ORIGINAL COMMUNICATIONS

Relative motion of selected carpal bones: A kinematic analysis of the normal wrist

The relative motion of selected carpal bones and the radius was studied using five cadaver specimens labeled with metal markers to precisely quantify their motions. Data was obtained by means of a combination of orthoradiography, sonic digitization, and computer analysis. We conclude that the wrist functions as two carpal rows with the distal row bones relatively tightly bound to one another and the proximal row bones less so but still moving together. Therefore, we theorize that the proximal row functions as a variable geometry intercalated segment between the distal row and the radius-triangular fibrocartilage. (J HAND SURG 1988;13A:1-10.)

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The study of wrist motion, both normal and pathologic, has interested investigators since the middle of the 19th century. Before 1895, investigations consisted of direct visualization of the carpus, since indirect methods were not available. In 1896, Bryce reported the first radiologic study of a colleague’s hand, and Johnson, Fisk and others studied wrist motion with x-ray examination. Recently, computer analysis has been used to increase the accuracy and precision of measurements of wrist motion.

Although some of the recent authors have studied individual carpal motions, none except Delange et al. have reported individual carpal bone motion with respect to another carpal using computer analysis. We undertook this study to test some of the currently popular theories of wrist function and directly measure intracarpal motion.

Fig. 1. Three dimensional carpal bone motion is measured from a fixed reference of orthogonal radiographs and defined as x,y,z axis system based on the distal radius.
Fig. 2. Custom designed tendon loading device and plexiglass biplanar x-ray grid. The radius and ulnar are rigidly mounted to the frame. Tendon forces to move the wrist is actuated through calibrated springs.

Materials and methods

From a group of 12 fresh-frozen human forearm specimens, five were chosen for study that were free of disease and traumatic changes. The age range of the five specimens was from 23 to 55 years. There were four males and one female. By means of the techniques described below, in four wrists the radius, scaphoid, lunate, triquetrum, and capitate were labeled; in the fifth wrist, the radius, trapezoid, capitate, hamate, and triquetrum were labeled. The trapezium was not labeled in any wrist.

The motions of the selected carpal bones were determined using biplanar orthoradiographs (two radiograms positioned at 90° to one another and fixed relative to the x-ray source) (Fig. 1). The selected bones were labeled with heavy duty “U”-shaped staples (Craftsman, Sears Robuck Co., Chicago, Ill.) embedded into each carpal bone. Four identifiable positions on each staple served as reference points to record carpal bone motion. A separate T marker was placed on the dorsal surface of the radius. The dorsal wrist capsule was opened, preserving major dorsal carpal ligaments. The markers were placed into the appropriate carpal bones and the dorsal capsule was closed. Each specimen was then rigidly mounted in a holding device with the radius and ulna fixed by two Steinman pins (Fig. 2). To apply active force across the wrist and to move the wrist under active tendon loading, each musculotendinous unit that crossed the wrist was loaded by attaching heavy (25 pound test) to each tendon group. The degree of load was based on forearm muscle cross-sectional area studies. The tension was delivered by calibrated springs attached to the holding device. Thus, active tendon loading was simulated to determine wrist motion and carpal bone alignment under physiologic conditions.
Fig. 4. Screw displacement axis defines individual carpal bone motion along rotation and translation axis systems, individual carpal bones rotate and translate similar to the threads of a screw.

The loaded specimen was brought to the x-ray room where a fixed distance orthogonal x-ray system was available. Biplanar radiographs were taken in five positions for each specimen: neutral, flexion, extension, radial deviation, and ulnar deviation. These wrist positions were obtained by using the spring loaded tendons to simulate physiologic motion and force. The load on each tendon group was measured in each position. This averaged 10.6 kg total load for each of the five specimens.

Multidirectional wrist positions were measured from biplanar films (Fig. 3, A and B) taken through a custom designed plexiglass x-ray grid that provided localization and threedimensional orientation of the carpal bones. The data points from the U markers and T marker were then digitized with the sonic digitizer (Graf/Pen Science Accessories Corp., Southport, Conn.) and the Apple IIe computer (USI International, Brisbane, Calif.). The digitized two-dimensional coordinates for each of the four identifiable “points” of each U marker and four “points” of the T markers in both anteriorposterior (x,y) and lateral (x,z) planes were then used to reconstruct the corresponding three-dimensional coordinates in space. Since the markers were rigidly fixed to the bones, the location and orientation of each labeled bone was defined by markers along the specific axis system (see below). These data were analyzed by PDP 11/34 (Digital Equipment Corp., Maynard, MA.) computer programs for calculation of the relative three-dimensional motion of individual carpal bones in space and applied to carpal bone kinematics during maximum wrist motion.

Relative motions between two selected carpal bones or between an individual carpal bone and the radius during wrist motion were described using the concept of screw displacement axis. The screw axis concept implies that each carpal bone both rotates and translates along its own axis system, which is not fixed but moves up and down, similar to the threads of a screw (Fig. 4). In this study, carpal bones were shown to both rotate and translate along an individual “screw axis” as the wrist moved from flexion to extension or from radial to ulnar deviation although the predominant motion was rotatory.

To ensure that these observations were accurate and reproducible, repeat testing was performed. The exact alignment of carpal bones was described by an x,y,z axis system (Fig. 5). This system was based on the bone structure of the distal radius. The x axis was defined as that axis that lies along the shaft of the radius.
Fig. 6. A, Pronation-supination of carpal bone(s) occurs about the x axis longitudinal. B, Flexion-extension of carpal bone(s) occurs about the y axis (transverse). C, Radial-ulnar deviation of carpal bone(s) occurs about the z axis (or vertical axis).

with the positive end pointing in the proximal direction. The y axis was defined as that axis that lies perpendicular to the x axis with the positive end pointing in the radial direction in the right hand. The z axis is that axis formed by the “right hand rule” of free body analysis; that is, perpendicular to both x and y axes, with the positive end pointing in the palmar direction in the right hand. In clinical terms of wrist motion, the x axis represents the axis of longitudinal rotation (or pronation-supination axis) (Fig. 6, A). The y axis is transverse and represents the flexion-extension axis (Fig. 6, B). The z axis is vertical and represents the axis of radial-ulnar rotation (Fig. 6, C). Wrist motion of the capitate with respect to the distal radius is called global motion. Motion between the proximal and distal carpal rows is referred to as intercarpal motion. Individual carpal motion (e.g., motion between the scaphoid and the lunate within the proximal carpal row) is called intracarpal bone motion. The results of relative motion of carpal bones were described based on the defined coordinate axis system and can be described by three components along the x, y, and z coordinates.

Fig. 7. A, Wrist-flexion-extension is 112° and occurs about the y axis. B, Scapholunate motion is (24°) and occurs primarily about the y axis. C, Lunotriquetral motion is (18°) and occurs primarily about the y axis (flexion-extension axis).
Table I. Relative carpal bone motion with respect to radius (n = 4)

<table>
<thead>
<tr>
<th>Wrist motion</th>
<th>Moving carpal bone</th>
<th>Reference carpal bone</th>
<th>Orientation of screw axis*</th>
<th>Rotation (°)</th>
<th>Carpal translation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>y</td>
<td>z</td>
</tr>
<tr>
<td>Flexion to extension</td>
<td>Capitate</td>
<td>Radius</td>
<td>0.09</td>
<td>-0.93</td>
<td>-0.07</td>
</tr>
<tr>
<td></td>
<td>Scaphoid</td>
<td>Radius</td>
<td>0.09</td>
<td>-0.94</td>
<td>-0.05</td>
</tr>
<tr>
<td></td>
<td>Lunate</td>
<td>Radius</td>
<td>0.24</td>
<td>-0.91</td>
<td>-0.14</td>
</tr>
<tr>
<td></td>
<td>Triquetrum</td>
<td>Radius</td>
<td>0.13</td>
<td>-0.94</td>
<td>-0.12</td>
</tr>
<tr>
<td>Neutral (0°) to extension</td>
<td>Capitate</td>
<td>Radius</td>
<td>0.27</td>
<td>0.24</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>Scaphoid</td>
<td>Radius</td>
<td>0.20</td>
<td>-0.66</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>Lunate</td>
<td>Radius</td>
<td>0.12</td>
<td>-0.72</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>Triquetrum</td>
<td>Radius</td>
<td>0.15</td>
<td>-0.04</td>
<td>0.65</td>
</tr>
<tr>
<td>Radial deviation to ulnar deviation</td>
<td>Capitate</td>
<td>Radius</td>
<td>0.27</td>
<td>0.24</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
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<td>Radius</td>
<td>0.20</td>
<td>-0.66</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>Lunate</td>
<td>Radius</td>
<td>0.12</td>
<td>-0.72</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>Triquetrum</td>
<td>Radius</td>
<td>0.15</td>
<td>-0.04</td>
<td>0.65</td>
</tr>
</tbody>
</table>

*Coordinates defined on radius. 

Table II. Proximal row intracarpal motion (n = 4)

<table>
<thead>
<tr>
<th>Wrist motion</th>
<th>Moving carpal bone</th>
<th>Reference carpal bone</th>
<th>Orientation of screw axis*</th>
<th>Rotation (°)</th>
<th>Carpal translation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>x</td>
<td>y</td>
<td>z</td>
</tr>
<tr>
<td>Flexion to extension</td>
<td>Scaphoid</td>
<td>Lunate</td>
<td>0.01</td>
<td>-0.92</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>Triquetrum</td>
<td>Lunate</td>
<td>-0.21</td>
<td>-0.89</td>
<td>0.08</td>
</tr>
<tr>
<td>Radial deviation to ulnar deviation</td>
<td>Scaphoid</td>
<td>Lunate</td>
<td>0.07</td>
<td>0.50</td>
<td>-0.55</td>
</tr>
<tr>
<td></td>
<td>Triquetrum</td>
<td>Lunate</td>
<td>0.15</td>
<td>0.79</td>
<td>0.16</td>
</tr>
</tbody>
</table>

*Coordinate defined on radius. 

Results

Motion of the wrist is a complex interaction of seven carpal bones, each with a separate axis of motion yet interdependent on the position of adjacent carpal components and the alignment of the carpus with the distal radius. The number of possible combinations of relative carpal position is so large that only the most clinically relevant were examined and are reported in this study.

Global wrist motion is defined as movement of the capitate with respect to the distal radius (Table I). During simulated full flexion-extension of 111.5° (motion about the y axis) the capitate rotates about the y axis with respect to the distal radius. The scaphoid rotates 80.3°, the lunate 58.6°, and the triquetrum 70.1°. In this model of dynamically loaded fresh cadaver wrist specimens, carpal motion is undoubtedly less than in clinical measurements of wrist motion that are a composite of radiocarpal, midcarpal, and carpalmetacarpal joint movements.

During global wrist motion from full radial deviation to full ulnar deviation (motion about the z axis, 36.0°) the lunate rotates 35.1° with respect to the distal radius, the scaphoid rotates 51.4° and the triquetrum 28.6° (Table I). This proximal carpal row rotation occurs primarily about the y axis (flexion-extension), but there is also a significant amount of motion about the z axis (radial-ulnar deviation). The scaphoid, lunate, and triquetrum move from a flexed position in radial deviation through neutral to an extended position in ulnar deviation. The majority of this flexion-extension movement occurs from the neutral wrist position to ulnar deviation, rather than from radial deviation to neutral. Flexion-extension, radial-ulnar angulation, and carpal translation are present as the proximal row moves on the distal radius in both flexion-extension and radial-ulnar deviation. The amount of carpal bone translation, however, is extremely small (range from 0.5 to 3.3 mm) (Table II).

Intracarpal bone motion occurs between both the proximal row bones and distal row bones during wrist movement. Intracarpal proximal row motion (Table II) is measured with the lunate as the reference body. Note that as the wrist moves from flexion to extension (Fig. 7, A) the scaphoid extends 24.6° with respect to
Fig. 8. A, Wrist radioulnar deviation is 36° and occurs about the z axis. B, Scapholunate motion is 10° about the y axis and C, 10° about the z axis. D, Triquetrolunate motion is 14° and occurs predominantly about the y axis during wrist radioulnar deviation (Table II).

the lunate (Fig. 7, B). During the same motion, the triquetrum extends 18.0° (Fig. 7, C) with respect to the lunate, indicating overall greater scapholunate than lunotriquetral motion. During radial to ulnar deviation (Fig. 8) scapholunate intracarpal motion is present about the z axis (10.0°) and the y axis (10°). That is, the scaphoid ulnar deviates and extends (Fig. 8, B and C). Lunotriquetral motion (14.0°) occurs primarily in flexion-extension (Fig. 8, D).

In the distal row, intracarpal motion is less than in the proximal row for both flexion-extension and radioulnar deviation motions (Table III). As the wrist moves from flexion to extension, the hamate rotates on the capitate 8.9°, while trapezoid capitate motion is only 6.8°. In radial to ulnar deviation, the hamate moves 3.9° on the capitate, and capito-trapezoidal motion is 5.1°.

The last important carpal motion that was measured is that which occurs between the proximal and distal carpal rows (intercarpal motion) (Table IV). The capitate represents the distal row and the lunate the proximal row. In wrist flexion-extension (global motion of 112°) (Fig. 9, A) there is 56.0° of lunocapitate motion (Fig. 9, B). From full flexion to neutral accounts for 34.8° (62%) and from neutral to full extension, 26.8° (38%) of lunocapitate motion. During radioulnar deviation (global motion of 36.0°) there is 40.7° of lunocapitate motion primarily in the flexion-extension axis, with a smaller degree of motion about the radioulnar axis (Fig. 9, C and D). Capitate scaphoid motion was
Table III. Distal row intracarpal motion (n = 1)

<table>
<thead>
<tr>
<th>Wrist motion</th>
<th>Moving carpal bone</th>
<th>Reference carpal bone</th>
<th>Orientation of screw axis*</th>
<th>Rotation (°)</th>
<th>Carpal translation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion to extension</td>
<td>Hamate</td>
<td>Capitate</td>
<td>-0.34 0.80 0.50</td>
<td>8.92</td>
<td>-0.48</td>
</tr>
<tr>
<td></td>
<td>Trapezoid</td>
<td>Capitate</td>
<td>0.16 -0.59 0.79</td>
<td>6.00</td>
<td>1.07</td>
</tr>
<tr>
<td></td>
<td>Trapezoid</td>
<td>Hamate</td>
<td>-0.71 0.70 0.10</td>
<td>5.40</td>
<td>0.19</td>
</tr>
<tr>
<td>Radial deviation to ulnar deviation</td>
<td>Hamate</td>
<td>Capitate</td>
<td>-0.67 0.19 -0.71</td>
<td>3.90</td>
<td>-0.10</td>
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<tr>
<td></td>
<td>Trapezoid</td>
<td>Capitate</td>
<td>0.10 0.70 0.71</td>
<td>5.10</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>Trapezoid</td>
<td>Hamate</td>
<td>0.26 0.53 0.81</td>
<td>7.99</td>
<td>0.71</td>
</tr>
</tbody>
</table>

*Coordinate defined on radius.

x Axis, + pronation, - supination; y axis, + flexion, - extension; z axis, + ulnar deviation, - radial deviation.

Table IV. Relative intercarpal bone motion of capitate with respect to proximal row (n = 4)

<table>
<thead>
<tr>
<th>Wrist motion</th>
<th>Moving carpal bone</th>
<th>Reference carpal bone</th>
<th>Orientation of screw axis*</th>
<th>Rotation (°)</th>
<th>Carpal translation (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion to extension</td>
<td>Capitate</td>
<td>Scaphoid</td>
<td>0.01 -0.92 -0.07</td>
<td>32.9 ± 8.7</td>
<td>1.20 ± 1.60</td>
</tr>
<tr>
<td></td>
<td>Capitate</td>
<td>Lunate</td>
<td>-0.01 -0.93 0.07</td>
<td>56.0 ± 14.3</td>
<td>0.54 ± 0.60</td>
</tr>
<tr>
<td></td>
<td>Capitate</td>
<td>Triquetrum</td>
<td>0.04 0.93 0.05</td>
<td>42.3 ± 13.4</td>
<td>0.69 ± 9.81</td>
</tr>
<tr>
<td>Neutral (0°) to extension</td>
<td>Capitate</td>
<td>Lunate</td>
<td>-0.01 -0.93 0.07</td>
<td>26.8 ± 12.1</td>
<td>0.50 ± 0.24</td>
</tr>
<tr>
<td>Neutral (0°) to flexion</td>
<td>Capitate</td>
<td>Lunate</td>
<td>-0.01 -0.93 0.07</td>
<td>34.8 ± 12.1</td>
<td>0.48 ± 0.25</td>
</tr>
<tr>
<td>Radial deviation to ulnar deviation</td>
<td>Capitate</td>
<td>Scaphoid</td>
<td>0.29 0.81 0.44</td>
<td>37.3 ± 20.0</td>
<td>-0.10 ± 0.30</td>
</tr>
<tr>
<td></td>
<td>Capitate</td>
<td>Lunate</td>
<td>0.33 0.85 0.25</td>
<td>40.7 ± 18.3</td>
<td>1.00 ± 0.30</td>
</tr>
<tr>
<td></td>
<td>Capitate</td>
<td>Triquetrum</td>
<td>0.42 0.78 0.26</td>
<td>30.2 ± 14.8</td>
<td>0.60 ± 1.01</td>
</tr>
</tbody>
</table>

*Coordinate defined on radius.

x Axis, + pronation, - supination; y axis, + flexion, - extension; z axis, + ulnar deviation, - radial deviation.

The carpus is only 30° capable of flexion-extension motion as is the case during dissection or surgical exposure. Further, most relative motion is quite small, which increases the error of observation. For these reasons, recent investigators have labeled the carpal bones and used sophisticated, accurate, and minimally invasive techniques to measure three-dimensional motion, such as light emitting diodes and sonic pulsation markers. 14, 15, 17-19

On the basis of principles established in measuring the motion of other upper extremity joints, 21, 22 we have elected to use a technique to directly measure carpal motion by means of metal staples attached to each bone. Orthogonal biplanar films allow visualization of the location of each marker. These markers were measured with the sonic digitizer, and computer analysis was used to generate an accurate quantitative analysis of individual carpal motion. Furthermore, to provide a de-
scription of carpal bone motion in a loaded wrist, we have activated the wrist motors based on physiologic cross-sectional area studies.

This technique of carpal bone marking (which has been used by the authors previously) has specific limitations. First, it can only be used in vitro. It requires exposure of the carpals and the implantation of metal markers. This has the potential for disturbing normal intercarpal motion by injuring normal structures, such as the dorsal capsular ligaments. Although an attempt was made to reproduce in vivo wrist loading with calibrated tension placed on the tendons, we cannot reasonably expect to have duplicated all of the normal forces that act on the wrist. Further, because of limitations of the technique and material available for study, only five specimens and four positions of carpal motion from neutral were examined. Specimen variation and constantly changing loading patterns may impose limits on the clinical application of such data. Compared with previous carpal motion studies, however, this technique has more precision than physiologically recorded displacement of light emitting diodes or three-dimensional sonic digitization. The disadvantages of these latter methods are that the transducers (spark gap and LED markers) project out from the carpus, which may interfere with ligament and tendon function, and are heavy, possibly disturbing carpal motion. Further, they are based on empirically loaded tendon forces and use passive wrist positioning in determining wrist motion.

Berger’s study, 19 for example, relates carpal bone motion to rotation magnitude ratios (RMR) rather than a direct comparison of carpal bone movement based on individual screw displacement axes. DeLange et al. 20 published a more accurate study involving assessment of three-dimensional carpal bone motion with x-ray stereophotogrammetric analysis. Here, rigid body motion of carpal bones demonstrated results similar to our own in that flexion-extension motion was equally divided between the radiocarpal and midcarpal joints and that the scaphoid had the largest rotation and the lunate the smallest rotation of bones in the proximal row. Although we agree with the conclusions of DeLange and associates 20 they reported their results as relative to the radius as a reference body. To the best of our knowledge, our study is unique in reporting accurate intercarpal and intracarpal motion.

If one accepts that capitate motion is a good indicator of total wrist motion, then total wrist motion from flexion to extension and radial deviation to ulnar deviation is similar to those described by previous authors. 11, 12 The distal row (trapezoid, capitate, and hamate) moves as a unit with very little intracarpal motion. The proximal row also moves as a unit, although significant motion between the scaphoid and lunate and lunate and triquetrum occurs with all wrist movement. 13, 14, 18 From radial to ulnar deviation (approximately 35° to 45°), the scaphoid and lunate rotate primarily about the flexion-extension axis in the same direction. In addition, in radial to ulnar deviation, the capitae translates predominantly in the dorsal-palmar axis, e.g., the capitate displaces palmarly in radial deviation and dorsally in ulnar deviation. These findings correlate well with previous observations 24, 25 and indicate that carpal bone motions are interdependent on each other, with the bones of the proximal carpal row having more individual rotation than those of the distal carpal row. This proximal row intracarpal motion creates a variable geometry intercalated segment so that no matter which position the wrist assumes, the proximal carpal row fits itself to both the distal row and the radius and triangular fibrocartilage. The small amount of distal row intracarpal motion and triangular fibrocartilage flexibility allow further adaptation of the articular surfaces to one another. This mechanism probably serves to maximize contact area and prevent incongruity. Also, since the center of wrist motion is in the head of the capitate, 17, 18 capitate displacement may allow change in the moment arms of the wrist motors increasing their efficiency. In summary, we believe that a proximal row-distal row model fits the kinematic data better as a column theory of wrist motion.

Some authors 11, 13 have found extension to be greater at the radiocarpal than midcarpal joints, while others, such as Volz 26 and Wagner 27 found radiocarpal and midcarpal motion to be equally divided. In the experiments reported here, carpal motion of flexion to extension through a mean total arc of 112° seemed to be equally divided between the radiocarpal (56°) and midcarpal joints (56°). However, each joint contributed a different percentage of the total arc of wrist motion. For example, as the wrist moves from neutral to flexion, capitulunate motion is 38° and radiolunate motion is 35°. From neutral to extension, however, there was 27° of midcarpal motion and 25° at the radiocarpal joint (Tables I and IV). We could not confirm the theory proposed by MacConaill 29 that the approximation of the proximal capitate row in extension acts like a vise to trap the capitae between the scaphoid and triquetrum, forcing the capitae into full extension.

In considering motion from radial to ulnar deviation, we found that more motion occurs at the midcarpal than the radiocarpal joint by about 25%. The capitae gen-
grewerly moves synchronously with respect to the lunate. But, as noted previously, when the wrist moves from radial to ulnar deviation, the capitate translates from palmar to dorsal and rotates about the dorsal-palmar (z) axis. The lunate and the rest of the proximal row, however, move from flexion into extension about the y axis.

Weber has proposed an ingenious theory of carpal motion. He states that the triquetrohamate interface controls the rotation of the proximal row by virtue of the bony anatomy. Our data, which show displacement of the proximal row bones from ulnar to radial deviation, is consistent with this theory, although does not prove it.

In general, this work confirms concepts popularized by Fisk and Linscheid and Dobyns, Sarrafian, and others, that the proximal row acts as an intercalated segment between the distal row and the radius. Since the trapezoid, capitate, and hamate have very little relative motion between them, the distal carpal row can be thought of as one functional unit. In radioulnar deviation, the capitate, lunate, and triquetrum exhibit little motion between them and can be thought of as one functional unit. In flexion-extension, however, there is more intracarpal motion between the proximal row bones, especially the scaphoid. However, in all wrist motions, there is always more motion between the proximal row and the distal row and between the proximal row and the radius than within the proximal row bones. Moreover, all the carpal bones in each row move in approximately the same direction no matter what global wrist motion occurs. Thus, insofar as kinematics is concerned, it is justifiable to consider the wrist as divided into two functional units—distal row and proximal row.

Conclusions

From the viewpoint of clinical application, it seems obvious that the complex mechanism of carpal motion would not readily adjust to alterations in the intracarpal, midcarpal of radiocarpal relationships. The recent enthusiasm for limited intracarpal arthrodesis might not be justified, for instance, considering the potential adverse, long-term sequelae. Fusions across the midcarpal and radiocarpal joints especially change normal carpal kinematics. The kinematics of the wrist require thorough understanding before rational treatment strategies can be developed. In summary, the following conclusions are drawn:

1. Total flexion and extension motion is about equally divided between radiocarpal and midcarpal joints, with a wide variation of normal. There is a greater contribution by the midcarpal joints to flexion than to extension. The same is true of the radiocarpal joint, which contributes more to flexion than to extension.

2. Radial and ulnar deviation takes place more at the midcarpal than the radiocarpal joint, although both contribute.

3. During radial to ulnar deviation, the proximal row moves from flexion to extension, and the distal row translates palmar to dorsal and rotates radial to ulnar.

4. In flexion to extension, the proximal row exhibits increased intracarpal motion, especially the scaphoid.

5. The lunate is the least mobile of the proximal row carpals with respect to the radius during wrist flexion-extension motion.

6. The screw axis concept accurately reflects carpal bone motion as a complex motion influenced by active wrist loading, position of adjacent carpal components, and alignment of the carpus with the distal radius.

7. On the basis of these kinematic studies, there is little evidence to support a columnar theory of wrist kinematics, as the wrist moves in two functional units—proximal and distal rows, with greater individual carpal bone motion occurring in the proximal row.

REFERENCES


JOURNAL EDITORSHIP

The position of Editor for this Journal will become vacant in the spring of 1989. Anyone interested in serving as Editor is requested to contact the Chairman, Journal Committee: Dr. Lee W. Milford, 869 Madison Ave., Memphis, TN 38104.