate ulnarly allowing the hamate no articulation with the lunate, and on the other end of the spectrum, the type 2 wrist with a flat distal capitate, its distal part positioned ulnarly which allows the hamate to be more centrally located and articulate with the lunate.

Rhee et al demonstrated that a lunate type 2 in the midcarpal joint is inversely related to dorsal intercalated instability (DISI) in the presence of a scapholunate tear.[7] They surmised that a type 2 lunate is more stable than a type 1 within the midcarpal joint. Our results support this theory since there seems to be less contact in the midcarpal joint, but more contact in the surrounding joints in type 1 wrists (more contact with the base of the middle metacarpal and a larger capitate lunate interphase). In another study, they found that lunates type 1 had a higher scapholunate angle—again indicating increased instability as compared with wrists with a lunate type 2.[8] Our findings also support another finding of this study where they found lunate type 2 to be associated with less severe Kienbock's disease and a lower incidence of coronal fractures of the lunate. This study evaluated 106 wrists, of which 75 (71%) were type 1, and 31 (29%) were type 2 lunates.[8] Type 1 wrists in our study were found to be associated with greater contact between the capitate and lunate as well as more contact between the base of the third metacarpal and the capitate. This could constitute a direct line of force transmission that preferentially loads the lunate during functional tasks leading to an increased tendency toward Kienbock's disease and fractures of the lunate.

Table 2 Radiographic intracarpal measurements—comparison between wrist types

			Comparison of Type 1 and 2		p-Value
	Total (N = 172)	Defined wrist types (N = 98)	Type 1 wrist (N = 49)	Type 2 wrist (N = 49)	
Capitate circumference (mm): Mean (SD) {median}	70.06 (6.83) {70.40}	69.19 (8.85) {70.48}	70.72 (6.45) {70.82}	67.65 (10.57) {69.60}	0.086
Length capitate circumference with lunate (mm): Mean (SD) {median}	8.64 (2.06) {8.54}	8.57 (2.31) {8.31}	9.01 (2.19) {8.65}	8.13 (2.36) {7.49}	**0.013**
Length capitate circumference with hamate (mm): Mean (SD) {median}	14.85 (2.76) {14.69}	18.6 (2.73) {18.67}	18.21 (3.22) {18.45}	18.98 (2.09) {18.75}	0.162
Length capitate circumference with trapezoid (mm): Mean (SD) {median}	6.64 (1.76) {6.55}	6.53 (1.81) {6.48}	6.59 (1.99) {6.48}	6.48 (1.63) {6.50}	0.77
Length capitate circumference with base M2 (CMC 2) (mm): Mean (SD) {median}	4.27 (1.31) {4.31}	4.17 (1.23) {4.25}	4.32 (1.25) {4.32}	4.03 (1.21) {4.10}	0.24
Length capitate circumference with base M3 (CMC 3) (mm): Mean (SD) {median}	9.43 (1.6) {9.41}	9.44 (1.54) {9.28}	9.96 (1.36) {10.06}	8.92 (1.55) {8.82}	**0.001**
Length capitate circumference with base M4 (CMC 4) (mm): Mean (SD) {median}	3.01 (1.49) {2.94}	2.94 (1.47) {2.71}	2.88 (1.52) {2.70}	2.99 (1.44) {2.78}	0.72
Length capitate circumference with scaphoid (mm): Mean (SD) {median}	18.84 (2.63) {18.87}	14.9 (2.75) {14.76}	15.18 (2.63) {15.2}	14.63 (2.87) {14.6}	0.33
Length capitate circumference with scapholunate (mm): Mean (SD) {median}	1.71 (1.07) {1.70}	1.62 (1.13) {1.61}	1.73 (1.09) {1.70}	1.52 (1.18) {1.54}	0.39
% Length capitate circumference with lunate: Mean (SD) {median}	12.34 (2.71) {12.15}	12.3 (3.02) {11.74}	12.73 (2.83) {12.14}	11.86 (3.17) {11.12}	0.16
%Length capitate circumference with hamate: Mean (SD) {median}	26.95 (3.09) {27.19}	26.75 (3.39) {27.28}	25.78 (4.00) {26.03}	27.73 (2.30) {28.01}	**0.004**
% Length capitate circumference with trapezoid: Mean (SD) {median}	9.54 (2.63) {9.32}	9.42 (2.63) {9.12}	9.32 (2.72) {8.97}	9.52 (2.55) {9.37}	0.7
% Length capitate circumference with base M2 (CMC 2): Mean (SD) {median}	6.14 (1.93) {5.85}	6.05 (1.91) {5.81}	6.15 (1.88) {5.86}	5.94 (1.95) {5.64}	0.58
% Length capitate circumference with base M3 (CMC 3): Mean (SD) {median}	13.48 (2.04) {13.43}	13.58 (2.04) {13.37}	14.16 (2.08) {14.10}	12.99 (1.84) {13.04}	**0.004**
%Length capitate circumference with base M4 (CMC 4): Mean (SD) {median}	4.28 (2.03) {4.16}	4.21 (2.07) {3.94}	4.1 (2.18) {3.94}	4.32 (1.96) {4.03}	0.61
%Length capitate circumference with scaphoid: Mean (SD) {median}	21.20 (3.31) {21.36}	21.39 (3.27) {21.61}	21.45 (3.06) {21.92}	21.32 (3.50) {21.51}	0.84

Abbreviations: mm, millimeters; SD, standard deviation; total, values for the group as a whole.
Note: Ulnar variance was measured in millimeters and was either negative or positive. Bold p-Values are statistically significant.

Table 3 Multivariable logistic regression model analysis to predict wrist type

	Type 1 wrist $n = 49$	Type 2 wrist $n = 49$	*p*-Value	Odds ratio (95% CI)
Capitate circumference lunate[a]				
≤ 8.5 mm	18 (36.7%)	32 (65.3%)		2.71
> 8.5 mm	31 (63.3%)	17 (34.7%)	0.036	(1.07, 6.87)
Capitate circumference middle metacarpal (CMC3)[b]				
≤ 9.45 mm	18 (36.7%)	34 (69.4%)		3.53
> 9.45 mm	31 (63.3%)	15 (30.6%)	0.008	(1.38, 9.03)
Capitate circumference % hamate[c]				
≤ 27%	30 (61.2%)	12 (24.5%)		0.2
> 27%	19 (38.8%)	37 (75.5%)	0.001	(0.08, 0.50)

Abbreviation: CMC, carpometacarpal joint.
Note: We used a logistic regression model with stepwise procedures to assess the association between the significantly associated parameters and wrist type.
The independent parameters were categorized into to two levels using the mean of each parameter. Both the lengths of the contact areas as measured in millimeters and the percent capitate circumference (%) were significantly associated with wrist type. Percent circumference measurements were more significantly associated with wrist type and were therefore used in this analysis.
[a]Occurrence of capitate circumference in contact with the lunate.
[b]Occurrence of capitate circumference in contact with the base of the middle metacarpal.
[c]Occurrence of capitate circumference in contact with the hamate bone.

A significant limitation of the study is that we used two-dimensional radiographs and not three-dimensional imaging. Plain radiographs were used since they are routinely obtained for imaging of the wrist so even though three-dimensional evaluation is closer to the true anatomical form, patterns can be clinically identifiable and useful for the clinician. Another reason for use of plain radiographs is that at our institution, very few normal wrists are sent for three-dimensional imaging, making it difficult to build a large database of normal wrist images.

Nonetheless, the next step in this study will be to evaluate the three-dimensional correlates of our two-dimensional measurements. Multiple studies have shown that three-dimensional imaging of carpal bones is closer to assessment of structure in cadavers and surgery.[23–26] Despite multiple studies looking at three-dimensional imaging, a recent study by Niacaris et al found that three-dimensional imaging did not improve on plain radiographs in the evaluation of capitate type.[27] We believe this step (translation of our findings into three-dimensional contact areas) is critical to understand the mechanics of the joint.

We found that most of the radiographs could be classified as wrist types 1 or 2. However, there was a large number of radiographs that could not be classified. These were radiographs in which the proximal capitate was not completely spherical or not completely flat, lunates with minimal facet with the hamate, etc. This was especially apparent regarding the proximal capitate shape. It is possible that this "side" of the midcarpal joint is less characteristic of wrist type or may actually develop with time and degeneration based on the shape of the distal lunate. We believe that there is a continuum of morphology. More study will need to be done to provide cutoff points that have mechanical significance. We also found that the "classifiable" wrist radiographs differed from the "nonclassifiable" wrists in the same parameters that distinguished between the two wrist types. This perhaps emphasizes that these areas are particularly variable between normal wrists. As stated, three-dimensional correlations will need to be done and may provide information that can assist in the uncovering of true structure and its mechanical significance.

The main limitations of this study stem from the use of plain radiographs to try and identify anatomical patterns. The importance of correlating these two-dimensional measurements with three-dimensional imaging has already been discussed. Other limitations include the lack of uniformity in the definition of the shapes of the bones and despite the use of a computerized system for measurements, the difference between observers in drawing and positioning of the lines.

In summary, this study is only a first step toward understanding anatomical/structural variations in the wrist. Appreciation of morphological patterns will aid in our understanding of the kinematics and transfer of forces through the wrist, consequently improving our understanding of the development of wrist pathology. This in turn may expand our ability to diagnose and treat different wrist conditions. Much study still needs to be done to better understand the mechanics of the wrist and to apply this understanding into clinical practice.

Note

Institutional review board approval was obtained prior to the study commencement. The study was performed at the Technion Israel Institute of Technology.

Conflict of Interest
None.

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