

Quantitative kinematics of the wrist using dynamic MRI

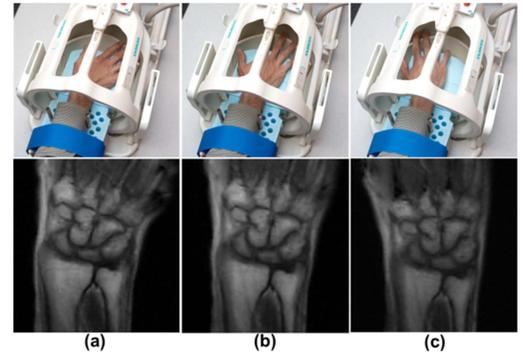
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Purpose: To develop an MRI protocol for observation and quantitative measurement of carpal bone angles and distances during active wrist motion, and to demonstrate its performance in healthy human volunteers.

Methods: With informed consent and IRB approval, eleven wrists of 7 asymptomatic volunteers (5 male 2 female, average age 33 years) were scanned on a 3T VB17A Trio Tim MRI system (Siemens Healthcare, Germany), using the true fast imaging with steady state precession (TrueFISP) pulse sequence [1], during radial/ulnar deviation, during a clenched fist motion in neutral and ulnar deviation wrist positions, during hand pronation/supination, and during volarflexion/dorsiflexion. Using an 8-channel RF head coil (Invivo Inc., Gainesville, FL), and for each type of motion, sixty images were acquired over 28.5 s (475 ms per image, one cycle of motion) with an in-plane resolution of $0.94 \times 0.94 \text{ mm}^2$. Magnetic susceptibility artifacts were minimized using "Satpads" (Image Engineering Labs, Avondale, PA) aligned with the long axis of the arm and in contact with the hand. A support apparatus (see figure) was built to immobilize the arm with the central axis of the RF coil. A musculoskeletal radiologist (R.D.B.) and orthopedist (I.I.) evaluated the images for distal radioulnar joint (DRUJ) congruity, translation of the extensor carpi ulnaris (ECU) tendon, the scapholunate (SL) gap and angle, the radiolunate (RL) angle and lunocapitate (LC) angle [2,3].

Results: Measurements were available from 11 wrists during radial/ulnar deviation, clenched-fist motion, and pronation/supination (11 for each), and from 9 wrists in volarflexion/dorsiflexion. The mean DRUJ subluxation ratio was 0.040 in supination, 0.097 in neutral, and 0.132 in pronation. The ECU tendon was perched or translated out of its groove in 3 wrists in pronation, 7 wrists in neutral, and 9 wrists in supination. The mean SL gap was 1.45 mm for neutral, ulnar deviation, radial deviation wrist positions. The mean RL angle measured 4.33 degrees dorsal in neutral, and 29.3 degrees dorsal in dorsiflexion. The mean LC angle was 3.8 degrees dorsal in neutral, and 23.8 degrees dorsal in dorsiflexion. The mean SL angle was 44.6 degrees in dorsiflexion and 59.6 degrees in the neutral wrist positions. In radial/ulnar deviation, the mean SL gap was 1.45 mm (range: 1 to 2 mm) in neutral, ulnar deviation, and radial deviation. The mean ulnar variance was -1.09 mm (range 0 to -2 mm) in neutral, -1.09 mm (range 0 to -2 mm) in ulnar deviation, and -1 mm (range 0 to -2 mm) in radial deviation. In the clenched fist motion, the mean SL gap was 1.36 mm (range 1-2 mm) with a relaxed fist in both neutral and ulnar-deviated positions, and increased to 1.54 mm (range 1-2 mm) during the clench. During forearm supination/pronation, the ulna translated in the dorsal direction, with a slight increase in the DRUJ translation ratio. In supination, the mean ratio was 0.0396 in the dorsal direction (range: 0.0625 volarly to 0.1667 dorsally). In the neutral position, the mean ratio was 0.097 in the dorsal direction (range: 0.0556 to 0.1667). In pronation, the mean translation ratio was 0.132 in the dorsal direction (range 0.0588 to 0.214). ECU tendon instability was observed with supination. In pronation, 1/11 wrists (9%) had a dislocated ECU tendon, and only 2/11 (18%) had a perched ECU tendon. In the neutral position, 2/11 (18%) of the wrists showed a dislocated ECU tendon, and 5/11 (45%) showed a perched ECU tendon. These numbers increased further in supination, with 5/11 (45%) of the wrists having a dislocated ECU tendon, and 4/11 (36%) having a perched ECU tendon. Due to limitations of the support apparatus, most volunteers were unable to reliably place their wrists in volarflexion. In the neutral wrist position, the mean RL angle was 4.33 degrees in the dorsal direction (range 0 to 17 degrees), the mean CL angle was 3.78 degrees in the dorsal direction (range 17 dorsally to 8 degrees volarly), and the mean SL angle was 59.6 degrees (range 34 to 84 degrees). In maximal wrist extension, the mean RL angle was 29.3 degrees in the dorsal direction (range 12 to 49 degrees), the mean CL angle was 23.8 degrees in the dorsal direction (range 7 to 45 degrees), and the mean SL angle was 44.6 degrees (range 29 to 59 degrees).



Hand in apparatus that maintains arm position in 8-channel RF coil during dynamic imaging: (a) ulnar, (b) neutral, (c) radial deviation position.

Discussion/Conclusion: The dynamic images provided many diagnostically important measurements, and overall the measurements agreed with values reported in the literature for normal subjects (see e.g., [2]). The susceptibility pads were successful in reducing the banding artifact of TrueFISP imaging. The TrueFISP sequence was implemented as a 2D single-slice acquisition, making selection of slice orientation and location from the localizer critically important. Future use of rapid 3D and multiband 2D data acquisition will reduce slice selection requirements without forfeiting time and spatial resolution. Higher spatial resolution will also be desirable for improving the accuracy of the measurements.

References: [1] H. H. Quick, M. E. Ladd, M. Hoevel, S. Bosk, J. F. Debatin, G. Laub, et al., "Real-time MRI of joint movement with trueFISP", *Journal of Magnetic Resonance Imaging*, vol. 15, pp. 710-715, 2002. [2] C. F. Larsen, F. K. Mathiesen, and S. Lindequist, "Measurements of carpal bone angles on lateral wrist radiographs", *J Hand Surg Am*, vol. 16, pp. 888-93, Sep 1991. [3] S. K. Lee, H. Desai, B. Silver, G. Dhaliwal, and N. Paksima, "Comparison of radiographic stress views for scapholunate dynamic instability in a cadaver model", *J Hand Surg Am*, vol. 36, pp. 1149-57, Jul 2011.