A three-dimensional quantitative analysis of carpal deformity in rheumatoid wrists

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We have measured the three-dimensional patterns of carpal deformity in 20 wrists in 20 rheumatoid patients in which the carpal bones were shifted ulnawards on plain radiography. Three-dimensional bone models of the carpus and radius were created by computerised tomography with the wrist in the neutral position. The location of the centroids and rotational angle of each carpal bone relative to the radius were calculated and compared with those of ten normal wrists.

In the radiocarpal joint, the proximal row was flexed and the centroids of all carpal bones translocated in an ulnar, proximal and volar direction with loss of congruity. In the midcarpal joint, the distal row was extended and congruity generally well preserved. These findings may facilitate more positive use of radiocarpal fusion alone for the deformed rheumatoid wrist.

The most common deformity of the wrist in rheumatoid arthritis (RA) has been described as carpal supination with ulnar translocation and many reports have attempted to evaluate this deformity. However, they have been two-dimensional studies based generally on radiological assessment, the value of which is limited because the complex, overlapping appearance makes measurement difficult, especially in wrists with severe deformity. We have therefore undertaken an analysis of such deformities using a new three-dimensional (3D) technique.

Patients and Methods

We studied 20 wrists in 20 rheumatoid patients in which there was ulnar translocation on the anteroposterior radiograph. We chose wrists with a carpal-ulnar distance ratio below 0.279 and in which the shape of each bone was easily recognisable (Fig. 1). There were 19 women and one man with a mean age of 61 years (21 to 80). The mean duration of the disease was 15 years (6 to 38). A total of 18 patients had the more erosive subset of the disease, one the least erosive and one juvenile RA. For comparison, we also chose a control group of ten normal wrists in ten men with a mean age of 41.4 years (18 to 76).

Imaging. Computerised tomography (CT) with a slice thickness of 0.625 mm was undertaken on a clinical helical-type scanner (LightSpeed Ultra16; General Electric, Mauksa, Wisconsin). During image acquisition, the wrists were in the neutral position with the axes of the third metacarpal and forearm aligned. The data were saved in a standard format (DICOM; Digital Imaging and Communications in Medicine).

Segmentation and construction of three-dimensional surface bone models. Segmentation is the extraction of individual bony regions. The anatomy or region of interest must be delineated and separated so that it can be viewed individually and 3D models reconstructed. Regions of individual bones were segmented semi-automatically using a software program for image analysis (Virtual Place-M; AZE Ltd, Tokyo, Japan). Surface models of the radius and each carpal bone were obtained by 3D surface generation of the bone cortex.

Measurement of centroid translocation and carpal rotation. First, the position of the volume centroid of any bone was calculated from the CT files. In order to measure the translocation, we defined the grid for the lower radius and each carpal bone within it. This was the orthogonal reference system originally advocated by Belsole et al (Figs 2 and 3). For the radius this was determined as follows: The Y axis was the longitudinal radial axis and indicated the proximal (+)/distal (-) direction; the Z axis was the line through the styloid perpendicular to the Y axis and indicated radial (+)/ulnar (-) displacement; the X axis was the
line perpendicular to the YZ plane and indicated palmar (+)/dorsal (-) displacement. Rotation around the Z axis produced flexion (+)/extension (-); that around the Y axis pronation (+)/supination (-) and that around the X axis indicated ulnar (+)/radial (-) deviation (Fig. 2). Thus, we calculated as a 3D vector the translocation of each carpal bone relative to the reference system determined for the radius.\textsuperscript{13,15}

Next, using the anatomical feature as described by Belsole et al\textsuperscript{14} the local co-ordinate system for the scaphoid, lunate, and capitate was established to characterise carpal direction (Fig. 3). The X axis of the scaphoid was defined as its principal axis, calculated as the line on which the moment of inertia was smallest and which ran through the centroid. The Z axis was defined as the line running through the dorsal ridge of the scaphoid in the plane perpendicular to the X axis and the Y axis was the line perpendicular to the XZ plane. The X axis of the lunate was defined as the line through the palmar and dorsal poles, the Y axis as the line through the centroid, perpendicular to the X axis and the Z axis as the line perpendicular to the XY plane. The Y axis of the capitate was defined as its principal axis\textsuperscript{14} and the Z axis as the line through the dorsal joint ridge of the capitated-hamate joint perpendicular to the Y axis, rotated +90˚ around the Y axis. The X axis was the line perpendicular to the YZ plane. From these planes the 3D vector of a carpus relative to the radius was calculated with six degrees of freedom using the Euler angle\textsuperscript{12} method. This quantified the direction and rotation of each carpal bone in the RA wrist relative to the normal wrist.

With regard to evaluating the translocation of location of the centroid, the variation in size of each carpal bone needed to be considered, and the translocation index was used for the purpose. It was calculated by dividing each of the three components of the vector of the centroids of the carpal bones by the square root of the cross-section of the radius at a plane perpendicular to its longitudinal axis and passing through Lister’s tubercle\textsuperscript{16} (Fig. 4).

The translocation index was as follows:

\[
(Tx, Ty, Tz) = \frac{x}{S}, \frac{y}{S}, \frac{z}{S},
\]

where \(x\), \(y\) and \(z\) represent the vectors of the centroid of the carpal bone, relative to the origin of the reference of the
the level of Lister’s tubercle (Fig. 4).

Results

Statistical analysis. The left hand was converted to the orientation of the right and comparison of the results between the control and RA groups performed using standard statistical formulae based on the Mann-Whitney U-test. The results were deemed to be significant if $p \leq 0.05$.

Carpal rotation.

Discussion

In the RA wrist, ligamentous laxity is probably the major cause of collapse and instability. There are many reports which have attempted to measure the deformity radiologically, but two-dimensional evaluation is of limited value. In our study, 3D imaging showed clearly that the rheumatoid carpus translocated obliquely in an ulnar, proximal and volar direction. This quantitative technique allowed an easier understanding of this complex deformity. The direction of carpal translocation followed the natural slope of the joint surface of the distal radius which had a mean inclination of 24° in the coronal and 11° in the sagittal plane. In normal wrists, displacement of the carpus was resisted mainly by the palmar and dorsal radiotriquetral and palmar radiolunate ligaments. Their laxity probably allowed the 3D oblique translocation.

Rotational deformity, one of the most common deformities in RA, has been described qualitatively as carpal supination. Our 3D study, however, showed quantitatively that the main rotational deformity of the proximal row was...
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Palmar flexion with no significant rotation. Accurate estimation of carpal supination by plain radiography may not be easy since palmar subluxation of the distal radius in relation to the ulna makes it difficult to obtain a true lateral view for measurement of carpal rotation in the transverse plane.

We also noticed a different pattern of rotational deformity between the radiocarpal and midcarpal joints. Our 3D study showed that the proximal row was flexed at the radiocarpal joint and the distal row extended at the midcarpal joint (Fig. 7). While flexion of the proximal row was associated with translocation, the extension of the distal row was associated only with minor translocation. Although our patients had joint narrowing throughout the carpus, the congruity and function of the midcarpal joint were better preserved even in deformed RA wrists than at the radiocarpal joint.

Moritomo et al.20 proposed a self-stabilising mechanism which is stronger in the midcarpal than in the radiocarpal joint. A scaphoid under axial load against the trapezium tends to rotate in a flexion/ulnar direction. This turning effect is constrained by the extension/radial deviation moment of the triquetrum, leading to a stable equilibrium provided that the interosseous ligaments in the proximal row are intact. We speculated that, with loosening of many carpal ligaments, the radiocarpal joint may easily lose congruity. Whereas the deformity in this joint included translational and rotational elements, in the midcarpal joint the deformity was predominantly rotational. We considered the radiocarpal joint to be more incongruent and thereby more prone to cartilaginous damage.

Our study has limitations, the most important of which is that it was based on selected cases in which the whole carpal bones were shifted to the ulnar side, but the shapes were relatively recognisable on plain radiography. The other limitation was that age and gender were not fully matched between the RA and control wrists. It is possible that calculation of centroids and angles of rotation are influenced by erosion of the carpal bones with a subsequent alteration of shape. Our quantitative information,
however, allowed early identification of the rheumatoid deformity and should be a guide to treatment, in particular in the decision as to whether to undertake radiocarpal fusion alone or to include the midcarpal joint.

Supplementary Material

A further opinion by Dr Klemens Trieb is available with the electronic version of this article on our website at www.jbjs.org.uk

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

References


Table I. Details of translocation in the carpal bones

<table>
<thead>
<tr>
<th>Direction</th>
<th>Capitate</th>
<th>Hamate</th>
<th>Lunate</th>
<th>Scaphoid</th>
<th>Triquetrum</th>
<th>Trapezium</th>
<th>Trapezoide</th>
</tr>
</thead>
<tbody>
<tr>
<td>AD (mm)</td>
<td>AD (mm)</td>
<td>AD (mm)</td>
<td>AD (mm)</td>
<td>AD (mm)</td>
<td>AD (mm)</td>
<td>AD (mm)</td>
<td>AD (mm)</td>
</tr>
<tr>
<td>TI†</td>
<td>SD</td>
<td>TI†</td>
<td>SD</td>
<td>TI†</td>
<td>SD</td>
<td>TI†</td>
<td>SD</td>
</tr>
<tr>
<td>Normal</td>
<td>3.21</td>
<td>0.01</td>
<td>0.11</td>
<td>2.99</td>
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<td>0.11</td>
<td>1.08</td>
</tr>
<tr>
<td>RA‡</td>
<td>0.17</td>
<td>0.16</td>
<td>0.22</td>
<td>0.21</td>
<td>0.33</td>
<td>0.18</td>
<td>0.37</td>
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<tr>
<td>Proximal</td>
<td>10.70</td>
<td>-0.57</td>
<td>0.14</td>
<td>9.41</td>
<td>-0.61</td>
<td>0.24</td>
<td>8.68</td>
</tr>
<tr>
<td>RA</td>
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<td>0.20</td>
<td>0.48</td>
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<td>Ulnar</td>
<td>6.28</td>
<td>0.19</td>
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<td>0.19</td>
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<td>1.04</td>
<td>0.23</td>
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<td>0.05</td>
</tr>
</tbody>
</table>

* AD, the absolute value of the difference of the mean translation (mm)
† TI, translocation index
‡ RA, rheumatoid arthritis