INTRODUCTION Malunion (dorsal angulation, radial inclination and shortening) continues to be the most common complication following the closed treatment of distal radius fractures. Patients with malunited distal radius fractures typically have radiocarpal and radioulnar pain, as well as limitations in supination and pronation, grip strength and wrist motion.

There is increasing evidence that complications resulting from malunited distal radius fractures are related to pathology of the distal radioulnar joint.1 Increasing dorsal tilt is associated with joint incongruity, tightening of the interosseous membrane.2

To date, much of the data on the biomechanics and kinematics of the normal and pathological distal radioulnar joint (DRUJ) has been generated in vitro, using techniques such as soft tissue sectioning, electromagnetic motion tracking, and cadaveric CT imaging. However, recent advances in image processing and motion tracking now permit the visualization and measurement of subtle three-dimensional (3-D) motions in vivo.

In this study, a novel CT image-based methodology was used to explore the three-dimensional kinematics of the DRUJ in vivo in normal and pathologic wrists. Kinematic data was generated via CT volume image reconstruction and surface fit registration of the reconstructed bones.

METHODS Volunteers were selected from individuals between the ages of 18 and 75, each with one malunited distal radius fracture and one healthy wrist. Patients were included if they had dorsal angulation greater than 15 degrees and radial shortening in excess of 2 mm (vs. contralateral).

Both wrists of each volunteer were simultaneously scanned with a GE HiSpeed Advantage CT scanner (120 kVP, 80 mAs, bone enhancement algorithm). Scans were made at multiple positions of supination and pronation (neutral and 30 increments to the limits of motion). At each position a CT volume image was generated from approximately forty-five 1.0 mm thick slices of the distal radius and ulna.

The bones were then segmented from the raw CT images using ANALYZE software (Mayo Biomedical Imaging Resource, Rochester, MN) and code written in MATLAB (The Mathworks Inc., Natick, MA) and C++. In brief, each gray-scale CT image was thresholded and manually edited to yield binary images of the bone on a contrasting background. An edge detection algorithm was used to generate bone surface contours for each slice and the contours were grouped to form separate 3-D surfaces of each bone. To facilitate comparison of the injured and uninjured wrists, the left wrists were mathematically transformed into “right” wrists.

For each position of pronation and supination, motion of the radius with respect to the ulna was determined by (1) registering each bone to its neutral position to account for changes in forearm positioning, and (2) calculation of the relative position of the radius with respect to the ulna. To facilitate description of the motion, an anatomic coordinate system was defined such that the origins of all motions of the radius were transformed into this coordinate system. The origin of the anatomic coordinate system was positioned at the center of the articular surface of the head of the ulna. One axis of the coordinate system was directed proximally along the shaft of the ulna (X), one axis was directed radially (Y), and one was directed volarly (Z).

The 3-D motions of the radius relative to the ulna were described using the helical axis of motion (HAM), which uniquely describes any three-dimensional motion of a rigid body as a rotation about, and translation along, an axis in space. The position (in the YZ, or plane) and orientation of the HAM axis in the injured and uninjured wrists were compared with the use of unpaired Student's t-tests. P values 0.05 were considered to be significant.

RESULTS Nine patients were enrolled in the study (3 M, 6 F, age 55.2 ± 15.4 yrs). Five had fractures of the right wrist, four of the left. The dorsal angulation and radial height of the injured wrists averaged 20.9 ± 5.8 degrees (range 15-30 degrees), and 4.9 ± 2.5 mm (range 2-8 mm), respectively. Clinically, the average pronation of the injured wrists was 75.2 ± 24.5 degrees, while the average supination was 72.9 ± 22.5 degrees. In the normal wrists, range of motion was ± 90 degrees.

The reconstructed CT images revealed no evidence of any bone contact that would limit pronation or supination, nor any diastasis of the radioulnar joint at any wrist position. In general, the rotation axis for all wrist motions, injured and uninjured, was in the approximate center of the ulnar head, and it was oriented primarily (~99%) along the long axis of the ulna, with minor components in the dorsal and radial directions (Z- and Y-axes, respectively).

In the normal wrists, the average HAM axis location across all positions was 1.31 mm volar and 0.20 mm ulnar to the origin of the anatomic coordinate system. In pronation, the average location of the rotation axis was 0.63 ± 1.75 mm radial and 0.90 ± 1.16 mm volar to the origin of the anatomic coordinate system (Figure 1), while in supination the average location of the axis was 1.00 ± 2.00 mm ulnar and 1.71 ± 1.71 mm volar to the origin of the anatomic coordinate system. However, only the radial-ulnar difference in axis location was statistically significant (p < 0.01).

CONCLUSIONS In this series of patients with malunited distal radius fractures, we found no bony blocks that would limit pronation or supination. We also found no significant injury-related differences in the average locations of the pronation or supination rotation axes, though we were able to detect subtle (< 2 mm) differences in the location of the pronation and supination axes in both the normal (1.63 mm radial-ulnar) and injured (1.90 mm dorsal-volar). Overall, our results suggest that in patients with an intact ulna, normal radioulnar articulation is possible, despite clinically significant shortening and dorsal tilt of the distal fragment.